Drinking Water Officers' Guide Part B: Section 17

Design Guidelines for Drinking Water Systems in British Columbia

Version 1.1

Published March 2023

Revised January 2024

Ministry of Health

Acknowledgements

The Ministry of Health would like to thank the following people who were involved in the development of these *Design Guidelines for Drinking Water Systems in British Columbia*:

WSP Canada Inc.

Stephen Horsman, Project Manager

Megan Wood, Assistant Project Manager

Ministry of Health

Alistair Stewart, Drinking Water/Wastewater Engineer, Health Protection Branch

Sabrina Diemert, Drinking Water/Wastewater Engineer, Health Protection Branch

Design Guidelines Working Group

Al Aderichin, Section Head, Utility Engineering, Ministry of Forests

Catriona Weidman, Senior Infrastructure Officer, Ministry of Municipal Affairs

Darrell Belanger, Public Health Engineer, Island Health Authority

Dave Tamblyn, Public Health Engineer, First Nations Health Authority

David Addison, Public Health Engineer, Northern Health Authority

Heather Thompson, Water Quality Resource Specialist, Ministry of Water, Land and Resource Stewardship

Jeff Huang, Public Health Engineer, Interior Health Authority

Jesal Shah, Manager, Dam Safety and Utility Regulation, Ministry of Forests

Kevin Rieberger, Head, Water Quality & Aquatic Science, Ministry of Water, Land and Resource Stewardship

Marianne Crowe, Public Health Engineer, Interior Health Authority

Michael Wu, Public Health Engineer, Vancouver Coastal Health Authority

U. Tin Tun, Public Health Engineer, Fraser Health Authority

Wayne Radomske, Public Health Engineer, Interior Health Authority

Yanan Xing, Sr. Waterworks Engineer, Ministry of Forests

Stakeholder Reviewers Group

Chris Lawrence, Manager of Operations, District of Houston

Christoph Moch, Manager, Water Quality and Demand Management, Capital Regional District (CRD)

Harshan Radhakrishnan, Manager, Climate Change and Sustainability Initiatives, Engineers and Geoscientists BC (EGBC)

Jenni Green, Technical Expert, The Environmental Operators Certification Program (EOCP)

Joel Melanson, Division Manager, Engineering and Construction Division, Metro Vancouver

Kalpna Solanki, Chief Executive Officer, The Environmental Operators Certification Program (EOCP)

Madjid Mohseni, Scientific Director, RES'EAU

Marian Hands, Interim Chief Executive Officer, British Columbia Water & Waste Association (BCWWA)

Marta Green, Sr. Geoscientist, British Columbia Ground Water Association (BCGWA)

Murray Walters, Water Services, Regional and Community Utilities, Regional District of Nanaimo (RDN)

Rod Maclean, Manager of Infrastructure Planning, City of Kelowna

Saad Jasim, Manager, Utilities, City of White Rock

Ted Molyneux, Sr. Engineer Water/Wastewater, Indigenous Services Canada (ISC)

Tyrone McCabe, Manager of Utility Services, Thompson-Nicola Regional District (TNRD)

Victor Shopland, General Manager of Integrated Services, City of Fort St. John

Zee Marcolin, Manager - Utility Operations, Regional District of North Okanagan (RDNO)

Preamble

These *Design Guidelines for Drinking Water Systems in British Columbia* (the *Design Guidelines*) provide guidance to Issuing Officials (i.e. Drinking Water Officers and Public Health Engineers) during the approvals process for changes in waterworks, particularly with respect to the issuance of Construction Permits under the *Drinking Water Protection Act* (DWPA) and Drinking Water Protection Regulation (DWPR). The *Design Guidelines* can also be used by Water Suppliers, Designers, and any other person or persons responsible for the planning and design of new water supply systems and when considering changes to existing systems.

The *Design Guidelines* have been incorporated into Part B of the *Drinking Water Officers' Guide* (DWOG) which is established as a guideline by the Minister of Health under section 4(1)(a) of the DWPA. According to section 4(1)(a) of the DWPA, as part of the DWOG the *Design Guidelines* must be considered by Drinking Water Officers and other officials in exercising powers and performing duties under the Act.

These *Design Guidelines* build on leading practices currently in place in British Columbia, incorporate applicable standards from other jurisdictions such as the Recommended Standards for Waterworks (also known as the "10 State Standards")[1], and reflect the diversity of water systems that serve communities across the province. The *Design Guidelines* emphasize the importance of well-integrated design, review, approval, and construction processes to protect public health and the environment. The approach is not to specify comprehensive design criteria and standards, but to focus on the factors in waterworks design that protect public health and the environment. Comprehensive design information is available from a number of sources, including those listed in Chapter 23 – References, and through various industry organizations.

Projects involving changes in waterworks should be based on a teamwork approach, involving drinking water system Owners, Designers, and Issuing Officials. Early communication and engagement with Issuing Officials is strongly recommended at the various stages of the planning, design, and construction phases to facilitate the approvals process.

These *Design Guidelines* are a living document and will be updated as required. Recommendations for additions and/or modifications can be forwarded to the Health Protection Branch of the Ministry of Health via email at HP-PHW@gov.bc.ca.

[1] Great Lakes – Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers (2018). Recommended Standards for Water Works.

Contents

1 Introduction

1.1 Purpose

Well-designed drinking water systems are critical for the protection of public health. The purpose of these *Design Guidelines for Drinking Water Systems in British Columbia* (the *Design Guidelines*) is to support the implementation of British Columbia's *Drinking Water Protection Act* and Drinking Water Protection Regulation by establishing guidance that can be used to inform the planning, design, review, and approval processes for the construction of new drinking water systems, and when considering changes to existing drinking water systems.

The *Design Guidelines* are not intended to be a comprehensive resource for waterworks design; instead, the *Design Guidelines* build on existing industry best practices and standards while recognizing the diverse and unique considerations of drinking water systems in the Province. The *Design Guidelines* provide guidance and design options that can be adapted for different situations, allowing for flexibility and innovation in design while addressing site-specific risks and concerns. Users of the *Design Guidelines* are encouraged to rely on their best professional judgement where the *Design Guidelines* are silent or not relevant to the proposed changes in waterworks or their unique situation. The *Design Guidelines* do not diminish the responsibility of the Designer or 'Engineer-of-Record', nor do they diminish the independence or authority of the Issuing Official in project approvals.

1.2 Legislative Framework

In British Columbia, the *Drinking Water Protection Act* (DWPA) and Drinking Water Protection Regulation (DWPR) specify roles and responsibilities, water quality standards, monitoring schedules and treatment aimed at reducing the risks of pathogens in drinking water. Administration of the DWPA and DWPR is the responsibility of the Ministry of Health.

Section 4(1)(a) of the DWPA enables the Minister of Health to establish guidelines that must be considered by Drinking Water Officers and other officials in exercising powers and performing duties under the Act. The Drinking Water Officers' Guide (DWOG), established by the Minister of Health under Section 4(1)(a) of the DWPA, contains provincial health policy related to drinking water. The DWOG provides guidance to Issuing Officials (i.e. Drinking Water Officers and Public Health Engineers) in their day-to-day statutory decision-making.

Part B of the DWOG contains several technical documents and best practice documents that provide guidance on applying B.C.'s drinking water legislation including:

- Drinking Water Treatment Objectives (Microbiological) for Surface Water Supplies in British Columbia;
- Drinking Water Treatment Objectives (Microbiological) for Ground Water Supplies in British Columbia;
- Guidance for Treatment of Rainwater Harvested for Potable Use in British Columbia;
- British Columbia Guidelines (Microbiological) on Maintaining Water Quality in Distribution Systems;
- Guidelines for Pathogen Log Reduction Credit Assignment; and
- Guidelines for Ultraviolet Disinfection of Drinking Water.

As the *Design Guidelines* have been incorporated into Part B of the DWOG, they must be considered by Drinking Water Officers and other officials in exercising powers and performing duties under the DWPA.

1.2.1 Water Supply System Definition

Section 6 of the DWPA states that subject to the regulations, a Water Supplier must provide, to the users served by its water supply system, drinking water from the water supply system that is potable and meets any additional requirements established by the regulations or its operating permit.

The DWPA defines a water supply system as a domestic water system other than:

(a) a domestic water system that serves only one single-family residence, and
(b) equipment, works or facilities prescribed by regulation as being excluded.

Section 3 of the DWPR excludes the following from the DWPA definition of domestic water system:

(a) equipment, works and facilities constructed, operated or maintained
 (i) under a licence, as defined in the *Water Sustainability Act*, for conservation, power or storage purposes,
 (ii) under a permit issued under the *Water Sustainability Act*,
 (iii) for bottled water production or distribution, or
 (iv) for drinking water dispensing machines;
(b) a reservoir relating to a licence or permit referred to in paragraph (a);
(c) a building system[2];
(d) a system within a system[3].

Furthermore, Section 3.1 of the DWPR states that the following are exempt from Section 6 of the DWPA:

(a) a small system, if
 (i) each recipient of the water from the small system has a point of entry or point-of-use treatment system that makes the water potable, and
 (ii) the Water Supplier ensures that the location of non-potable water discharge and non-potable water piping are identified by markings that are permanent, distinct and easily recognized.
(b) a water supply system, including a small system, if
 (i) the system does not provide water for human consumption or food preparation purposes,
 (ii) the system is not connected to a water supply system that provides water for human consumption or food preparation purposes, and
 (iii) the Water Supplier ensures that the location of non-potable water discharge and non-potable water piping are identified by markings that are permanent, distinct and easily recognized.

[2] *Building system* means a system, within a building, to which the British Columbia Plumbing Code applies, that receives water from a water supply system operating under a valid operating permit under the DWPA.
[3] *System within a system* means a water supply system that, in the opinion of a Drinking Water Officer or Issuing Official, (a) redistributes water from a water supply system operating under a valid operating permit under the DWPA, and (b) does not require further treatment processes, additional infrastructure or ongoing maintenance to prevent a drinking water health hazard.

In addition to the above exclusions and exemptions in the DWPR, the DWOG advises that regional Health Authorities should consult with their legal counsel in determining whether or to what extent the DWPA may apply to any particular case involving:

- (a) Lands or facilities with federal oversight:
  - (i) Canadian Forces Bases;
  - (ii) Department of Fisheries' facilities; and
  - (iii) Parks Canada.
- (b) Drinking water systems managed by First Nations communities.

1.2.2 Issuing Officials

As defined in the DWPA, Issuing Official means a person authorized under the regulations (DWPR) to issue a Construction Permit, Operating Permit or other permit required under the Act. According to the Drinking Water Officers' Guide, a Construction Permit is generally issued by a Public Health Engineer (PHE) and an Operating Permit is issued by a Drinking Water Officer (DWO) or their delegates. These Issuing Officials work together to coordinate their respective functions.

1.3 Design Guidelines Audience

These *Design Guidelines* provide guidance to Issuing Officials at the regional Health Authorities during the approvals process, particularly with respect to the issuance of Construction Permits under the DWPA and the Drinking Water Protection Regulation (DWPR). The *Design Guidelines* can also be used by Water Suppliers, Designers, and any other person or persons responsible for the planning and design of new water supply systems and when considering changes to existing systems.

Table 1-1 below describes the *Design Guidelines* audience and the intended application of the guidelines.

Table 1-1 Design Guideline Audience

Design Guideline Audience	Intended Application of the Design Guidelines
Water Suppliers	Will use the *Design Guidelines* for planning changes in waterworks and to understand the expectations of the Issuing Official for water system design.
Designers	Will use the *Design Guidelines*, with their best professional judgement and experience, to inform the design of changes in waterworks. Where departure from the guidance in the *Design Guidelines* occurs, Designers should consult with the Issuing Official. Designers should document the technical rationale (e.g. supporting calculations, bench- or pilot-scale studies to support the design decision, demonstration of successful implementation in other jurisdictions) and justification for such departure to the satisfaction of the Issuing Official.
Issuing Officials	Will use the *Design Guidelines* in the exercise of their duties. Issuing Officials have the authority to depart from the guidance in the *Design Guidelines* in cases where, in their best professional judgement, the guidance is not suitable for the situation and alternative approaches are warranted or appropriate.

1.4 Consultation with Other Officials and Relevant Parties

In British Columbia, drinking water regulation and oversight intersect with many different agencies and parties in addition to the regional Health Authorities. Table 1-2 shows the officials and parties (outside of the regional Health Authorities) that might need to be consulted during proposed changes in waterworks based on the type of work being considered.

Table 1-2 Other Officials and Parties for Consultation

Officials/Parties	Watershed	Water Treatment	Water Distribution	Waste Residuals Management
ENV	✔			✔
First Nations	✔	✔	✔	✔
First Nations Health Authority	✔	✔	✔	✔
EOCP		✔	✔	
MOTI			✔	
Technical Safety BC		✔	✔	
WLRS	✔	✔		✔
WorkSafe BC	✔	✔	✔	✔

The following is a brief list of the other officials and their roles in relation to drinking water regulation and oversight.

Ministry of Environment and Climate Change Strategy (ENV) should be contacted about any questions related to discharges to the environment which require authorization under the *Environmental Management Act*.

ENV is also responsible for the following:

.1 Regulating pollutants that may contaminate water supplies (*Environmental Management Act*); and
.2 Ambient and targeted water quality monitoring.

First Nations: In BC, First Nations, Indigenous Services Canada (ISC) and the First Nations Health Authority (FNHA) work in partnership to support the provision of safe drinking water for First Nation communities. First Nations operate and maintain water supply systems on reserves, infrastructure funding is provided by ISC, and FNHA's Drinking Water Safety Program provides public health advice and guidance (see more details under "First Nations Health Authority" below).

When planning a new water system or making changes to a water system that may impact a First Nation, it is recommended that the First Nation is engaged early on in the planning stages.

First Nations Health Authority (FNHA): The FNHA provides community-based programs and services, largely focused on health promotion and disease prevention, to over 200 First Nations communities and citizens across BC. The FNHA collaborates, coordinates, and integrates health programs and services with the regional Health Authorities and the Ministry of Health to achieve better health outcomes for BC First Nations. The FNHA is a component of the British Columbia First Nations Health Governance

Structure, which was formed through and is supported by a series of plans and agreements between the Tripartite partners: B.C. First Nations, the Province of BC, and the Government of Canada.

The FNHA Drinking Water Safety Program (DWSP) works in partnership with First Nations communities to support access to safe and reliable drinking water from their community water systems. As part of the DWSP team, Environmental Health Officers (EHOs) provide support in a number of ways, including the review of plans for new or upgraded community water systems from a public health perspective. FNHA's DWSP team should be consulted when planning for the construction of new drinking water systems and when considering changes to existing systems in communities served by FNHA.

Environmental Operator's Certification Program (EOCP) is a society established under the Society Act. As per Section 12 of the DWPR, the Environmental Operators Certification Program (EOCP) classifies water supply systems and certifies water supply system operators. A person is qualified to operate, maintain, or repair a water supply system if the person is certified by the Environmental Operators Certification Program for that class of system. The classification of the system determines the certification level of the operator required to operate the system.

The EOCP's mission statement is to "protect human health, the environment, and the investment in facilities through increased knowledge, skill, and proficiency of the members of the Program in all matters relating to water treatment and distribution, and wastewater collection, treatment, reuse, and disposal"[4].

Ministry of Transportation and Infrastructure (MOTI) is responsible for issuing utilities permits for any utility construction within the provincial highway right-of-way. A utilities permit is required for work, including watermains, crossing provincial highways and any watermains within provincial highway rights-of-way. Refer to MOTI's Utility Policy Manual for further information. MOTI should be consulted when expanding a water system outside of incorporated areas.

MOTI also will need to review and approve drainage plans if discharging from municipal land to existing drainage courses within electoral areas.

Ministry of Water, Land and Resource Stewardship (WLRS) – in relation to water, WLRS is responsible for providing provincial leadership on water policy and strategies and the integration of science-based land, aquatic resource, and geographic data. Examples include:

- Leading provincial water related strategies, such as the Watershed Security Strategy and Fund;
- Coordinating government's source to tap strategy to protect drinking water;
- Developing ambient water quality objectives and source drinking water guidelines;
- Advancing policy regarding water related legislation such as the *Water Protection Act* and the *Water Sustainability Act*;
- Progressing surface, groundwater, and watershed science; and
- Collecting well and groundwater related information and data.

WLRS is responsible for water utilities that are regulated under the *Water Utility Act*, including any water utilities created for subdivision approval by developers as part of a rural land development. Prior

[4] EOCP Program Guide (2021)

to construction, private utilities must get approval from the Comptroller of Water Rights (the Comptroller) through a Certificate of Public Convenience and Necessity (CPCN). The CPCN authorizes a private water utility in B.C. to construct and operate a water system to serve customers within a defined area.

WLRS is also responsible for issuing water licenses, regulating provincial water resources, and administering the *Water Sustainability Act* (WSA). A water licence is required as per Section 6 of the WSA to divert water from a stream or aquifer. Additionally, under Section 11 of the WSA, a change approval is required for any complex changes in and about a stream. Similarly, under the Dam Safety Regulation, any alteration, improvement or replacement of all or part of a dam must be authorized under the WSA through a change approval, unless the work is for routine maintenance, addressing hazardous conditions or a condition investigation.

Additionally, WLRS is responsible for area-based planning to protect surface water and groundwater resources (under the *Environmental Management Act*, *Water Sustainability Act*, and Riparian Areas Protection Regulation).

More information on water in B.C. can be found at:
https://www2.gov.bc.ca/gov/content/environment/air-land-water/water

Information for well drillers and pump installers is also available at:
https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/groundwater-wells-aquifers/groundwater-wells/information-for-well-drillers-well-pump-installers

Technical Safety BC oversees the safe installation and operation of technical systems and equipment in B.C. Technical Safety BC administers the *Safety Standards Act* and *Railway Safety Act*. Refer to the Technical Safety BC website for either an installation permit or an operating permit.

Other officials and relevant parties may need to be consulted when planning the construction of new drinking water systems, and when considering changes to existing systems. It is up to the Designer to consult with the correct officials and parties. This may include federal, provincial, or local officials.

WorkSafeBC provides safe work practices that should be followed in the design and operation of water supply systems in B.C. WorkSafeBC should be consulted to ensure that the proposed design meets its requirements. Exposure limits should be reviewed when designing chemical treatment systems.

1.5 Materials Standards

When making changes in waterworks, in addition to these guidelines, the following standards should be considered during the design phase:

- .1 National Sanitation Foundation (NSF) International standards;
- .2 American Water Works Association (AWWA) standards; and
- .3 Canadian Standards Association (CSA) standards.

Generally, these standards ensure that materials in contact with potable water are acceptable in terms of public health. The Designer should ensure that materials in contact with potable water do not create a risk to public health.

1.6 Safety

Besides ensuring the provision of clean, safe and reliable drinking water, Designers must incorporate safety considerations into the design and operation of drinking water systems. Risks to operator and staff safety should be assessed and mitigated early in the design process, and should be revisited at different stages of design.

In addition to requirements and recommendations from WorkSafeBC and Technical Safety BC, practices and processes to identify risks and implement design changes or engineering controls should be incorporated into the design process. Examples of methodologies include:

.1 Process hazard analysis, including hazard and operability (HAZOP) studies; and
.2 Prevention through Design: industry-specific guidance can be found in the Water Research Foundation *Report #3104 – Water Utility Safety and Health: Review of Best Practices,* and *Report #4236 – Workforce Health and Safety: Prevention Through Design.* Similar approaches may be referred to as “safety in design” or “safety by design”.

2 Acronyms and Definitions

2.1 Acronyms

AA	Activated alumina
ACI	American Concrete Institute
ACWWA	Atlantic Canada Water & Wastewater Association
ADD	Average day demand
AFN	Assembly of First Nations
ALARA	As low as reasonably achievable
ANA	Anatoxin-a
ANSI	American National Standards Institute
AO	Aesthetic objective
AOP	Advanced oxidation process
APHA	American Public Health Association
ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ASTTBC	Applied Science Technologists & Technicians of BC
ATP	Adenosine triphosphate
AWWA	American Water Works Association
BC	British Columbia
BCBC	BC Building Code
BCGWA	BC Ground Water Association
BCWWA	BC Water and Waste Association
BDOC	Biological dissolved organic carbon
BEP	Best efficiency point
CEC	Canadian Electric Code
CEFT	Critical environmental flow threshold
CFD	Computational fluid dynamics
CFR	Code of Federal Regulations
CFU	Colony forming unit
CGSB	Canadian General Standards Board
CIP	Clean-in-place
COD	Chemical oxygen demand
CPCN	Certificate of Public Convenience and Necessity
CS2TA	Comprehensive Source-to-Tap Assessment
CSA	Canadian Standards Association
CSMR	Chloride-to-sulphate mass ratio
CT	Contact time
CU	Colour unit

DAF	Dissolved air flotation
DBP	Disinfection by-product
DBP-FP	Disinfection by-product formation potential
DC	Direct current
DCS	Distributed control system
DDT	Dichlorodiphenyltrichloroethane
DE	Diatomaceous earth
DFO	Department of Fisheries and Oceans
DI	Ductile iron
DIC	Dissolved inorganic carbon
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DP	Decentralized peripheral
DPD	N,N-diethyl-P-phenylenediamine
DWO	Drinking Water Officer
DWPA	Drinking Water Protection Act
DWPR	Drinking Water Protection Regulation
EBCT	Empty bed contact time
EC	Electrolysis cells
EDC	Endocrine disrupting chemicals
EDR	Electrodialysis reversal
EGBC	Engineers and Geoscientists BC
EHU	Essential household use
EOCP	Environmental Operators Certification Program
ENV	Ministry of Environment and Climate Change Strategy
EPDM	Ethylene propylene diene monomer
ERP	Emergency Response Plan
FAU	Formazin attenuation units
FBWW	Filter backwash water
FCM	Federation of Canadian Municipalities
FF	Fire flow
FITFIR	“First in time, first in right”
FOC	Fisheries and Oceans Canada
FNU	Formazin nephelometric unit
FUS	Fire Underwriters Survey
G	Velocity gradient
GAC	Granular activated carbon
GARP	Groundwater at risk of containing pathogens
GCDWQ	Guidelines for Canadian Drinking Water Quality
GFCI	Ground force circuit interrupter
GFI	Ground fault interrupter

GHG	Greenhouse gases
GIS	Geographic information system
GWPR	Groundwater Protection Regulation
HAAs	Haloacetic acids
HART	Highway Addressable Remote Transducer
HDPE	High density polyethylene (pipe)
HHR	Health Hazards Regulation
HGL	Hydraulic grade line
HMI	Human machine interface
HP	Horsepower
HPC	Heterotrophic plate count
HRT	Hydraulic retention time
HTH	High test hypochlorite
HVAC	Heating, Ventilation, and Air Conditioning
ICC	International Code Council
ID	Inside diameter
IEEE	Institute of Electrical and Electronic Engineers
IESNA	Illuminating Engineering Society of North America
IEX	Ion exchange
INAC	Indian and Northern Affairs Canada
IOC	Inorganic chemical
IP	Internet protocol
IPCC	Intergovernmental Panel on Climate Change
ISC	Indigenous Services Canada
ISO	International Organization for Standardization
km^2	Square kilometre
L	Litre
L/cap/day	Litres per capita per day
L/s	Litres per second
LAN	Local area network
LEL	Lower explosive limit
LP	Low pressure
LPHO	Low pressure-high output
LSI	Langelier saturation index
LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
m	Metre
m^3/s	Cubic metres per second
MAC	Maximum acceptable concentration
MCC	Motor control center
MCL	Maximum contaminant level
MDD	Maximum day demand

MDF	Maximum day factor
MF	Microfiltration
mg/L	Milligrams/Litre (parts per million)
µg/L	Micrograms/Litre (parts per billion)
MHO	Medical Health Officer
MIB	2-Methylisoborneol
ML	Megalitre (one million litres)
ML/d	Megalitres per day
MLR	Microcystin-LR
MMCD	Master Municipal Contract Document
MOH	Ministry of Health
MOTI	Ministry of Transportation and Infrastructure
MP	Medium pressure
MWCO	Molecular weight cut-off
MWH	MWH Global Inc. (Stantec Inc.)
NA	Not applicable
NBC	National Building Code
NBR	Nitrile-butadiene rubber
NDMA	N-nitrosodimethylamine
NF	Nanofiltration
NFC	National Fire Code
NFPA	National Fire Protection Association
NH_3-N	Ammonia nitrogen
NIOSH	National Institute for Occupational Safety and Health
NOM	Natural organic matter
NORM	Naturally occurring radioactive materials
NPSH	Net positive suction head
NPV	Net present value
NSF	National Sanitation Foundation
NTU	Nephelometric turbidity unit
OCCT	Optimal Corrosion Control Treatment
OD	Outside diameter
OHS	Occupational Health and Safety
O & M	Operations and maintenance
ORP	Oxidation reduction potential
OSHG	On-site hypochlorite generation
PA	Process automation
PAC	Powder activated carbon
PBDE	Polybrominated diphenyl ethers
PCA	Portland Cement Association
PCB	Polychlorinated biphenyls

PCIC	Pacific Climate Impacts Consortium
PDC	Power distribution center
PE	Polyethylene
PET	Polyethylene terephthalate
PEX	Crosslinked polyethylene
PFAS	Perfluoroalkyl and polyfluoroalkyl substances
P&ID	Piping and Instrumentation Diagram
PIEVC	Public Infrastructure Engineering Vulnerability Committee
PHD	Peak hourly demand
PHE	Public Health Engineer
PHO	Provincial Health Officer
PHSA	Provincial Health Services Authority
PLC	Programmable logic controller
POE	Point-of-entry
POP	Persistent organic pollutant
POU	Point-of-use
PP	Polypropylene
PPCP	Pharmaceutical and personal care product
PPE	Personal protective equipment
PRV	Pressure reducing valve
psi	Pounds per square inch
PTA	Packed tower aeration
PVC	Polyvinyl chloride
PVDF	Polyvinylidene fluoride
QA/QC	Quality assurance/quality control
QMRA	Quantitative microbial risk assessment
QWD	Qualified Well Driller
RCP	Representative concentration pathways
RCRA	Resource Conservation and Recovery Act
RO	Reverse osmosis
SAC	Strong acid cationic
SBA	Strong base anionic
SCADA	Supervisory Control and Data Acquisition
SDS	Safety data sheet
SDWQGs	Source Drinking Water Quality Guidelines
SOC	Synthetic organic chemical
SSR	Sewerage System Regulation
SUVA	Specific UV absorbance
TCLP	Toxicity Characteristic Leaching Procedure
TCU	True colour units

TDH	Total dynamic head
TDS	Total dissolved solids
THM	Trihalomethanes
TMP	Transmembrane pressure
TOC	Total organic carbon
TSS	Total suspended solids
TWL	Top water level
UC	Uniformity coefficient
UF	Ultrafiltration
ULC	Underwriters Laboratories of Canada (UL Canada)
UPS	Uninterruptable power supply
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
UV254	Ultraviolet absorbance at 254 nm
UVT	Ultraviolet transmittance
VFD	Variable frequency drive
VOC	Volatile organic compound
WAC	Weak acid cationic
WBA	Weak base anionic
WCB	Workers Compensation Board
WEF	Water Environment Federation
WHMIS	Workplace Hazardous Materials Information System
WHO	World Health Organization
WLRS	Ministry of Water, Land and Resource Stewardship
WRF	Water Research Foundation
WSA	Water Sustainability Act
WTP	Water treatment plant

2.2 Definitions

Word	Definition
Adaptation	Adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change. Also, actions/measures that reduce the negative impacts of climate change, while taking advantage of potential new opportunities.
Aeration	Aeration systems add air to water and can be used to oxidize specific contaminants.

Word	Definition
Air stripping	Air stripping systems remove gases from water and may be used to remove objectionable concentrations of dissolved gases (e.g. hydrogen sulphide, carbon dioxide), trihalomethanes or volatile organic compounds (VOCs).
Alkalinity	The capacity of water to neutralize acid. It is the sum of carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), and hydroxide (OH^-) anions in the water.
Anion	A negatively charged ion (e.g. Cl^-, OH^-).
Aquifer	Defined in the *Water Sustainability Act* as: (a) a geological formation, (b) a group of geological formations, or (c) a part of one or more geological formations, that is groundwater bearing and capable of storing, transmitting and yielding groundwater.
Average day demand (ADD)	The average actual or estimated water consumption (as a flow rate) that is, or expected to be, used over a 24-hour period. When water use data is available, ADD can be determined as the product of the following: (a) design population of the facility (e.g. population during the design year); and (b) the average daily per capita flow (where several years of data is available, the greatest average value should be used) Refer to Section 21.4.1 – Domestic Water Demand for options if water use data is not available.
Backflow	A hydraulic condition, caused by a difference in pressures, which causes non-potable water or other fluid to flow into a potable water system.
Backpressure	A pressure that can cause water to backflow into a water supply system when a user's water system is at a higher pressure than the water supply system.
Backsiphonage	A form of backflow caused by a negative or sub-atmospheric pressure within a water supply system.
Bacteria	Unicellular prokaryotic microorganisms, occurring in a wide variety of forms, existing either as free-living organisms or as parasites. Can be pathogenic or symbiotic.

Word	Definition
Blowdown	(a) the continuous or intermittent removal of a portion of any process flow to maintain the constituents of the flow within desired levels. (b) the water discharged from a boiler, cooling tower or membrane water treatment system to dispose accumulated dissolved solids.
Building system	Defined in the DWPR as a system, within a building, to which the British Columbia Plumbing Code applies, that receives water from a water supply system operating under a valid Operating Permit under the DWPA.
Capacity	The flow rate that a treatment process unit, process train or treatment plant is capable of producing. See also rated capacity.
Cation	A positively charged ion (e.g. Fe^{2+}).
Cavitation	The formation and sudden collapse of vapour bubbles in a liquid, usually resulting from local low pressures, as on the trailing edge of a propeller. This phenomenon develops a momentary high local pressure that can cause mechanical damage to the surface on which the bubbles collapse. Cavitation can occur in pumps when the suction side has insufficient head for the current.
Change approval	Written authorization to make complex changes in and about a stream, per the *Water Sustainability Act*.
Changes in waterworks	Improvements to a water supply system which includes, per Section 7(1) of the DWPA, the construction, installation, alteration, or extension of: (a) a water supply system, or (b) works, facilities or equipment that are intended to be a water supply system or part of a water supply system.
Chemically enhanced backwash	Backwashing of a membrane with the addition of chlorine or other chemicals. Also referred to as maintenance clean or wash, enhanced flux maintenance, or extended backpulse clean.
Clarification	All methods of removing solids from process water, not including filtration processes.
Clean-in-place (CIP)	A chemical cleaning process in which the membranes in a membrane water treatment system: (a) are not removed from their housings (pressure vessels) or the system, and (b) are cleaned by being exposed to cleaning solutions, which are commonly recirculated through the cleaning system and membranes. May also be referred to as a recovery clean.

Word	Definition
Clearwell	A tank or vessel used for storing treated water. Typical examples of storage needs include: (a) chemically-disinfected water storage to provide contact time to achieve CT for primary disinfection, (b) finished water storage to prevent the need to vary the rate of filtration with variations in distribution system demand, and (c) backwash water for filters. Clearwells are located on-site at a water treatment plant. A clearwell may also be called a filtered water reservoir.
Climate change	A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is, in addition to natural climate variability, observed over comparable time periods.
Coagulant aid	A chemical added during coagulation to improve the process by stimulating floc formation or by strengthening the floc so it holds together better. Such a chemical is also called a flocculant aid.
Coagulation	The process of consolidating colloidal particles by chemical neutralization of negatively charged dissolved and particulate matter, to facilitate removal from the treated water by clarification and/or filtration.
Coliform	A group of bacteria, defined by a set of biochemical characteristics, which are commonly used as indicators of fecal contamination.
Compound gauge	A compound gauge is used to measure atmospheric and vacuum pressure. Atmospheric pressure is measured in kilopascals (kPa) or pounds per square inch (psi). Vacuum pressure is generally measured in mm of Hg.
Concentrate	The concentrated solution containing constituents removed or separated from the feedwater by a membrane water treatment system. Concentrate is also called reject, brine, retentate or blowdown, depending on the specific membrane process.
Connection	Defined in the DWPR as the line from the watermain to a dwelling, campsite or premises.
Construction Permit	A permit required under Section 7 of the DWPA to make changes in waterworks.
Contact time	The period of time provided for disinfection in water treatment. Refer to T_{10} definition for more information.
Contaminant	Any undesirable physical, chemical, biological or radiological substance or matter in water.

Word	Definition
CT	A measure of efficacy for chemical disinfectants, which is the product of the residual concentration of the disinfectant (C, in units of mg/L) and the contact time (T, in units of minutes).
Design Guidelines	These *Design Guidelines for Drinking Water Systems in British Columbia* by the Ministry of Health.
Design year	The expected design period, which is used to forecast flowrates for equipment/infrastructure sizing (e.g. the 20-year MDD). Also called the planning period or design horizon.
Designer	The qualified professional responsible for the design of changes in waterworks.
Detention time	The theoretical time required for water to pass through a tank, pipe or process at a given flow rate. May be calculated (e.g. using T_{10}) or estimated empirically using tracer tests. Also referred to as retention time or residence time.
Dissolved inorganic carbon (DIC)	An estimate of the amount of total carbonates in the form of carbon dioxide gas (CO_2 or H_2CO_3), bicarbonate ion (HCO_3^-), and carbonate ion (CO_3^{2-}). Appendix B of the USEPA's *Optimal Corrosion Control Treatment Evaluation Technical Recommendations for Primacy Agencies and Public Water Systems* (2016) provides a lookup table for systems to determine dissolved inorganic carbon (DIC) based on pH and alkalinity.
Distribution mains	Pipes that deliver water to individual customer service lines and provide water for fire protection through fire hydrants, if applicable.
Domestic purposes	Defined in the DWPA as the use of water for: (a) human consumption, food preparation or sanitation, (b) household purposes not covered by paragraph (a), or (c) other prescribed purposes.
Domestic water system	Defined in the DWPA as a system by which water is provided or offered for domestic purposes, including: (a) works used to obtain intake water, (b) equipment, works and facilities used for treatment, diversion, storage, pumping, transmission and distribution, (c) any other equipment, works or facilities prescribed by regulation as being included, (d) a tank truck, vehicle water tank or other prescribed means of transporting drinking water, whether or not there are any related works or facilities, and (e) the intake water and the water in the system,

Word	Definition
	but excluding equipment, works or facilities prescribed by regulation as being excluded.
Drinking water	Defined in the DWPA as water used or intended to be used for domestic purposes.
Drinking water health hazard	Defined in the DWPA as: (a) A condition or thing in relation to drinking water that does or is likely to: (i) endanger the public health, or (ii) prevent or hinder the prevention or suppression of disease. (b) a prescribed condition or thing, or (c) a prescribed condition or thing that fails to meet a prescribed standard.
Drinking Water Officer	As per Section 3 of the DWPA: (1) Unless another person is appointed under subsection (2), the Drinking Water Officer for an area is: (a) the person appointed by the Medical Health Officer as the Drinking Water Officer, or (b) if no appointment is made under paragraph (a), the Medical Health Officer. (2) The Minister may, by order, appoint persons, by name or by title, as Drinking Water Officers and establish the area of their jurisdiction. (3) In determining the qualifications for appointments under subsection (2), the Minister must consult with the Provincial Health Officer. (4) Subject to the regulations, a Drinking Water Officer may, in writing, delegate to any person a power or duty of the Drinking Water Officer under this or another enactment.
Drinking water source	Defined in the DWPA as a stream, reservoir, well or aquifer from which drinking water is taken. Rainwater may also be a drinking water source.
Effective size (D10)	The size of a sieve opening that will allow for no more than 10% of a representative sample of granular filter media to pass through.
Empty bed contact time (EBCT)	A standard convention or measure of the time during which water to be treated is in contact with the treatment medium (for example, sand in a filter column). The empty bed contact time is calculated as: $EBCT = V/Q$ Where (in any consistent set of units):

Word	Definition
	V = the empty volume of the vessel that will be occupied by the treatment medium and Q = the flow rate. Because the treatment medium, such as granular activated carbon, will occupy some volume, the EBCT overestimates the actual time that the flow resides in the vessel.
Engineer-of-Record	The Professional Engineer responsible for a specific portion of the project design.
Environmental flow needs	Defined in the WSA, and in relation to a steam, as the volume and timing of water flow required for the proper functioning of the aquatic ecosystem of the stream.
Environmental Health Officer	A person designated by a health authority as an Environmental Health Officer under Section 78 of the *Public Health Act*.
Filter-to-waste	Water used to condition filters after backwashing that has turbidity above regulatory action levels.
Filtration system	A treatment process which uses physical straining to remove particulate matter. Refer to the *Guidelines for Pathogen Log Reduction Credit Assignment* for details on pathogen inactivation/removal credits.
Fire protection	The ability to provide water through a distribution system for fighting fires in addition to meeting the normal demands of water usage.
Floating storage (floating on the system)	A method of operating a water storage facility such that daily flow into the facility approximately equals the average day demand for water. When consumer demands for water are low, the storage facility will be filling. During periods of high demands, the facility will be emptying.
Flocculation	The process following coagulation which uses gentle mixing to bring suspended particles together so they will form larger, more settleable aggregate particles, called floc.
Flux	For a membrane separation process, the volume or mass of permeate passing through the membrane per unit area per unit time. Solvent (water) flux rate is commonly expressed in cubic metres per square metre per second, or metres per second.
Force main	A pipeline that conveys wastewater under pressure from the discharge side of a pump to a discharge point.

Word	Definition
Freeboard	The vertical distance from the maximum operating water surface elevation (including overflow condition) to ground surface, top of berm, underside of slab, or equivalent natural or built structure.
Groundwater	Defined in the *Water Sustainability Act* as water naturally occurring below the surface of the ground.
Gt	The product of the velocity gradient, G (expressed in units per second), and the flocculation or mixing time (in seconds).
Health Authority	Defined in the *Public Health Act* as a regional health board or a prescribed body. There are five regional health authorities in British Columbia: Fraser Health, Interior Health, Island Health, Northern Health, and Vancouver Coastal Health.
Hydrant	An upright pipe with a spout, or other outlet, to which a hose can be attached, and water can be drawn from a watermain. Typically, this would be a fire hydrant or standpipe.
Hydropneumatic tank (or pressure tank)	A tank that is used in connection with a water distribution system for a single household, for several houses, or for a portion of a larger water system, which is airtight and holds both air and water, and in which the air is compressed and the pressure is transmitted to the water.
Instantaneous demand	The maximum rate of flow that is drawn from a water system to meet customer consumption demands from the water storage and distribution system.
Instantaneous flow rate	A flow rate of water measured at any particular instant, such as by a metering device.
Intake water	Per the DWPA, in relation to a domestic water system, the water at or near the point of intake into the system.
Issuing Official	Defined in the DWPA as a person authorized under the regulations to issue a Construction Permit, Operating Permit or other permit required under the DWPA.
L10	The predicted service life, for a given population of identical bearings operating under controlled conditions, for which 90% will meet or exceed the predicted life, and 10% will fail before reaching that value.
Laboratory	A corporation, agency or other person engaged in conducting analyses for the purposes of these *Design Guidelines*. Section 8(4) of the DWPR requires that laboratories monitoring for *E. coli* and total coliform bacteria in water be approved in writing by the Provincial Health Officer. For the analysis of other parameters, the laboratory should be CALA accredited and/or a

Word	Definition
	qualified laboratory under the Environmental Data Quality Assurance Regulation.
Langelier saturation index	The most known of the calcium carbonate ($CaCO_3$) saturation indexes, the formula for the Langelier index is based on a comparison of the measured pH of a water (pHa) with the pH the water would have (pHs) if at saturation with $CaCO_3$ (calcite form) given the same calcium hardness and alkalinity for both pH cases. The basic formula is LSI = pHa – pHs.
Licence	A conditional licence or a final licence under the *Water Sustainability Act*.
Local Authority	Defined in the DWPA as: (a) a local government, (b) an improvement district, as defined in the *Local Government Act*, that is responsible for the provision of drinking water, (c) a greater board, as defined in the Community Charter, that is responsible for the provision of drinking water, and (d) a local body prescribed by regulation as a local authority for the purposes of the provision in which the term appears.
Local Government	Defined in the DWPA as: (a) the council of a municipality, (b) the board of a regional district, and (c) a local trust committee under the *Islands Trust Act*.
Major changes in waterworks	Major changes in waterworks include but are not limited to: (a) the creation of a new water supply system; (b) an existing unpermitted water supply system becoming a permitted water supply system; (c) modifications to or the addition of treatment infrastructure; and (d) modifications to or the development of a water source.
Maximum day demand (MDD)	The highest actual or estimated water consumption (as a flow rate) that is, or expected to be, used over a 24-hour period, excluding unusual events or emergencies. MDD is normally expressed as m^3/day or ML/day.
Medical Health Officer (MHO)	A physician appointed under the *Public Health Act* to advise and report on local public health issues within a Health Authority. The MHO is responsible for fulfilling the role of a DWO unless the MHO delegates the responsibility to another qualified individual.
Membrane backwash	A cleaning operation that typically involves periodic reverse flow to remove particulate accumulated on a membrane surface. Also referred to as backpulse, backpulse clean, or flux maintenance.

Word	Definition
Monitoring well	Defined in the WSA as a well that: (a) is used or intended to be used for the purpose of monitoring, observing, testing, measuring or assessing: (i) the level, quantity or quality of groundwater, or (ii) subsurface conditions, including geophysical conditions, and (b) is not used or intended to be used for the purpose of (i) exploring for or diverting groundwater for a water use purpose, or (ii) injecting water or any other substance into groundwater on an ongoing basis.
Nephelometric turbidity unit (NTU)	The unit of measurement that is used for evaluating the level of turbidity (suspended and colloidal particles and/or microscopic organisms) in water.
Operating Permit	A permit under Section 8 of the DWPA to operate a prescribed water supply system.
Owner	As defined by the DWPA, in relation to a water supply system includes: (a) a person who is (i) responsible for the ongoing operation of the water supply system, or (ii) in charge of managing that operation, and (b) if (i) parts of the water supply system are owned by different persons, or (ii) all or part of the system is jointly owned by different persons, all of those persons;
Pathogen	An organism (normally a microorganism) that causes disease.
Peak hourly demand (PHD)	The maximum hourly rate of flow supplied by a water system. Typically two to five times the maximum daily demand, depending on the population.
pH	A measure of water acidity which is related to the hydrogen ion concentration (H^+ or H_3O^+).
Potable water	As defined in the DWPA, water provided by a domestic water system that: (a) meets the standards prescribed by regulation, and (b) is safe to drink and fit for domestic purposes without further treatment.

Word	Definition
Protozoa	Unicellular eukaryotic microorganisms, occurring in a wide variety of forms, existing either as free-living organisms or as parasites. Can be pathogenic (e.g. *Cryptosporidium* and *Giardia*) or symbiotic.
Public Health Engineer	Public Health Engineers review submitted proposals (i.e. Construction Permit applications) and provide an assessment of the potential health risks in the design and a public health assessment of whether the design will meet health protection objectives.
Qualified Professional	Includes professional engineers, geoscientists and architects and other professional entities as required by applicable laws or industry practice. The Qualified Professional should be qualified to practice in B.C. and be in good standing through the completion of the works.
Rainwater	Water collected from natural precipitation from a roof or similar structure.
Rainwater harvesting system	Any system used to collect, convey, store, treat and distribute rainwater for use.
Rated capacity	The maximum volume of treated water expressed in m^3/day, that a water treatment facility is capable of producing that: (a) meets the Water Quality Standards for Potable Water prescribed in Schedule A to the DWPR; and (b) can be supplied from the water treatment facility to the distribution system in any 24-hour period.
Raw water	Water from the supply source prior to treatment.
Readiness to connect	The state of the changes in waterworks in which all changes have been completed, satisfactorily tested to confirm hydraulic and electrical continuity, and the water demonstrated to be potable. This state can occur at the readiness to commission stage, when offline commissioning is not practical or feasible, or at the construction permit close-out where systems are commissioned offline.
Reclaimed Water	As defined in the Municipal Wastewater Regulation, municipal wastewater that is: (a) treated by a wastewater facility, and (b) suitable for reuse in accordance with the regulation.
Recovery clean	Recirculating a cleaning solution and/or soaking the membranes in a cleaning solution to restore the membrane transmembrane pressure. Also known as clean-in-place (CIP).

Word	Definition
Recovery rate	In a membrane water treatment system, the fraction of the feedwater that is converted to permeate, filtrate or product. Recovery is sometimes called permeate recovery, product water recovery, feedwater recovery, or conversion.
Regional Health Authority	One of B.C.'s five regional Health Authorities that deliver health services to meet the needs of the population within their respective geographic regions. Regulated under the *Health Authorities Act*.
Residual	(a) any gaseous, liquid, or solid by-product of a treatment process that ultimately will be disposed. For example, in a fixed-bed filter for removing particles from water, both the filter backwash water and the solids in the backwash water are residuals. (b) the concentration of free available chemical disinfectant remaining after a given contact time under specified conditions or treatment chemical after the final process (i.e. in the treated water).
Resilience	Resilience refers to the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.
Reverse osmosis	A water filtration process using high pressure to force water through a membrane.
Risk	The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity.
Safety data sheet (SDS)	A summary document required under the Workplace Hazardous Materials Information System (WHMIS) which contains information on the use, handling and storage of specific chemicals or products. Safety data sheets contain mandated types of information concerning physical characteristics, reactivity, required personal protective equipment and other safeguards.
Sanitary sewer	A gravity pipe carrying untreated wastewater.
Secondary disinfection	The maintenance of a disinfectant residual in the distribution system to protect water from microbiological re-contamination, reduce bacterial re-growth, control biofilm formation, and serve as an indicator of distribution system integrity (loss of disinfectant residual indicating that the system integrity has been

Word	Definition
	compromised). Only chlorine and monochloramine provide a persistent disinfectant residual and can be used for the maintenance of a residual in a distribution system. Also called residual disinfection.
Sedimentation	The process by which flocculated particles are removed from suspension through settling.
Sludge	(a) the accumulated solids separated from a liquid, such as water, during processing, (b) organic deposits on the bottoms of streams or other bodies of water, (c) the removed material resulting from chemical treatment, coagulation, flocculation, sedimentation, or flotation (in which case the sludge is called float) of water, and (d) any solid material containing large amounts of entrained water and collected during water treatment.
Small system	Defined in the DWPR as a water supply system that serves up to 500 individuals during any 24-hour period.
Specific DBP yield	The mass of disinfection by-product (DBP) produced by disinfection, divided by the dissolved organic carbon (DOC) in the water prior to disinfection, in units of µg DBP/mg DOC.
Specific throughput	The volume of water passed through an ion exchange resin bed or water treatment system before the exchanger or system reaches exhaustion.
Stormwater management system	Management system for the capture, diversion and/or treatment of stormwater runoff. Can include basins, tanks, filters, infiltrators, storm drains, vortex separators, seepage manholes and swales, among other options.
Stormwater sewer	A gravity pipe, natural ditch or roadside ditch (including highway and driveway culverts if connected to ditch) carrying surface water runoff to a point of discharge.
Surface water	Water bodies (lakes, wetlands and ponds, including dug-outs), water courses (rivers, streams, drainage ditches), infiltration trenches and areas of temporary precipitation ponding. Defined in the DWPR as water from a source which is open to the atmosphere and includes streams, lakes, rivers, creeks and springs.
System within a System	Defined in the DWPR as a water supply system that, in the opinion of a Drinking Water Officer or Issuing Official, (a) redistributes water from a water supply system operating under a valid Operating Permit under the DWPA, and

Word	Definition
	(b) does not require further treatment processes, additional infrastructure, or ongoing maintenance to prevent a drinking water health hazard.
T_{10}	The length of time during which not more than 10% of the influent water passes through a process. The use of T_{10} ensures that 90% of the water will therefore have a longer contact time.
Tank	A structure or container used to hold solids or liquids for such purposes as aeration, disinfection, equalization, holding, sedimentation, treatment, mixing, dilution, feeding, or other handling of chemical additives.
Threat	In relation to drinking water, a condition or thing, or circumstance that may lead to a condition or thing, that may result in drinking water provided by a domestic water system not being potable.
Total dynamic head (TDH)	The difference in height between the hydraulic grade line on the discharge side of the pump and the hydraulic grade line on the suction side of the pump. This head is a measure of the total energy that a pump must impart to the water to move it from one point to another.
Transmission mains	Pipes that convey water from the source, treatment, or storage facilities to the distribution system.
Treated water	Water that has been subjected to treatment processes.
Turndown ratio	The ratio of the design range of an instrument to the range of acceptable accuracy or precision.
Uniformity coefficient	A ratio of the sieve size opening that will pass 60% of the media sample divided by the sieve size opening that will just pass 10% of the media sample.
Velocity gradient (g)	A measure of the mixing intensity in a water process. The velocity gradient, which is expressed in units per second, is dependent on the power input, the viscosity and the reactor volume. Very high velocity gradients (greater than 300 per second) are used for complete mixing and dissolution of chemicals in a coagulation process, whereas lower values (less than 75 per second) are used in flocculation to bring particles together and promote agglomeration.
Vulnerability	A condition or set of conditions determined by physical, social, economic and environmental factors or processes that increase the susceptibility of an asset or a community to the impact of hazards.
Water Supplier	As defined in the DWPA, a person who is the owner of a water supply system.

Word	Definition
Water supply system	Defined in the DWPA as a domestic water system, other than (a) a domestic water system that serves only one single-family residence, and (b) equipment, works or facilities prescribed by regulation as being excluded.
Watershed	An area of land that drains runoff to a common point, such as a surface water or an aquifer. A watershed is also called a catchment area, drainage area or drainage basin.
Waterworks	Any part of a drinking water system including collection, production, treatment, storage, supply and distribution of water, or any part of such works.
Well	Defined in the WSA as an artificial opening in the ground made for the purpose of: (a) exploring for or diverting groundwater, (b) testing or measuring groundwater, (c) recharging or dewatering an aquifer, (d) groundwater remediation, (e) use as a monitoring well, (f) use as a closed-loop geoexchange well, or (g) use as a geotechnical well, but does not include: (h) an artificial opening, other than a water source well, to which the *Geothermal Resources Act* or the *Oil and Gas Activities Act* applies, or (i) an artificial opening of a prescribed class, made for a prescribed purpose or in prescribed circumstances.
Well cap	Defined in the WSA as a secure cap or lid that prevents vermin, contaminants, debris or other foreign objects or substances from entering the interior of the production casing, and includes a sanitary well seal.
Well cover	Defined in the WSA as a secure cover, lid or structure that prevents vermin, contaminants, debris or other foreign objects or substances from entering the well.
Well pump	Defined in the WSA as a pump that: (a) is at or in a well, and (b) is used or intended to be used for the purposes of (i) diverting groundwater from a well, (ii) adding water to a well to recharge the well or an aquifer, or (iii) dewatering an aquifer.

Word	Definition
Well recharge zone	Defined in the DWPA as the area of land from which water percolates into an aquifer and is transmitted from there into one or more wells that are used, or are intended to be used, to provide drinking water.
Wellhead	Defined in the WSA as: (a) the physical structure, facility, well cover, adapter or device (i) that is at the top of, or at the side and near the top of, a well, and (ii) from or through which groundwater flows or is pumped from the well, and (b) any casing, well cap, valve, grout, liner, seal, vent or drain relating to the well, but does not include a well pump or a pump house.
Wet well	A wet well is a below-grade structure often located within the treatment building that provides storage for finished, potable water. A wet well is used to ensure that a minimum volume is available to be pumped to subsequent unit processes or the distribution system. The level in the wet well may vary, and the pumping rate may be changed, to respond to needed changes in the flow rate and to permit continuous plant operation. The wet well should be watertight.
Wetland	Defined in the WSA as a swamp, marsh, fen or prescribed feature.
Yield test	A pumping test that provides an approximate estimate of the capacity of the well. It should be completed after construction and prior to installing the permanent pump to provide an approximate estimate of the capacity of the well.

3 General Design Guidance

3.1 General

This chapter provides general recommendations for planning, designing, and commissioning a water supply system. This includes design considerations which affect various aspects and phases of design: water quantity/demand calculations, water quality objectives, preliminary testing to demonstrate treatment (bench- and pilot-scale testing), and start-up/commissioning processes.

For design guidance for specific treatment processes, refer to Chapters 7 through 15.

3.2 Water Quantity

When designing water system infrastructure, Designers should determine the quantity of water that will be needed under current and future projected demand scenarios. Designers should size infrastructure to meet the minimum, average and maximum anticipated water demands for the selected design year with consideration to:

a) efficient allocation of financial resources,
b) the likelihood of anticipated changes in water demand,
c) the effects of demand management,
d) the quality of water under current and future demand conditions,
e) the potential impacts of climate change,
f) the design life expectancy of the infrastructure,
g) the ease of staging and expansion,
h) the relative importance or criticality of the infrastructure,
i) negative impacts to the natural environment, and
j) any other factors that may be relevant to the safe and reliable supply of drinking water under current and future conditions.

During times of scarcity or drought, water use restrictions may be applied under rules of the WSA to manage critical ecological and domestic demands on streams and aquifers.

Design year is a key consideration for infrastructure sizing. Water system infrastructure planning should generally include the development of the current, 10-year, 20-year and 50-year or build-out projected demand conditions early in the design process in order to understand the financial, operational, and environmental impacts on the water system under each scenario. Furthermore, specific components equipment are often sized to different design years depending on cost, feasibility, and operational considerations. Additional discussion of design year selection and general guidance for water system infrastructure sizing is provided in Section 3.2.1 – Source Development and Raw Water Supply Infrastructure and Section 3.2.2 – Treatment Facilities and Treatment Infrastructure.

Refer to Chapter 4 – Climate Change Risk Assessment and Adaptation for specific considerations related to climate change and water system infrastructure sizing.

3.2.1 Source Development and Raw Water Supply Infrastructure

Source development and raw water supply infrastructure should generally be sized to meet the water system maximum day demand (MDD) of the selected design year. Where treated water storage is not provided, the source and raw water supply infrastructure should be sized to meet the peak hourly demand (PHD) of the selected design year.

Due to the level of difficulty, high costs of construction, and potential impacts on the environment, the sizing of source diversion facilities or infrastructure that is constructed in or near waterbodies[5] should be based on a minimum 50-year projected demand (e.g. MDD for 50-year design) or build-out condition of the water system. Source water conveyance and mechanical systems should be based on a minimum 20-year projected demand. Where cost is an overriding driver, source infrastructure sizing may be based on a minimum 10-year projected demand, with provision to expand to meet the 20-year projected design flow. The design year should be selected in consultation with the water supply system Owner and should consider public health protection, and financial and environmental impacts.

3.2.2 Treatment Facilities and Treatment Infrastructure

Treatment facilities and treatment infrastructure should be sized to meet the water system maximum day demand of the design year. Where treated water storage is not provided, the treatment infrastructure should be sized to meet the peak hourly demand of the selected design year and coordinated with the source water supply infrastructure sizing.

Sizing of treatment facilities should be based on a minimum 20-year projected demand condition of the water system, with provision to expand to meet the 50-year or build-out projected demand. Conveyance and mechanical systems should be based on a minimum 20-year projected demand. Where cost is an overriding driver, conveyance and mechanical sizing may be based on a minimum 10-year projected demand, with provision to expand to meet the 20-year and 50-year projected design flows.

Treatment infrastructure sizing should include consideration to seasonal fluctuations in water demands (i.e. due to transient populations or increased water use due to higher temperatures/low rainfall) such that the infrastructure is properly configured and designed to reliably meet the minimum and maximum projected demand conditions. This may include a separate dosing system for low flow conditions or a side streamflow meter if the piping does not remain full during low flow. Designers should consider whether batch versus continuous operation would be most suitable for the infrastructure operation to reliably meet the anticipated variation in system water demand.

3.2.3 Distribution Water Storage Facilities, Transmission Mains and Distribution Mains

Distribution water storage facilities should be designed to meet the greater of the peak hourly demand (PHD) or the maximum day demand plus fire flow demand condition of the design year. Fire flow requirements should be determined in accordance with the latest version of the Fire Underwriters Survey™, or other industry standards where more appropriate for the specific situation. Reference should be made to Chapter 16 – Transmission and Distribution.

[5] Reference *Standards and Best Management Practices for Instream Works in British Columbia* and *Change Approval for Work In and About a Stream.*

3.2.4 Calculating Demand

To calculate demand (including maximum day demand and peak hourly demand for the design year), the Designer should consider the following:

a) Future demands (e.g. water conservation, population growth, and climate change);
b) Local government by-laws and design guidelines, where applicable;
c) Historic demand;
d) The *Design Guidelines for Rural Residential Community Water Systems*, 2012 (prepared by the former Ministry of Forests, Lands, Natural Resource Operations & Rural Development); and
e) The *Master Municipal Contract Documents (MMCD) Design Guidelines*, 2014.

Additional guidance for demand calculations is provided for small systems in Section 21.4 – Water Demand.

3.3 Water Quality

The Water Supplier is responsible for demonstrating compliance with the DWPA and DWPR through ongoing monitoring and reporting, as directed by the DWO. Potable water is defined under the DWPA as water provided by a domestic water system that (a) meets the standards prescribed by regulation, and (b) is safe to drink and fit for domestic purposes without further treatment. Refer to Chapter 22 – Water Quality Monitoring for specific recommendations to demonstrate treatment effectiveness.

At a minimum, drinking water needs to be treated to meet Schedule A of the DWPR which specifies bacteriological water quality standards for potable water.

In addition, the following should be considered based on potential risks to the drinking water system:

.1 Provincial drinking water policy as outlined in the *Drinking Water Officers' Guide*, including the provincial drinking water treatment objectives (refer to Section 3.3.1 – Treatment Objectives);
.2 Finished water quality parameters listed in the *Guidelines for Canadian Drinking Water Quality*, including the Guideline Technical Documents. Note: The Ministry of Health has departed from the *Guidelines for Canadian Drinking Water Quality* for selenium. The maximum acceptable concentration (MAC) for selenium in drinking water in B.C. is 10 µg/L;
.3 Stable and non-corrosive water; reference should be made to the *Guidelines on Evaluating and Mitigating Lead in Drinking Water Supplies, Schools, Daycares and Other Buildings,* and Chapter 12 – Internal Corrosion Control;
.4 Operational water quality parameters for the proper performance and operation of water treatment equipment (e.g. turbidity for filtration); and
.5 Any additional requirements specified by a DWO in terms and conditions to the water supply system's Operating Permit.

3.3.1 Treatment Objectives

Minimum performance targets for surface water and groundwater at risk of containing pathogens are set out in provincial drinking water treatment objectives.

Surface Water

The *Drinking Water Treatment Objectives (Microbiological) for Surface Water Supplies in British Columbia* establish a minimum performance target for water suppliers to treat surface water to produce microbiologically safe drinking water. These objectives are often referred to as the "4-3-2-1-0 objectives" and are as follows:

- 4-log (99.99 percent) reduction of enteric viruses
- 3-log (99.9 percent) reduction of *Giardia* and *Cryptosporidium* (both protozoa)
- 2 forms of treatment for pathogen log reduction
- 1-Less than or equal to 1 nephelometric turbidity unit (NTU) of turbidity
- 0 detectable *E. coli,* total coliform, and fecal coliform

The *Guidance for Treatment of Rainwater Harvested for Potable Use in British Columbia* recommends that rainwater treatment should achieve 4-log reduction of both protozoa and viruses.

Groundwater

The *Drinking Water Treatment Objectives (Microbiological) for Groundwater Supplies in British Columbia* specify treatment objectives for groundwater at risk of containing pathogens (GARP), groundwater at risk of containing viruses only ('GARP-viruses only') and groundwater at low risk of containing pathogens.

Drinking water systems that draw water from sources determined to be GARP or 'GARP-viruses only' must employ disinfection. As a minimum, GARP water sources require disinfection by treatment methods that are equivalent to surface water supplies (i.e. 4-log reduction of enteric viruses, 3-log reduction of *Giardia* and *Cryptosporidium*, 2 forms of treatment for pathogen log reduction, less than 1 NTU turbidity, and 0 detectable *E. coli*, total coliform, and fecal coliform in delivered water). Water sources that are determined to be 'GARP-viruses only', require treatment for 4-log virus reduction only. Two forms of treatment are not required for 'GARP-viruses only' raw water sources.

Groundwater sources determined to be at low risk of containing pathogens do not require disinfection unless specified by a Drinking Water Officer per the DWPA.

Table 3-1 below sets out the provincial drinking water treatment objectives for the different types of raw water supply.

Table 3-1 Provincial Drinking Water Treatment Objectives for Various Source Waters

Provincial Drinking Water Treatment Objectives	Source Water			
	Rainwater	Surface Water and GARP	GARP – Viruses Only	Groundwater at low risk of containing pathogens
4-log virus inactivation	✓	✓	✓	
4-log protozoa inactivation	✓			
3-log protozoa inactivation		✓		
2 Forms of treatment	✓	✓		
1 Less than or equal to 1 NTU [2]	✓	✓	1	
0 *E. coli*, Fecal Coliforms and Total Coliforms	✓	✓	✓	✓

1. GARP-viruses only wells should be designated on the basis that risk of enteric viral contamination is the only GARP-associated hazard identified during well assessment, and that turbidity is consistent and stable. Accordingly, raw water turbidity in the groundwater should not pose a hazard and therefore should not require treatment. Refer to the ***Guidance Document for Determining Groundwater at Risk of Containing Pathogens (GARP)*** for more details.
2. ***Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Turbidity*** by Health Canada states that it is best practice to keep turbidity levels below 1.0 NTU to minimize the potential for interference with disinfection. In addition, to minimize particulate loading and effectively operate the distribution system, it is also good practice to ensure that water entering the distribution system has turbidity levels below 1.0 NTU.

The provincial drinking water treatment objectives in Table 3-1 provide minimum performance targets for water suppliers to produce microbiologically safe drinking water. The assessment of source water quality could identify other parameters of concern that could require treatment or management in addition to the microbiological parameters identified in the table. Depending on source water quality and the risks identified during a source-to-tap assessment, the actual level of treatment required to produce microbiologically safe drinking water might be higher.

To define when greater levels of treatment may be warranted, quantitative microbial risk assessment (QMRA) may be conducted - refer to the *Health Canada Guidance on the Use of QMRA in Drinking Water (2019)* for more information. Alternatively, source water can be monitored for *Cryptosporidium* concentration, assigned to risk-related "bins", and treatment requirements determined per the US EPA LT2ESWTR approach.

The *Guidelines for Pathogen Log Reduction Credit Assignment* by the Ministry of Health provide guidance on pathogen log reduction credit assignment for the production of microbiologically safe drinking water and should be reviewed when designing a new water supply system or when considering changes to an existing system.

3.4 Bench- and Pilot-Scale Testing Recommendations

Bench- and pilot-scale testing are key tools to inform treatment process selection for a specific water source. Bench- and pilot-scale testing allows Designers to assess the reliability and efficiency of water treatment, determine final design and operational parameters, and estimate construction and operational costs. Bench- and/or pilot-scale testing may not be necessary for all designs, but even simple treatment designs may benefit from preliminary testing (e.g. to determine disinfectant dose and potential DBP production in bench-scale tests).

The scope of bench- and pilot-scale testing should balance practical, cost and design limitations. Where possible, bench- and/or pilot-scale testing should be long or extensive enough to demonstrate the effectiveness, stability, and reliability of the proposed treatment system. The tests should include the period of most challenging water quality. If the bench- or pilot-scale study is too short or misses important seasonal changes in source water quality, the process may not work as designed or incur higher than expected operational costs. The challenges and costs of water collection, laboratory analysis, and conducting the tests can limit the feasibility of extensive bench- and/or pilot-scale testing so flexibility may be warranted.

3.4.1 Bench-Scale Testing Recommendations

Bench-scale testing can be used for initial testing of the effectiveness of various treatment processes and chemicals without an extensive amount of equipment. Bench-scale testing allows the Designer to:

a) Shortlist the most effective chemicals and/or processes for pilot testing;
b) Optimize chemical coagulants;
c) Determine chemical application sequence(s);
d) Confirm proper mixing conditions for flocculation;
e) Estimate the hydraulic surface loading for the sedimentation process through the measurement of floc settling velocities;
f) Determine disinfectant demand and doses;
g) Assess the total levels of disinfection by-products (DBPs) potentially produced by the water; and
h) Test methods for control of taste- and odour-producing compounds through the use of oxidants or activated carbon.

Some common bench-scale methods include:

.1 Disinfectant demand and DBP formation potential tests;
.2 Jar-testing to optimize the coagulation, flocculation and settling processes by experimenting with mixing speeds, chemical dosing and settling velocities. Reference should be made to the ASTM D2035 *Standard Practice for Coagulation-Flocculation Jar Test of Water*;
.3 Lab-scale filtration tests, including reduced-size media filters and rapid small-scale column tests (RSSCTs). These can be used for regular filtration media and for adsorptive media including GAC, ion exchange and activated alumina.

Less commonly employed bench-scale methods which require more specialized equipment include:

.4 Flat-sheet membranes to test membrane filtration at a bench-scale;
.5 Collimated beam experiments to test UV disinfection at a bench-scale; and
.6 A continuous-flow bench-scale ozone system to test ozone at a bench-scale.

It should be noted that the treatment processes assessed through methods .3 to .6 are normally completed at pilot-scale instead of bench-scale.

Designers should understand the limitations of bench-scale testing and use caution when extrapolating results from bench- to full-scale. Chemical balance calculations (manually or through modelling software) can be helpful to assess and/or validate bench scale results, especially if the testing period may not capture challenging water quality conditions.

3.4.2 Pilot Test Recommendations

Pilot plants are scaled-down versions of a proposed treatment process; as opposed to bench-scale tests (which are normally batch tests), pilot testing is commonly run continuously for a predetermined duration. Pilot tests are often used to assess the viability of the chosen treatment approach or to confirm and/or optimize operational parameters.

Pilot studies should attempt to replicate the anticipated operating conditions and treatment results expected at full-scale as closely as possible. Where practical, pilot studies should be conducted to confirm the treatment process suitability, anticipated treatment parameters (see Table 3-2) and treatment operating conditions.

Pilot testing typically provides more accurate and reliable information than bench-scale testing; however, it also adds considerable costs. Depending on the treatment processes being considered, bench-scale testing combined with desktop or modelling calculations may provide sufficient information for design.

Pilot testing is recommended for the following situations:

a) Development of a new water source;
b) Assessment of treatment for challenging raw water quality, for example: high levels of contamination (i.e. chemical parameters drastically exceeding GCDWQ MACs) or conditions which may interfere with treatment (i.e. high hardness or low alkalinity);
c) Assessment and improvement of existing treatment processes, especially for large WTPs seeking cost optimization;
d) Selection of novel or non-conventional treatment processes;
e) Deviation from the design criteria set out in the *Design Guidelines*; and
f) Operation under non-conventional operating conditions.

The following should be considered to determine the scope of a pilot study:

.1 Selection of an appropriate treatment technology;
.2 The operational feasibility of the selected technology;
.3 Full-scale water treatment design criteria;
.4 The development of more refined cost estimates;
.5 Requirements for hands-on training for operators and other water system personnel;
.6 Projected hydraulic impacts on the water system; and
.7 Waste disposal requirements and constraints.

Pilot studies should ideally be carried out for at least one year; however, as with bench-scale testing, the scope and duration of pilot studies should balance practical, cost and design limitations. Recommended pilot study durations for different treatment processes are listed in Table 3-2, but flexibility is warranted for pilot duration.

If there are plans to include a recycled water stream (i.e. recycled backwash) at the full-scale WTP, this should be considered in the pilot study design as well. Filtration pilots should be preceded by flocculation/clarification pilot units as appropriate.

Table 3-2 outlines the duration and objectives of piloting for various technologies. For all pilot studies, finished water quality should be included as a parameter to optimize.

Table 3-2 Pilot Studies Duration and Objectives

Treatment	Contaminants Targeted/ Purpose	Minimum Recommended Duration	Parameters to Monitor and/or Optimize
Adsorption	DBP precursors, inorganic chemicals (IOCs), volatile organic compounds (VOCs), synthetic organic chemicals (SOCs)	6-12 months; this can be reduced if rapid small-scale column tests are used	• Run length • Hydraulic loading rate • Empty bed contact time
Ion exchange	IOCs	2-12 months	• Regeneration frequency • Leakage • Resin stability • Potential for chromatographic peaking • pH/corrosion control
Oxidation/ filtration	IOCs	1-6 weeks	• Oxidant type, demand and dose • Coagulant dose (if required) • Media type • Hydraulic loading rate • Filter run length
Reverse osmosis	Desalination, softening, dissolved solids	2-7 months	• Pretreatment required • Flux rate and stability • Back flush parameters
Coagulation, flocculation, and clarification	Organics and turbidity	6-12 months	• Mixing intensity • Chemical feed rate • Various coagulants and coagulant aids • Flocculation time • Retention times • Surface overflow rate/Loading rates • Plate/tube design criteria • Weir loading rates, recycle rates • Air concentration and bubble diameters • Sludge flows and concentration • Coagulant dose(s) • Polymer dose(s)

Treatment	Contaminants Targeted/ Purpose	Minimum Recommended Duration	Parameters to Monitor and/or Optimize
			• Types of coagulants and coagulant aid • Sufficient alkalinity • pH adjustment • Sedimentation rate
Rapid rate filtration	Organics, turbidity	6–12 months	• Filtration rates • Types of media • Depths of media • Length of filter run • Head loss • Filter breakthrough conditions • Backwash parameters • Length of backwash cycles • Disinfection by-product (DBP) precursor removal • Finished water quality • Quantities and make-up of the backwash • Impacts of recycling backwash
Slow sand filtration	Organics, turbidity	12 months	• Pretreatment requirements • Ripening period • Run length • Filter loading rate • Sand type
Biological filtration	IOCs, organics and turbidity	12 months or sufficient to ensure establishment of steady-state biological activity and to encompass all anticipated operational conditions.	• All parameters listed in “Rapid rate filtration” • Continuous vs. cyclical operation • EBCT • Enzyme activity and/or ATP analysis • Additional chemical addition (peroxide, nutrients) • Prior to the initiation of design plans and specifications, a pilot study report should be prepared including the engineer’s design recommendations.
Diatomaceous earth (DE) filtration	Organics	1–4 months	• Pretreatment requirements • Precoat rate • Filter media grade • Screen size • Body feed rate • Run length

Treatment	Contaminants Targeted/ Purpose	Minimum Recommended Duration	Parameters to Monitor and/or Optimize
Cartridge filtration	Turbidity	2–6 weeks	• Pretreatment requirements • Replacement frequency to estimate operational costs • Viability of treatment method
Membrane filtration	Organics	4–7 months	• Pretreatment requirements • Flux rate and stability • Back flush parameters • Chemical dose(s) • Cleaning frequency and chemical types required • Fibre breakage • DBP precursor removal • Finished water quality • To determine membrane types, materials, and manufacturers best suited for source water
Pressure filtration	Specific contaminant removal (i.e. Fe, Mn)	Sufficient to encompass all anticipated operational conditions.	• All parameters listed in “Rapid rate filtration”
Chemical disinfection	Pathogens	Sufficient to encompass all anticipated operational conditions.	• Disinfectant demand • Contact time • Residual concentrations • Disinfectant decay • DBP production
Thickening / Dewatering processes	Liquid waste residual treatment prior to disposal	6-12 months	• Flows • Solids content as well as chemical, physical and microbiological quality • Treatment requirements including equalization • Chemical addition • Effluent quality and clarification requirements • Recycling feasibility

Pilot study monitoring programs should be developed to collect representative data to demonstrate the operating conditions and treatment process performance under normal and worst-case operating conditions and include:

.1 Complete raw water characterization;
.2 Climatic conditions during the piloting;
.3 Water quality parameters and the associated sampling location(s) for each unit process being tested;
.4 Monitoring frequency for each parameter and sampling locations; and
.5 Monitoring equipment and calibration standards.

The final piloting report should contain the following:

a) Description of the piloting process;
b) Schematic of pilot facility design, including unit processes, pipe sizes, pipe connections, flow direction, chemicals and application points, monitoring points, flow control devices, monitoring equipment or gauges, and various process elements (such as intakes, pumps and blowers);
c) Summary of raw water quality and climatic conditions during the pilot testing period;
d) Summary of sampling results demonstrating treatment process performance;
e) Sufficient detail to prove that the proposed treatment can sufficiently treat the water;
f) Quality assurance procedures followed;
g) Capital cost estimates as well as cost projections for full-scale operation (yearly, monthly, and per customer);
h) Comparison of recommended design and operational parameters to design goals, water quality goals, and other performance benchmarks;
i) Final design and operational parameters; and
j) Recommendations for full-scale implementation.

3.5 Testing and Commissioning

3.5.1 Performance and Operational Testing

A testing period should be conducted for all new or upgraded drinking water treatment infrastructure to calibrate all new instruments, pressure test, leak test, and prove the equipment’s functionality. The testing period can be divided into performance testing and operational testing, as described in the following sections. These tests may require temporary pumps and piping; additionally, test water will need to be disposed of correctly through an approved method.

A Testing Plan should be developed, which details all of the procedures proposed for performance testing and operational testing. The Testing Plan should be organized by unit process or major equipment for ease of planning and scheduling. The Testing Plan should contain a schedule of the planned activities with the anticipated dates of each test. The Testing Plan should include forms that can be completed during the performance and operational testing periods to document the testing results.

3.5.1.1 Performance Testing

Performance testing is used to test each item installed to demonstrate compliance with the specified performance requirements. Performance testing should be incorporated into contract documents for equipment supply and installation contracts or similar agreements.

Prior to beginning the performance testing the following should be completed:

.1 Installation inspection (including piping alignment, adjustment and placement of pipe hangers, anchors, thrust restraints and expansion joints);

.2 Cleaning (construction debris, dust, etc.);
.3 Pressure and/or leakage tests of piping and tanks;
.4 Functional checkout of all electrical systems;
.5 Resistance tests for all electrical equipment and electrical systems;
.6 Simulated controls testing to verify programming logic;
.7 Component calibration, loop test, loop commissioning and tuning;
.8 Pre-operational checkout for all mechanical equipment including lubrication, rotation/torque tests/cold alignment, setting pressure regulating/release valves, installation of seals or packing; and
.9 Disinfection of process piping, tanks, and other equipment (per *AWWA C651, C652 and C653*).

The performance testing period should include the following tests:

.1 Test all electrical equipment, instrumentation, mechanical, and piping system;
.2 Functional tests of all mechanical, electrical, and instrumentation equipment and systems, which should include the following:
    a. Manufacturer or equipment representatives should conduct field installation inspections and site acceptance tests as required to confirm performance of specific equipment and/or systems; and
    b. Functional testing may include pump tests (confirming pump curve), chemical dosing calibration, noise/vibration checks, gate/valve testing, testing water level calibration and control, etc.

3.5.1.2 Operational Testing

Operational testing is initiated upon successful completion of the performance testing. The purpose of operational testing is to prove the operation and coordination of all aspects of the system including mechanical, electrical and instrumentation. As with performance testing, operational testing should be incorporated into contract documents for equipment supply and installation contracts or similar agreements.

During operational testing, the systems are filled with their respective liquid, and liquids are circulated and continuously operated for an agreed upon period of time. If the testing is halted for any reason the operational test period should be restarted. The operational testing may include pressure/leak testing, disinfection certification, alignment data, calibration forms, and check-out tags with sign-off for the equipment supplier, if required.

3.5.2 Commissioning

Once the testing period has successfully been completed, the commissioning period will verify the proper performance of the modified or new system. Any temporary installations that were used for the testing period should be removed prior to commissioning. It is recommended that operations staff are on-site during the commissioning to observe the operation of the new equipment.

Prior to beginning commissioning, a Commissioning Plan should be developed, setting forth a step-by-step description of the procedures for commissioning all equipment and systems. The document will serve as the guidance manual for the commissioning process. The Commissioning Plan should include a schedule establishing the dates of the planned work. The Commissioning Plan should also contain a P&ID with the sample taps labelled with the parameters of concern that the WTP is designed to remove and the treated water quality objectives for the plant.

The Designer should make provision for testing the control system during a period of operation or an appropriate period that reflects the range of operating conditions anticipated, which includes periods of seasonal changes or the extremes of the treatment conditions, to compare the actual control sequences with those described in the control narratives. Control narratives should be updated after the testing and as needed to reflect the "as is" status.

In advance of commissioning the following should be verified for completion:

.1 Confirmation that process piping and/or storage reservoirs have been properly disinfected following appropriate *American Water Works Association (AWWA) Standards* or an equivalent;
.2 Confirmation that all components of the primary disinfection system are working in accordance with the Designer's design or manufacturer's specification, where applicable;
.3 If secondary disinfection is required, confirmation that the system has adequate secondary disinfection residual levels (i.e. either free chlorine or combined chlorine dependent on the system and how it is designed);
.4 Confirmation by the Water Supplier that the Emergency Response and Contingency Plan, and the Operating and Maintenance Manual have been updated to reflect the changes that have been made;
.5 Confirmation on system start up, that all analyzers have been calibrated (and confirmed), and that all alarms have been tested and are functioning properly. Sampling points should be installed/located throughout the treatment system to facilitate effective treatment process performance monitoring;
.6 Confirmation that any new watermain connecting the new WTP to the existing distribution system has been pressure tested, swabbed, super chlorinated, flushed and that there are two subsequent satisfactory microbiological tests results;
.7 Confirmation that a suitably trained and certified operator will be taking over control and operation of the facility;
.8 Where applicable, confirmation that the water treatment facility is capable of achieving adequate contact time under worst case operating conditions. Provide calculations to verify this is being achieved. Refer to the *Guidelines for the Pathogen Log Reduction Credit Assignment;*
.9 Confirmation that all components and chemicals in contact with water meet NSF standards or the equivalent; and
.10 Confirmation that post-treatment drinking water quality meets the requirements in the *Guidelines for Canadian Drinking Water Quality (GCDWQ)* and in provincial standards and guidelines. Parameters subject to seasonal variations should remain within their limits for a period of 12 months following commissioning.

A Post Commissioning Report following the commissioning period should document and address any problems and alarms that occurred during the demonstration period as well as a description of the tests that were performed and their evaluation.

Table 3-3 recommends the length of time for commissioning various treatment processes and the key tasks that should be completed. During commissioning the processes should be stress tested to confirm performance under worst case operating scenarios including peak demand and poor water quality.

Before the system can be put into operation, all tanks, pipes and equipment which convey or store potable water should be disinfected in accordance with AWWA procedures as well as the Designer's plans and specifications.

Table 3-3 Treatment Process Commissioning Recommendations (sourced from Washington State Guidelines)

Treatment	Minimum Recommended Duration	Final Commissioning Tasks
All types of treatment	N/A	Confirm instrumentation and process control work correctly; test alarms. Compare instrumentation output with readings in SCADA. Complete applicable portions of operational reports. Check finished water quality.
Coagulation/ flocculation/clarification	7 days	Confirm set points for mixing speeds, pH and chemical dosing with jar testing results. These will need to be monitored as water quality changes with the seasons.
Rapid rate filtration	30 days	Assess backwash process, settings, and filter-to-waste. Complete at least two filter runs, including backwash and filter-to-waste cycles.
Slow sand filtration	3 months	Allow filters to fully ripen. Complete coliform or other biological testing.
Diatomaceous earth (DE) filtration	7 days	Complete at least two filter cycles (precoat, body feed, DE removal) to ensure all systems work.
Bag and cartridge filtration	8 hours	Confirm that instrumentation works correctly, test alarms (if applicable).
Membrane filtration	30 days	Complete at least 16 hours of operational multiple filtration cycles, test maintenance cleaning process.
UV disinfection	7 days	Refer to the Ministry of Health *Guidelines for Ultraviolet Disinfection of Drinking Water*. Additional time may be required to determine combined aging and fouling factor.

4 Climate Change Risk Assessment and Adaptation

4.1 Introduction

Water resources are under increasing pressure in British Columbia due to a changing climate and increasing demand from population growth *(BC Ministry of Environment, 2008).* Climate change will impact drinking water systems in several ways. Changes in precipitation and temperature will impact source water quality and quantity. Hazards such as wildfire and flood pose significant risks to drinking water infrastructure and operations. In this context, anticipating and understanding the potential impacts of climate change is an important consideration in the planning, design, operation, and maintenance of drinking water systems. Resilient system design is crucial for ensuring public health and long-term access to safe drinking water in communities. When investing in new drinking water systems, or upgrading existing infrastructure, understanding the risk of a changing climate will lead to robust decision-making and guide the development of adaptation measures and strategies.

It is important for Designers to recognize that climate adaptation strategies will differ between each drinking water system, as each strategy should be uniquely suited to the needs, resources, and environment in which the drinking water system operates. The climate hazards facing each drinking water system are location-specific as climate varies spatially (across regions) and temporally (from one season and/or year to another) throughout British Columbia. The risks associated with climate hazards depend on several factors including type of infrastructure, infrastructure condition, environmental conditions, and socioeconomic considerations. Therefore, it is prudent for Designers to take a risk management-based approach to design and assess climate risks unique to the system and location. This chapter provides Designers with a framework for identifying and assessing climate risks and developing climate adaptation plans. Some examples of climate impacts to drinking water systems are provided to help Designers understand the types of climate related hazards to consider.

Although there is uncertainty related to future climate change scenarios, the impacts of climate change on drinking water system infrastructure are already being experienced. Where water systems have typically been designed using climate norms incorporating historic variability, future climate is projected to deviate significantly from these norms. The cost of relying on historic norms may be greatly underestimated and can be offset by taking preventative action today and planning for an anticipated future state. Studies have shown that for every dollar invested in climate adaptation, six dollars is saved in future damages *(Insurance Bureau of Canada & Federation of Canadian Municipalities, 2020).*

By incorporating climate change into a risk management-based approach to system planning, design, and operations, new infrastructure investments can significantly improve the reliability of water resources and drinking water systems throughout their life cycle. Taking a holistic, interdisciplinary, and collaborative approach to climate adaptation planning can ensure that actions will address a broad range of challenges while remaining flexible enough to adapt to changing conditions and new information. Figure 4-1 illustrates the relationship between climate change effects on water resources and management responses. When identifying climate adaptation responses, there may be opportunities to provide co-benefits, such as more sustainable and efficient operations which contribute to a reduction of greenhouse gas emissions.

Note: As defined by the Intergovernmental Panel on Climate Change (IPCC) (2014), climate change mitigation is a human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs). Although climate mitigation will be discussed briefly in Section 4.10 – Climate Change Mitigation, the focus in the *Design Guidelines* is on climate change adaptation.

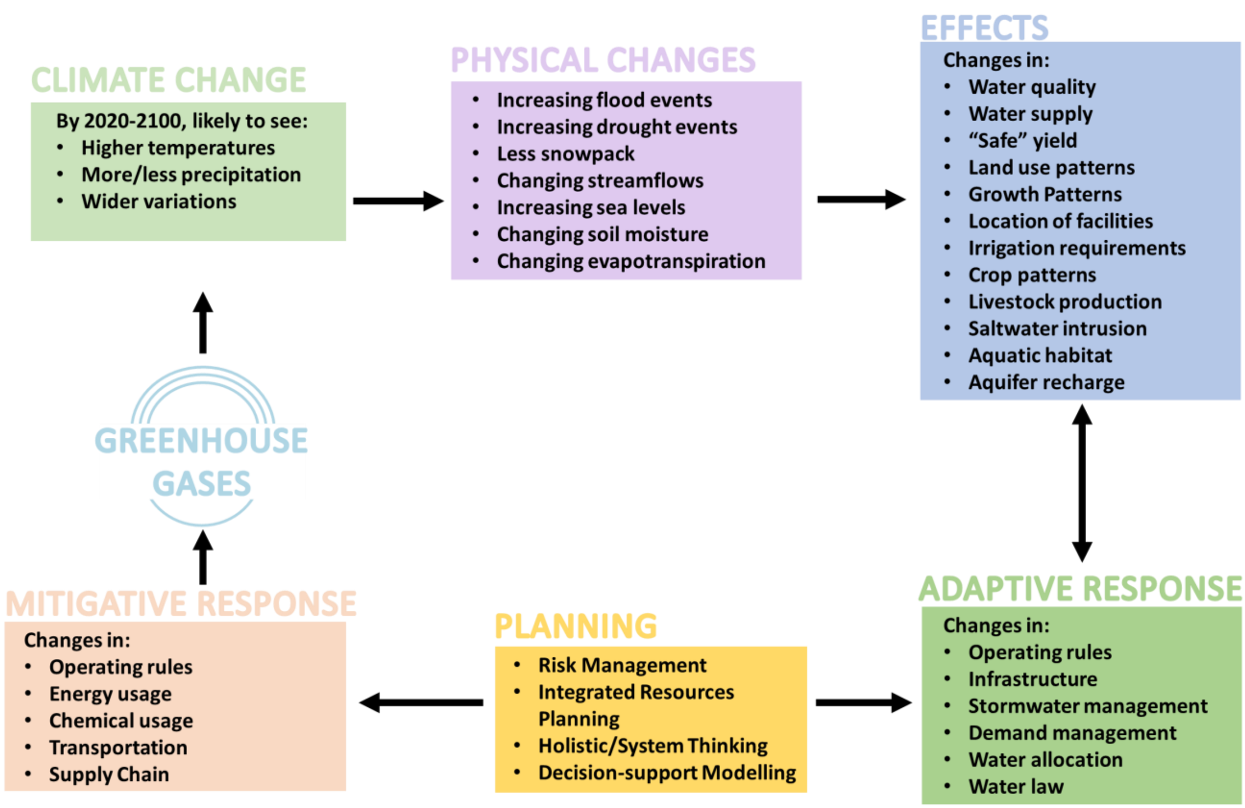


Figure 4-1 Relationship between Climate Change Effects, Effects on Water Resources, and Management Responses. Figure was produced by the American Water Works Association (AWWA). From: AWWA M71 Manual: Climate Action Plans – Adaptive Management Strategies for Utilities, 2021. p. 9. Copyright 2021 by the American Water Works Association.

4.1.1 Climate Change Terms and Definitions

The following terms will be used throughout this document. Definitions included below are from *Infrastructure Canada's Climate Lens – General Guidance (2019).*

Table 4-1 Climate Change Terms and Definitions (from Infrastructure Canada (2019) Climate Lens – General Guidance)

Term	Definition
Adaptation	Adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change. Actions/measures that reduce the negative impacts of climate change, while taking advantage of potential new opportunities.
Climate change	A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is, in addition to natural climate variability, observed over comparable time periods.
Climate hazard	The potential occurrence of a natural or human-induced physical event or trend, or physical impact, that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources.
Climate impacts	The effects on lives, livelihoods, health status, ecosystems, economic, social, and cultural assets, services (including environmental), and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes.
Climate resilience	The capacity of a community, business, or natural environment to anticipate, prevent, withstand, respond to, and recover from a climate change related disruption or impact.
Risk	The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically (quantitatively or qualitatively).
Vulnerability	A condition or set of conditions determined by physical, social, economic and environmental factors or processes that increase the susceptibility of an asset or a community to the impact of hazards.

4.1.2 Guidelines for Professional Practice

Engineering professionals are bound by their code of ethics to “hold paramount the safety, health and welfare of the public, protection of the environment and promote health and safety in the workplace.” *(Engineers Canada, 2018)*. These *Design Guidelines* seek to assist Designers in understanding their professional obligations in relation to climate change resilience for drinking water systems.

In response to climate change in British Columbia, Engineers and Geoscientists British Columbia (EGBC), released a Climate Change Position Paper on evolving responsibilities for engineers and geoscientists *(Engineers and Geoscientists BC, 2014)* which states the following:

.1 EGBC recognizes that the climate is changing and commits to raising awareness about the potential impacts of the changing climate as they relate to professional engineering and geoscience practice, and to provide information and assistance to EGBC registrants in managing implications for their own professional practice; and

.2 EGBC registrants (professional engineers, professional geoscientists, provisional members, licensees, limited licensees, engineers-in-training and geoscientists-in-training) are expected to keep themselves informed about the changing climate and consider potential impacts on their professional activities.

EGBC also presents a definition for a Qualified Professional as a part of the Professional Practice Guideline for *Developing Climate Change-Resilient Designs for Highway Infrastructure in British Columbia*. The definition of a Qualified Professional (within the context of climate change) is presented here, along with the associated definition of a Climate Specialist, to help Designers understand the qualifications required to complete a Climate Change Risk Assessment. If Designers do not have the relevant knowledge to complete a Climate Change Risk Assessment as outlined below, they should engage with the appropriate Qualified Professionals.

> **Qualified Professional:** An Engineering/Geoscience Professional with the appropriate knowledge and experience to carry out a Climate Change Risk Assessment. The Qualified Professional should have knowledge of climate science as it relates to the practice of professional engineering and geoscience, in order to be able to carry out appropriately comprehensive Climate Change Risk Assessments. This knowledge should include familiarity with the climate models, tools, and resources appropriate for the project, and the ability to implement design changes in consideration of the Climate Change Risk Assessment. The Qualified Professional is not expected to have competencies like those of a Climate Specialist but should understand what information must be obtained from a Climate Specialist, in order to carry out a Climate Change Risk Assessment when required. *(EGBC, 2020)*

> **Climate Specialist:** A specialist who studies long-term weather patterns and the processes that cause them. Climate Specialists use long-term meteorological data to study trends in weather patterns, understand their causes, and make predictions. *(EGBC, 2020)*

Not all professional regulatory bodies have guidelines directly related to climate change. Other regulated professions should consult with their respective regulatory bodies for guidance where it may exist with regards to climate change adaptability in design or design support practice.

4.2 Climate Impacts on Drinking Water Systems – Source to Tap

The following sections identify climate change phenomena which may affect the supply, treatment, storage, distribution and operation of drinking water supply systems. The information in this section is meant to serve as an illustration of the variety of climate change parameters, indices and processes which can influence safe and reliable access to drinking water and is not wholly encompassing. The information provided in this chapter is intended to prompt Designers to identify potential impacts which may impact the system.

4.2.1 Source Water Impacts

In British Columbia, climate change scenarios indicate that average annual temperatures and precipitation amounts are projected to increase, with greater regional and seasonal variability. For example, although precipitation is projected to increase annually, summer precipitation may decrease.

Some areas will receive significantly more precipitation and others will experience reduced recharge and longer/more severe droughts.

For communities considering major upgrades to drinking water treatment facilities, specific assessments of long-term source water reliability should be conducted. Considerations should include potential changes to aquifer recharge, climate impacts to the quality of groundwater versus surface water and balancing increased water demand associated with higher temperatures with reductions in source availability. Communities should also focus on protecting and enhancing the health of surface water and groundwater through watershed and groundwater protection. *(AFN, 2008)*

Water Suppliers are encourage to monitor source water quantity and quality parameters in order to establish baseline source characterization and assess climate effects over time. Planning for anticipated changes in water availability and quality degradation is critical to ensure continued supply of clean, safe, and reliable drinking water.

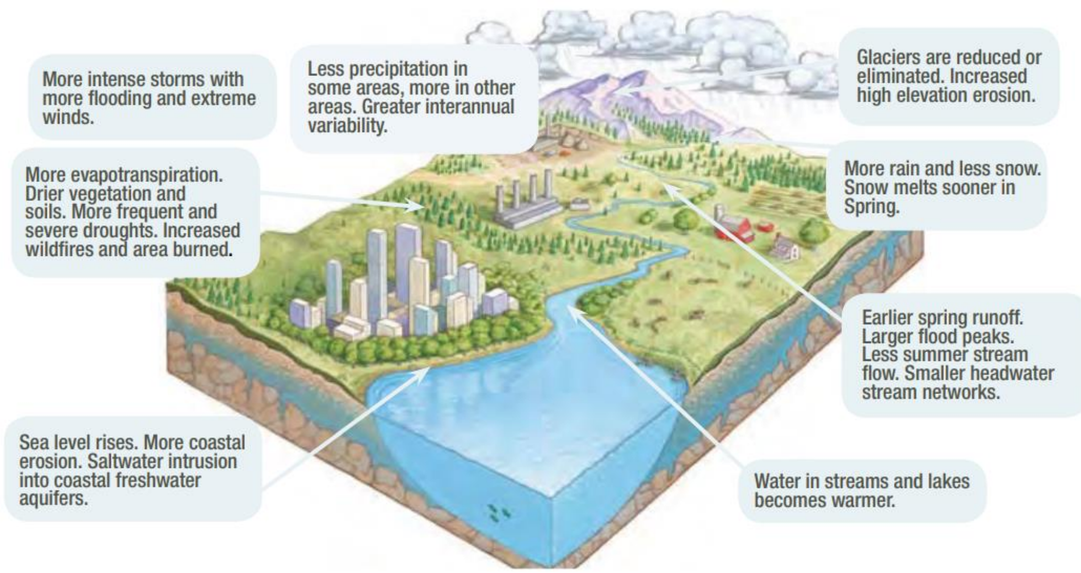


Figure 4-2 Projected Climate Changes to the Hydrologic Cycle, Note: this figure was produced by the US Department of Agriculture from "Climate Change and Water Perspectives from the Forest Service", by U.S. Department of Agriculture, 2008, Sustaining Healthy Watershed, FS 908

4.2.1.1 Surface Water Quantity

Although numerous surface water sources in British Columbia have historically provided sustainable yields as sources for drinking water systems, future streamflow will be impacted by variability in annual and seasonal precipitation and temperature. While annual variability in streamflow is a component of water supply planning, these historical norms can no longer be relied upon for future system planning. As environmental flow needs for a stream must be considered under the *Water Sustainability Act*, there may be increasing pressure on streams to meet both ecological and community water needs.

The following table provides examples of how source water availability may be affected for surface water sources. These impacts should also be considered in determining the viability of a rainwater harvesting system as a main source of potable water. *(BC Ministry of Environment, 2016; Bush & Lemmen, 2019; Compendium of Forest Hydrology in British Columbia, 2016).*

Table 4-2 Observed and Possible Impacts to Surface Water Quantity

Climate Impact	Design Considerations
Changes in snowpack	Changes to water availability in snow dominated watersheds, seasonal streamflow.
Shifts in rainfall patterns	Changing streamflow patterns, including magnitude and timing of peak flows.
	Increased probability and duration of drought.
Increasing atmospheric temperature	Reduction in water availability in watersheds fed by glaciers, impacting streamflow, timing of freshet, and temperature of glacial fed water systems.
	Contributes to increased evaporative losses from water bodies, vegetation, and soils.
Drought	Reduced water availability in summer months.

4.2.1.2 Surface Water Quality

The following table highlights potential impacts for Designers to consider related to surface water quality. Changing surface water quality may impact treatment requirements to meet drinking water quality guidelines.

Table 4-3 Observed and Possible Impacts to Surface Water Quality

Climate Impact	Design Considerations
Increasing temperature	Warmer water temperatures will support algae growth, which can deplete dissolved oxygen levels. Harmful algae (i.e. blue-green algae) usually bloom when water temperatures are warmer than usual. Harmful algal blooms may release cyanotoxins into source water. *(EPA, 2019; AWWA, 2016)*
	Waterborne pathogens may thrive more readily as a result of warmer temperatures.
	Changing water temperatures may change thermal structure, stratification, and mixing of lakes which could impact water quality.
	Warmer water holds less dissolved oxygen, making instances of low oxygen levels (“hypoxia”) more likely and altering the toxicity of some pollutants. *(EPA, 2014)*
Extreme precipitation events	Increased runoff, which could impact water quality by increasing nutrient levels, waterborne pathogen concentrations, organic matter, turbidity, metals, major ions, or sedimentation. *(EPA, 2014)*
Flooding	Flooding of sewage infrastructure (lagoons and lift stations), sewage backflows, or direct overflows associated with sanitary and storm water infrastructure could add significantly to the waterborne pathogen load of the floodwater. Inundation of fuel tanks and chemical storage areas could likewise release petroleum hydrocarbons and other pollutants.

Sea level rise	For rivers discharging into the ocean, sea level rise may lead to saltwater intrusion and increased salinity further upstream. Reduced river flows are likely to exacerbate this issue. *(EPA, 2016)*
Wildfire	May change watershed characteristics, impacting both source water quantity and quality. May increase soil erosion and sedimentation, increase water pollution, increase risk of flooding, and pose a threat to aquatic habitats and water infrastructure. Wildfire can affect drinking water quality due to build-up of ash, soil erosion, and fire debris. This may impact taste, colour, smell, and treatability of drinking water. In the event that fire retardant is used and enters the water supply, it may cause an increase in levels of phosphate, nitrate, and nitrite. *(HealthLinkBC, 2018)*

4.2.1.3 Groundwater Quantity

As an integral part of the hydrologic cycle, the availability of groundwater resources providing critical freshwater supply are likely to be affected by climate change. However, the direct impacts of changes to temperature, precipitation and evapotranspiration on the aquifer recharge are complex to predict. Regional or site-specific aquifer characterization and groundwater monitoring is required to determine how climate change could impact the recharge rates of a particular aquifer.

4.2.1.4 Groundwater Quality

Climate change may impact groundwater quality, Table 4-4 describes some impacts of climate change on groundwater.

Table 4-4 Observed and Possible Impacts to Groundwater Quality

Climate Impact	Design Considerations
Sea level rise	Saltwater intrusion may be exacerbated if there is increased demand and increased groundwater pumping. *(EPA, 2016)*
Flooding	May mobilize pathogens and could lead to the release of chemical contaminants.
Drought	Aquifer depletion may require deeper wells with poorer water quality *(Famiglietti, 2014)*. May have other site-specific, complex impacts on quality.

4.2.2 Water Demand Impacts

Climate change will cause increased demand on water systems, especially in summer months, due to:

.1 Increased irrigation demand due to higher temperatures, reduced summer precipitation and/or summer drought; and
.2 A lengthened growing season which could lead to increased annual agricultural demand for water.

Designers should consider that peak demand will likely coincide with periods of lowest supply. Strategies incorporating increased monitoring, response planning, and community water conservation programs should be implemented to manage water demand.

4.2.3 Site and Facility Impacts

When selecting a site for new drinking water treatment infrastructure or upgrading existing systems, Designers should be aware of climate change impacts that could affect the facility and future levels of service. Table 4-5 provides some examples of climate change impacts on sites and facilities.

Table 4-5 Observed and Possible Site and Facility Impacts

Climate Impact	Design Considerations
Increased flood risk (due to changing precipitation patterns and/or extreme storm events) and fluvial flooding	Site flood risk may increase as flood risk areas expand in the future. Flood elevations should be considered for assets, especially critical infrastructure and/or assets with a long design life.
Increased wildfire risk (increased summer temperatures and drought)	Site wildfire risk may increase requiring design modification to improve resilience and/or support emergency response (for example, alternative and/or remote site access).
Changes in snowfall	Changes to winter precipitation, including the possibility of heavier, wetter, snow, could impact the structural design of above ground facilities.
Changing wind patterns	Extreme wind events could impact the structural design of above ground facilities.
Increased precipitation – extreme storm events	Changes in precipitation may impact stormwater management practices and building envelope design.

An additional consideration for Designers is related to indirect climate change impacts which could impact facility operations. For example, extreme weather events could disrupt utility service from third party utility providers or damage roads, limiting site access. There could also be supply chain impacts which could impact operations.

4.2.3.1 Considerations for Coastal Sites

Coastal areas of British Columbia may face additional challenges *(EPA, 2014 and AFN, 2008 and Lemmen and Warren, 2004),* including:

.1 Rising sea levels which may shift ocean and estuarine shorelines by inundating lowlands, displacing wetlands, and altering the tidal range in rivers and bays; and
.2 Storm surges resulting from more extreme weather events which will increase areas subject to periodic inundation.

These overlapping impacts make protecting water resources and infrastructure in coastal areas especially challenging. Impacts could vary from increased distribution system maintenance due to saltwater intrusion, to overall site inundation. As noted by the EPA (2014) “watershed-level planning will need to incorporate an integrated approach to coastal management in light of sea level rise including land use planning, building codes, land acquisition and easements, shoreline protection structures (e.g. seawalls and channels), beach nourishment, wetlands management, and underground injection to control salt water intrusion to fresh water supplies”. Ongoing monitoring of coastal impacts will be an important component of adaptation planning for coastal facilities.

4.2.4 Impacts to Treatment Process

As outlined in the previous section, climate change may result in impacts to raw water quality. Designers should consider these potential impacts and determine how the treatment process may need to be altered to accommodate projected changes to water quality. Designers may also consider taking a flexible approach to their design to allow for future modifications to the treatment process if water quality changes.

For example, higher concentrations of organic matter due to higher temperatures and increased turbidity due to precipitation events in surface water are projected impacts of climate change. Greater extremes and variations in raw water quality will require planning for adaptable treatment processes, and considerations for more intensive operations, maintenance and management of waste residuals. Some examples of planning for adaptability in treatment may include the ability to add or modify chemical dosing in pre- or post-treatment processes; selecting treatment options which are less sensitive to changing water quality; or including space provisions for additional treatment process installation or expansion if needed. Another consideration for treatment is that while increased organic loading may increase the types and concentrations of chemicals used and decrease filtration rates, increased water temperatures may also benefit chemical reaction and filtration rates.

4.2.5 Storage System Impacts

Climate change is altering snow deposition and snow melt patterns. This is important because snow acts as a massive slow-release water reservoir. Changes to the timing and rate of snow melt and seasonal precipitation can have significant implications for long term storage in community water systems, especially in mid-to-late summer and early fall when peak summer demand coincides with seasonal lows in water levels. Designing sufficient storage for projected demands should consider these changes in seasonal variability. In addition, as peak demand increases during summer months, peak hourly demand calculations for treated water storage may be insufficient without the implementation of strategic demand management practices. Ensuring water quality in storage systems may also become increasingly challenging in a changing climate. For example, designs for water storage infrastructure should account for water quality and rising temperatures that will promote algal and bacterial growth in standing water.

4.2.6 Building - Electrical and Mechanical System Impacts

Electrical systems can be vulnerable to projected changes in climate. For example, the risk of extreme storm events may result in a higher incidence of power outages, resulting in increased requirements for back-up generators. Designing electrical and mechanical systems for flood risk is another important consideration to ensure that critical equipment is located above flood levels. Ensuring access to critical equipment in the event of a flood or other natural disasters is another important design consideration, and may include considerations of alternative site access methods or remote SCADA control.

HVAC design will need to consider future temperatures to ensure that heating and cooling will be sufficient in a changing climate. This will be of particular importance for cooling capacity since temperatures are generally projected to rise. Ensuring adequate cooling capacity is important both from a health and safety perspective for operations and maintenance staff, as well as to ensure spaces that house electrical and heat generating mechanical equipment are kept cool. Consideration should be given to increased condensation on pipes and floors as a result of air conditioning. Additionally, changing air quality due to increased wildfire events may impact operations and maintenance of HVAC systems (i.e. filter requirements and replacements).

4.2.7 Conveyance System Impacts

Transmission and distribution system infrastructure may be impacted by extreme precipitation events leading to flooding or soil failures. Sea level rise or storm surge impacts could vary from increased underground infrastructure system maintenance due to saltwater intrusion, to overall site inundation *(EPA, 2015)*. Increases to winter seasonal freeze-thaw cycles could lead to greater incidences of fractures, cracking and deterioration of underground infrastructure, leading to increased operations and maintenance.

4.3 Climate Change Risk Assessment

Determining the regional and local effects of climate change is critical to assessing vulnerability and risk, which is necessary information to create implementable adaptation strategies. The following sections include key concepts and a risk assessment framework for Designers.

4.3.1 Methodologies for Climate Change Risk Assessments

There are several approaches available to assess climate change risk. These *Design Guidelines* do not prescribe a detailed methodology for Designers to follow, although it is recommended that any methodology used is aligned with *ISO 31000 Risk Management - Guidelines*. A globally recognized approach, this standard provides a generic risk management model that walks users through the steps of gathering information, assessing risk and developing a risk treatment plan. The resource list included at the end of this chapter includes a list of methodologies that are consistent with the *ISO 31000* standard.

4.3.2 Level of Effort and Detail

The required level of effort for a climate risk assessment will vary for every project. Designers should determine the required level of effort and detail based on a number of factors including the scope and scale of the project, acceptable risk thresholds, and the required level of service for the drinking water system. The availability of site-specific climate data may also influence the level of detail which is practicable for a risk assessment.

4.3.3 Risk Assessment Timeline

It is recommended that Designers complete a screening-level risk assessment during planning and conceptual design to understand site vulnerabilities and identify high-level considerations for siting and design. During preliminary design, Designers should conduct a comprehensive risk assessment to further analyze components or processes which are most at-risk due to climate change. Finally, to document decisions made, an adaptation plan should be developed and implemented to mitigate climate risks. Beyond the design stage, climate impacts and adaptation measures should be monitored and reassessed on a regular basis during operations.

4.3.4 Managing Uncertainty

Historical climate records are considered to be a reflection of "reality" and, through statistical analysis, they assist in the development of design values to address climate uncertainty. From an engineering perspective, the full ensemble of global climate models (GCMs) encompass greater uncertainty in future climate projections than those in historical records. The fact that climate models are being refined, especially with respect to projecting extreme values, creates a perceived increase in risk, which should be acknowledged and managed to ensure resilience over the full design life of the infrastructure.

Uncertainty should not prevent Water Suppliers from taking action now with regards to potential climate change impacts. Typically, engineers, planners, policy makers, and operators are already well equipped to deal with uncertainty by the very nature of their occupation. Using risk assessment as a decision-making process in the face of unknowns is not a new concept. Making decisions based on projections for long-term climate changes can be approached in the same manner.

4.3.5 Ongoing Monitoring and Updates

Climate science is an evolving discipline, where new data, models and projections are regularly published. For this reason, it is worthwhile to monitor new projections and compare them to those used in a design, adaptation planning, or operational plans. If new projections differ substantially from prior projections, it may be warranted to revisit a project climate risk assessment or adaptation plan for infrastructure, policies, or programs. A schedule can be created to evaluate updates to climate data, as it pertains to critical aspects of existing operations or new projects.

4.3.6 Reporting and Documentation

Designers should continuously document and report on their climate risk assessment process and include this documentation as part of project design reports.

4.4 Climate Change Risk Assessment Framework

The following framework is presented to guide Designers through various steps of understanding climate risks and incorporating resilience into drinking water system design. Illustrated in Figure 4-3, each step of the process is described in greater detail in the subsequent sections. Although this framework is focused on drinking water system design, it is important for Owners and Operators of drinking water systems to monitor climate risks and engage in ongoing adaptation planning.

STEP	OBJECTIVE	TIMING
Step 1: Project Definition (Section 4.5)	Determine relevant climate parameters and components to assess in risk assessment.	Project Planning
Step 2: Screening-Level Risk Assessment (Section 4.6)	Identify climate hazards.	Project Planning/Conceptual Design
Step 3: Detailed Risk Assessment (Section 4.7)	Assess the likelihood and severity of risks.	Preliminary Design
Step 4: Climate Adaptation Plans (Section 4.8)	Identify and implement measures to mitigate and manage risks.	Preliminary/Detailed Design/Operations

Figure 4-3 Climate Change Risk Assessment Framework

4.5 Step 1: Project Definition

The first step of the risk assessment process is Project Definition where climate parameters and project components to be included in the risk assessment are identified. Project Definition also includes stakeholder identification and building an understanding of organizational risk tolerance to inform the risk assessment process. The following activities are adapted from the framework presented in EGBC's *Professional Practice Guidelines for Developing Climate Change-Resilient Designs for Highway Infrastructure in British Columbia (2020)*:

.1 Characterize the project location;
.2 List project infrastructure components;
.3 Identify relevant climate parameters;
.4 Define project time horizons;
.5 Identify team members and stakeholders to be involved in risk assessment;
.6 Identify risk tolerance and level of service; and
.7 Identify non-climate design drivers.

The following sections provide additional detail on these activities.

4.5.1 Characterize the Project Location

When characterizing a project's location, Designers should assess not only the project footprint, but also the surrounding area which could impact the system. This is required to identify geographic characteristics, topography, water bodies, environmental features, and nearby infrastructure. During this stage, Designers should also consider regulatory requirements and standards which apply to the site.

4.5.2 List Project Infrastructure Components

At this stage of the process, Designers should identify key infrastructure components to be included in the project. High-level identification of infrastructure components is sufficient; details on the infrastructure design are not required at this stage. Designers should note which infrastructure components will be constructed as a part of the project, and which components, if any, will be retained or refurbished. Older and overextended drinking water infrastructure is likely to be more susceptible to climate hazards *(J. Boyle, M. Cunningham, J. Dekens, 2013)* and so it is important to include infrastructure to be retained as it will affect the overall resilience of the drinking water system.

4.5.3 Identify Relevant Climate Parameters

When identifying relevant climate parameters, Designers should consider not just parameters which could have a direct impact on the drinking water system (i.e. flooding damaging infrastructure), but also parameters which could have an indirect impact (i.e. impacts to supply chain due to climate hazards occurring in other geographic locations). Designers should ensure they are considering the full range of parameters and looking not just at annual averages, but also looking at extreme values and seasonal changes to determine how drinking water infrastructure could be impacted.

Climate parameters which may be considered include, but are not limited to:

.1 Rainfall (intensity, duration, frequency, seasonal shifts);
.2 Temperature (averages and extremes, heating and cooling degree days, heat waves);
.3 Snow and ice (daily snowfall, snow depth, snowpack, timing of freshet, ice storms, rain on snow events);
.4 Wind (average speed, gust speed, wind direction); and
.5 Sea level (average level, high tide/king tide, storm surges).

Climate parameters may also interact resulting in climate hazards which could impact drinking water systems. For example, drought, extreme storm events, wildfire risk, etc. Furthermore, interacting climate parameters may result in cascading effects which could result in increased risk for infrastructure components.

It is important to note that certain climate phenomena are not currently well captured by climate models. Examples include lightning, freezing rain, wind gusts, tornadoes, blizzards, shortwave (UV) radiation, and air quality. If these parameters are to be included, it is recommended to consider how the factors that affect these phenomena are changing. Such an assessment should be completed by a Climate Specialist.

4.5.4 Define Project Time Horizons

The time horizons for climate projections should align with the design life of infrastructure being considered. In some cases, it may be appropriate to use more than one-time horizon to capture risks related to different types of infrastructure.

As stated by EGBC (2020), "Infrastructure with a short service life is usually subject to periodic refurbishment or replacement. This provides an opportunity to re-evaluate corresponding climate risks and adaptation measures. Risks associated with climate change for such infrastructure may be low because the climate trend has had little time to develop. However, for infrastructure components that are not eligible for replacement or refurbishment before the end of their service lives, the consequences of decisions made during the design process can be significant."

4.5.5 Identify Team Members and Stakeholders to be Involved in Risk Assessment

The team members and stakeholders to be involved in a climate risk assessment will be project specific. At a minimum, Designers should include the Owner and Operator of the drinking water system as a part of the risk assessment process.

For a detailed risk assessment it is recommended that Designers also engage with individuals from the following groups:

.1 All relevant Qualified Professionals involved in the design of the project (i.e. hydrogeological, geotechnical, structural, hydrotechnical, electrical, mechanical, civil, etc.);
.2 Operations and maintenance;
.3 If Designers do not have a strong background in climate science, they should include a Climate Specialist as a part of the risk assessment team; and
.4 If Designers are not familiar with risk assessment processes, they should include a Risk Assessment Professional as a part of their team.

In most cases, it will also be valuable to engage with individuals with knowledge and experience in one or more of the following fields:

.1 Public safety;
.2 Social impacts;
.3 Economic impacts;
.4 Environmental impacts, including watershed and ecosystem impacts;
.5 Local climate and knowledge of historical climate events;
.6 Traditional knowledge;
.7 Politics;
.8 Insurance;
.9 Community issues;
.10 Land use planning;
.11 Emergency preparedness and response; and
.12 Law and accounting.

If public engagement is a part of the project scope, it is recommended that climate change considerations be included as a part of stakeholder engagement activities. Similarly, climate change considerations should be included when consulting or engaging with Indigenous communities.

4.5.6 Identify Risk Tolerance and Level of Service

Prior to completing a risk assessment, Designers should consult with the Owner and Operator to define their risk tolerance and the required level of service for the drinking water system. Risk thresholds typically depend on the function and design life of the infrastructure, and should be discussed and agreed upon to ensure that the climate risk assessment is aligned with these thresholds.

When determining and setting these objectives, it may be helpful to consider stakeholder expectations, strategic objectives, financial risk tolerance, and risks related to not meeting the required level of service. Regulatory requirements may also inform risk tolerance, such as requirements of the *Drinking Water Protection Act* and Drinking Water Protection Regulation, as well as conditions set out in Operating Permits.

4.5.7 Identify Non-climate Design Drivers

To provide context for a climate risk assessment, Designers should consider non-climate design drivers (for example, protection of public health, preserving or enhancing the ecological services of existing watersheds, meeting population growth demands, other regulatory requirements, etc.). Although these design drivers and project objectives may not be directly included in the risk assessment, they provide important context and could inform risk prioritization and adaptation planning.

4.6 Step 2: Screening-Level Risk Assessment

Completing a screening-level risk assessment during the planning process and/or conceptual design phase of a project allows Designers to identify potential climate impacts and vulnerabilities and determine if a more comprehensive risk assessment is required. The screening-level risk assessment answers the following questions:

- .1 What climate hazards will the drinking water system be exposed to; and
- .2 Which infrastructure components or processes might be impacted by these climate hazards?

4.6.1 Climate Projections

Climate projections are generally completed by a Climate Specialist using climate models. In some cases, regional climate projections may have already been completed and Designers may be able to use these projections when undertaking a climate risk assessment. There are publicly available resources for climate data which Designers may access to inform a climate risk assessment (Section 4.9 – Suggested Resources includes resources for climate data). However, it is not recommended that Designers rely solely on these resources if they do not have appropriate knowledge and experience with interpreting climate data in relation to typical design criteria. When using climate change projections to inform design, Designers should understand the source, data accuracy, spatial resolution as well as assumptions and limitations associated with the climate data. Understanding uncertainties associated with climate data is important to enable Designers to manage this uncertainty in the vulnerability and risk assessment process (also see Section 4.3.4 on Managing Uncertainty). If Designers do not have experience interpreting climate change projections and incorporating into design, they should engage with a Qualified Professional.

4.6.1.1 Climate Modelling

There are over thirty Global Climate Models (GCMs) which are owned by leading scientific institutions around the world. Per best practice in climate science, multiple climate models (i.e. multi-model ensembles that group results from multiple climate models together) that project future changes across a range of greenhouse gas emission scenarios should be used when assessing the potential impacts of climate change. Emission scenarios represent possible GHG emission patterns over the 21st century from anthropogenic emission sources. There are currently four industry standard scenarios, called Representative Concentration Pathways (RCP), that have been established by the Intergovernmental Panel on Climate Change (IPCC). These are commonly known as:

.1 RCP 2.6 – Assumes that GHG emissions stay consistent until 2020 when they begin to decline until 2100, where average global warming is limited to approximately ~2.0 °C in this time period;
.2 RCP 4.5 – A future with relatively ambitious emissions reductions where CO_2 emissions increase only slightly before a decline commences around 2040, where average global warming is limited to approximately ~2.4 °C by 2100;
.3 RCP 6.0 – A future where CO_2 emissions stabilize, where average global warming is limited to approximately ~2.8 °C by 2100; and
.4 RCP 8.5 – A future with no implementation of policy changes to reduce emissions, and thus increasing GHG emissions into the future, where average global warming is anticipated to increase by ~4.3 °C by 2100.

Designers may select a range of emissions scenarios to consider for the time horizon of the infrastructure components. While RCP 8.5 is the worst-case scenario of greenhouse gas concentration trajectories referred to in the IPCC report, it is the general consensus among local climate change scientists that RCP 8.5 is the likely pathway given the current state of anthropogenic (human) activity; therefore, it may be most appropriate for long-range planning. As climate science continues to evolve, best practices around emission scenario selection may also change.

It is important to recognize that improvements in climate modelling and process understanding will ultimately lead to better climate change projection data. It is encouraged for Designers using this guideline to maintain awareness of the rapid evolution in climate science and technology, and always use the best available data. Relevant climate data resources are provided at the end of this chapter.

4.6.2 Identify Infrastructure Components & Operational Processes

To complete the screening-level risk assessment, the key infrastructure components for the project are identified. Operational processes, policies, and human resources may also be included in this list to capture how climate change may impact future operations (i.e. extreme weather could prevent operators from accessing the site). Designers will need to determine the appropriate level of detail when identifying infrastructure components. It may be appropriate to group components or look at some components at a system or sub-system level.

4.6.3 Identify Climate Hazards

This step of the process considers the impact of climate projections on identified infrastructure components and operational processes. If an interaction between the selected infrastructure component or process and a climate hazard is found to exist and be of significance, this interaction should be included in the risk assessment. This process is repeated until all components or processes identified by the climate risk assessment team have been considered. Each identified climate hazard is then carried forward to be further analyzed in the detailed risk assessment.

4.7 Step 3: Detailed Risk Assessment

The detailed climate risk assessment builds on the work completed as a part of the Screening-Level Risk Assessment. What differentiates the detailed risk assessment from the screening-level risk assessment is that the detailed risk assessment considers not just whether an infrastructure component is vulnerable to a climate hazard, but what the likelihood and consequences of that interaction may be.

Generally, risk can be defined as the probability (or likelihood) of an event occurring and the severity (or consequence) of impacts if that event occurred. These processes can be numerically defined, or assigned qualitative rankings based on a specific scale. Designers should work with their key stakeholders and risk assessment team to define the scales and scoring terms for probability and severity which are aligned with the owner's risk tolerance: for example, very low probability may be an estimated likelihood of less than 1%, and very high severity could be permanent damage to infrastructure and long-term service disruption. *The Strategic Climate Risk Assessment Framework for British Columbia* also provides comparable definitions for likelihood and consequence scales. Figure 4-4 shows an example of how probability and severity scores can be used to determine an overall risk score using a five-point scale for severity and probability. If a numeric scale is used for probability and severity, risk scores are the product of the two scores.

RISK = PROBABILITY x SEVERITY

It is recommended that risk scoring exercises are completed in a workshop setting with key stakeholders representing multiple disciplines. Multi-disciplinary attendance at roundtable discussions related to severity and expert guidance by Climate Specialists in the assignment of probability will help to ensure that infrastructure impacts and climate information are properly accounted for in scoring. The scoring system can be adjusted and tailored to a specific site or process on a case-by-case basis, as long as it remains consistent throughout the entire assessment.

		SEVERITY (CONSEQUENCE)				
Risk Rating		**Very Low (1)**	**Low (2)**	**Moderate (3)**	**High (4)**	**Very High (5)**
PROBABILITY (LIKELIHOOD)	**Very Low (1)**	Very Low (1)	Very Low (2)	Low (3)	Low (4)	Low (5)
	Low (2)	Very Low (2)	Low (4)	Low (6)	Moderate (8)	Moderate (10)
	Moderate (3)	Low (3)	Low (6)	Moderate (9)	High (12)	High (15)
	High (4)	Low (4)	Moderate (8)	High (12)	High (16)	Very High (20)
	Very High (5)	Low (5)	Moderate (10)	High (15)	Very High (20)	Very High (25)

Figure 4-4 Sample Risk Matrix

4.7.1 Probability Scoring

Probability scoring is based on the likelihood of occurrence of a climate event within the lifetime of a specific infrastructure component which will lead to an impact. Probability scoring is informed by climate thresholds set for different infrastructure components. These climate thresholds help Designers to identify at what point infrastructure may be impacted. Thresholds can be determined through design standards, review of event and performance history, modeling of system performance or inspection of assets. It is recommended that Designers and Climate Specialists work together to set thresholds and then use climate projections to determine the probability that these thresholds might be exceeded.

4.7.2 Severity Scoring

Severity scores are specific to risk tolerance levels and required levels of service for each drinking water system component. When evaluating severity, it may be helpful to identify sub-categories to capture different types of consequences. The following list is an example of the types of consequence sub-categories that could be used *(ICLR, 2014)*.

.1 People (health and safety, displacement, loss of livelihood, reputation, disproportionate impacts to vulnerable populations);
.2 Economic (infrastructure damage, financial impact on organization); and
.3 Environment (air, water, land, ecosystems).

4.7.3 Risk Ranking and Prioritization

The risk analysis will generate a long list of risk scores. Scoring on a numeric scale allows for a quantitative comparison of various climate impacts to determine a priority for mitigation or adaptation. For infrastructure that is categorized as a high risk, adaptation measures should be implemented immediately. As the level of risk decreases, adaptation measures generally tend to decrease. Risk-based planning focuses on minimizing the risk associated with the asset through an appropriate intervention strategy, while ensuring that any risks are managed at the minimum cost.

4.7.4 Engineering Analysis

If there are gaps in data which do not allow for an adequate assignment of risk, additional engineering analysis may need to be completed in order to better understand the probability or severity of different potential impacts. Engineering analysis may also be completed after a risk assessment is completed in order to inform risk mitigation options to be included in a climate adaptation plan or design brief.

4.8 Step 4: Climate Adaptation Plans

4.8.1 Identifying Adaptation Options

After the risk assessment is completed, a climate adaptation plan can be developed to identify actions to mitigate climate risks and reduce vulnerabilities to climate change.

As noted by *EGBC (2020)*, adaptation is not restricted only to increasing capacity or strength, but may include:

.1 Enhanced operation and maintenance practices;
.2 Different construction materials or methods;

.3 Different siting;
.4 Phasing opportunities triggered by threshold events;
.5 Further study or more detailed analysis; and
.6 Monitoring, or any number of items that could enhance climate change resilience.

The climate change adaptation plan can be incorporated into a design brief.

4.8.2 Cost-Benefit Analysis of Adaptation Options

Once a range of possible adaptation options has been identified, the Designer may prioritize a shortlist of the most appropriate options for implementation. As part of this process, it is recommended that the Designer develop a cost-benefit analysis as a form of economic evaluation, and a multi-criteria analysis where costing is difficult to quantify.

.1 Cost-Benefit Analysis: Quantifies and assesses intervention costs against economic benefits such as improved safety and reduced risk of service disruptions to enable selection of the "best" option to close a performance gap. Lifecycle cost-benefit analysis is used to determine the set of investments with the lowest Net Present Value (NPV) or other financial parameter over the analysis period; and

.2 Multi-Criteria Analysis: Prioritizes competing options where benefits and costs are less tangible to define. Criteria are selected that align with climate change objectives. A weighting to demonstrate the relative importance of these factors is selected from an overall score.

Designers and stakeholders should work together to develop adaptation plans that take a holistic approach to climate adaptation and identify which climate risks are to be addressed through design and which risks will be addressed through other measures. These decisions should be well documented and communicated to ensure all parties are aware of the adaptation measures to be taken. Though often representing higher upfront costs, investments in a more resilient design, such as one that considers a full range of climate projections, can help avoid larger future costs (in terms of maintenance, repair and replacement), and make a project more resilient to future climate and weather extremes.

4.8.3 Adaptation During Design

Designers should consider the following categories of adaptation measures that can be used in the design process:

.1 Status quo design;
.2 Flexible design;
.3 Robust design; and
.4 Low- or no-regret strategies.

These adaptation measures are not mutually exclusive, and it is likely that a combination of strategies will be employed to realize adaptation objectives.

The following sections describing these adaptation measures are excerpts that have been adapted from EGBC's Professional Practice Guidelines for *Developing Climate Change-Resilient Designs for Highway Infrastructure in British Columbia (2020)*.

4.8.3.1 Status-Quo Design

Status-quo design recognizes that implementing no explicit adaptation measures is a valid response, provided that the reason or reasons are well documented and supported by evidence.

Situations where status-quo design may be a valid design method include the following:

.1 The risk assessment shows that the infrastructure is at no risk or low risk due to climate change; and
.2 The service life of the subject infrastructure is very short, and adaptation measures will be considered when the infrastructure is replaced or refurbished.

4.8.3.2 Flexible Design

Flexible design assumes that there will be opportunities to adapt in the future and allows for changes to be made when required. This option reduces up-front capital costs by designing the infrastructure to meet short term needs and/or probable future conditions, with planned design modifications for future scenarios. Flexible design is most appropriate for gradual changes over time, such as sea level rise or melting permafrost. Successful flexible design requires monitoring of climate, loads, and infrastructure performance, and should only be implemented if the Owner has the funds, authority, and willingness to maintain the monitoring program and implement predetermined upgrades as required.

With a flexible design approach, adaptation measures can be implemented when predefined trigger events occur. Trigger events should be defined in a way that ensures continued integrity of the infrastructure, but still signals increasing likelihood that the climate is trending toward conditions more severe than those used for initial design. For example, a trigger may be a flood level, flow rate, or rainfall intensity that reaches or exceeds a threshold value.

Flexible design involves the following steps:

.1 Base the project design on the most-probable weather or climate conditions, as opposed to the most-unfavorable conditions;
.2 Establish a course of action and design modification for every foreseeable unfavorable deviation from the most-probable weather and climate condition. Actions may increase adaptation through one or more of the following measures:
   a. Increase the infrastructure’s capacity or capacities;
   b. Reduce loads;
   c. Reduce the consequences of failure;
.3 Conduct a continuous monitoring program to determine the performance of infrastructure to evaluate its performance and response to observed changes; and
.4 Implement a plan of action to modify design and construction in response to observed climate changes.

4.8.3.3 Robust Design

Robust design seeks to ensure the proposed infrastructure will perform as expected over a range of possible future climate conditions, including the “worst-case” design scenario. This option usually results in higher initial construction costs for the infrastructure and ultimately lower vulnerability to climate change.

Some considerations for choosing the robust design approach may be as follows:

.1 The overall cost of implementing flexible design far exceeds the additional cost of implementing robust design;
.2 Flexible design is not an option because there are no feasible opportunities to phase in adaptation measures;
.3 There are social or political issues that are better addressed through robust design; and
.4 Robust design will not compromise level of service for present-day conditions.

Robust design may include, but is not limited to, the following:

.1 Use of generous safety factors applied to loads generated using "average" projected climate values and ensuring that capacities are designed accordingly;
.2 Capacities designed to service loads generated using "worst-case" projected design climate values; and
.3 Redundant features added to the design to protect against failure.

4.8.3.4 Low- or No-Regret Strategies

Low- or no-regret strategies can offer benefits under a range of climate change scenarios (including current and uncertain future climates) and lay the foundation for addressing projected changes *(IPCC 2012)*. These strategies include early warning systems, sustainable land-use planning, ecosystem management and restoration, and risk communication between decision-makers and local residents to minimize the extent of negative impacts. It is recommended that Designers connect with land use planners and watershed managers to identify watershed-scale opportunities for climate adaptation (i.e. erosion prevention or natural flood control). Identifying nature-based solutions to improve watershed resilience to climate change can increase drinking water system resilience as well as provide ecosystem and community co-benefits.

4.9 Suggested Resources

Suggested resources for climate change guidance are included in Table 4-6.

Table 4-6 Available Resources for Climate Change Guidance

Category	Resource	Link
Climate adaptation	EGBC Climate Portal	https://www.egbc.ca/Practice-Resources/Programs-Resources/Climate-Sustainability/Climate-Change-Information-Portal
	ISO 14090 Adaptation to climate change: Principle, requirements, and guidelines	https://www.iso.org/standard/68507.html
	AWWA M71 Climate Action Plans – Adaptive Management Strategies for Utilities (2021)	https://doi.org/10.12999/AWWA.M71ed1

Category	Resource	Link
	Climate Change and Water, IPCC Technical Paper VI, Intergovernmental Panel on Climate Change, June 2008	https://www.ipcc.ch/publication/climate-change-and-water-2/
Climate data	Climate Atlas	https://climateatlas.ca/
	PCIC Data Portal	https://pacificclimate.org/data
	Climatedata.ca	https://climatedata.ca/
	Canadian Climate Data and Scenarios	https://climate-scenarios.canada.ca/
	Climate Normals	https://climate.weather.gc.ca/climate_normals/index_e.htm
Risk assessment	ISO 31000: Risk Management	https://www.iso.org/iso-31000-risk-management.html
	ISO 14091 Adaptation to climate change – Guidelines on vulnerability, impacts and risk assessment standard	https://www.iso.org/standard/68508.html
	PIEVC Protocol	https://pievc.ca/protocol
	Preliminary Strategic Climate Risk Assessment for British Columbia	https://www2.gov.bc.ca/gov/content/environment/climate-change/adaptation/risk-assessment
Resilient infrastructure	Envision Framework	https://sustainableinfrastructure.org/envision/use-envision/#climate-and-resilience
	USEPA Creating Resilient Water Utilities (CRWU) – Resilient Strategies Guide	https://www.epa.gov/crwu
	World Bank Group's Water Global Practice – Resilient Water Infrastructure Design Brief	https://openknowledge.worldbank.org/bitstream/handle/10986/34448/Resilient-Water-Infrastructure-Design-Brief.pdf
BC-specific resources	Drought Information (including *BC Drought and Water Scarcity Plan* and *Dealing with Drought: A Handbook for Water Suppliers in British Columbia*)	https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/drought-information
	Modernizing BC's Emergency Management Legislation (Sendai Framework)	https://engage.gov.bc.ca/app/uploads/sites/121/2019/10/modernizing_bcs_emergencymanagement_legislation.pdf

4.10 Climate Change Mitigation

Climate change mitigation is an approach to reduce the human-induced greenhouse gas emissions that are released into the atmosphere and limit the extent of future climate change. Although the focus of this chapter is on climate adaptation, Designers and Water Suppliers have opportunities to reduce the emissions associated with drinking water system planning, design, operation, and maintenance activities. The energy consumed to treat and pump water, alongside that used in broader operations and facilities, plays a key role in contributing to emissions. To identify where the opportunities may lie to reduce emissions and approach carbon neutrality, it is important to understand what the existing carbon footprint of the water supplier is – where and what is driving emissions. Adaptation solutions to increase system resilience need to be considered with carbon in mind to avoid any potential conflicts/trade-offs with mitigation goals. To illustrate this, for example, diesel back-up power may increase resilience to a power outage but counteracts efforts to reduce GHG emissions. Co-benefits may be realized throughout this process as some design options will provide both mitigation opportunities as well as climate adaptation. In general, utilities should seek opportunities to reduce energy use and consumption, as it can be both economical and serve to limit future climate change impacts.

If Designers are not familiar with these concepts, it is recommended that they engage with Climate Mitigation Specialists to identify and implement opportunities. Although this is by no means an exhaustive list of resources, the following Table 4-7 includes some International standards that may help to guide Designers to understand and integrate these concepts into their design.

Table 4-7 Relevant ISO Standards

Category	Relevant ISO Standards
Greenhouse gas accounting	ISO 14064-1: Greenhouse Gases – Part 1: Specification with Guidance at the Organization Level for Quantification and Reporting of Greenhouse Gas Emissions and Removals
	ISO 14064-2: Greenhouse Gases – Part 2: Specification with Guidance at the Project Level for Quantification, Monitoring, and Reporting of Greenhouse Gas Emissions Reductions or Removal Enhancements
	ISO 14064-3: Greenhouse Gases – Part 3: Specification with Guidance for the Verification and Validation of Greenhouse Gas Statements
Life cycle assessment	ISO 14040: Environmental Management – Lifecycle Assessment – Principles and Framework
	ISO 14044: Environmental Management – Lifecycle Assessment – Requirements and Guidelines
Carbon footprint	ISO 14067 Greenhouse Gases – Carbon Footprint of Projects – Requirements and Guidelines for Quantification

5 Facility Recommendations

5.1 General

This chapter provides considerations for the siting and design of drinking water system buildings, structures, and facilities (e.g. pumping stations, pressure reducing stations, and water treatment plants).

In addition to the guidelines included in this chapter, consideration should be given to the design requirements of the *BC Building Code* (BCBC) and other federal, provincial, regional and/or municipal regulatory agencies.

5.2 Site Selection

The siting of new or expanded water system facilities should be done with careful consideration to the functional, safety, and long-term needs of the proposed facility. Factors that should be considered when selecting a site for new or expanded water supply, treatment, and/or distribution works include:

.1 Zoning by-laws or restrictions for the proposed site;
.2 Isolation from non-compatible land uses including potential pollution sources that may interfere with the quality of water or interfere with the effective operation of the water system;
.3 Facility location with respect to the raw water source, the area being serviced, and proximity to associated utilities for efficient management of the water system components;
.4 Off-site utility servicing such as electrical, natural gas, communications, sanitary, and stormwater;
.5 Site access during winter and emergency conditions;
.6 Site security including emergency access, neighbouring land uses, and normal activity within the area;
.7 Long term source water availability;
.8 Proximity to areas susceptible to forest fires;
.9 Physical site conditions such as susceptibility to flooding, geotechnical issues, groundwater/aquifer characteristics or proximity to natural watershed areas;
.10 Archeological and environmental assessments and/or impacts to confirm site constraints and alteration requirements; and
.11 Adequacy of the site for future expansion.

5.3 Facility Layout

The layout of new facility sites and buildings should be done with consideration to the design of safe, efficient and cost-effective infrastructure. The Designer should consider the site topography, geotechnical issues (slope stability, dewatering during construction and post construction, and vulnerability of shallow aquifers), climate, and weather conditions to develop the most economical design. The Designer should prepare a facility layout where the various processing units are arranged in a logical progression to avoid the necessity for major pipelines or conduits to transmit water from one module to the next. The plant layout should also provide convenience of operation, accessibility of equipment for operational needs, maintenance and removal, as well as to ensure operator safety. The building layout should provide for adequate ventilation, lighting, heating and drainage, and dehumidification equipment as required, and should minimize snow drifts in exterior areas.

WTP design should consider functional aspects of the plant layout, access roads, access to the power grid, location of the backup generator, site grading, site drainage, walkways, driveways and chemical delivery and receiving areas. The plant design should also incorporate spill control features for bulk chemical off-loading areas.

Roadways for chemical deliveries should be designed to be sufficient to accommodate the largest anticipated delivery with allowance made for vehicle turning and forward exit from the site. Typically, the largest delivery would be a 27,000 L tank truck, but some chemical deliveries may be done solely through totes transported via flatbed.

Where possible, the Designer should take advantage of natural grades in arranging the various process units. Consideration may be given to the use of inter-stage transfer pumps where they are more economical (capital and operating) than extensive construction in adverse ground such as rock.

5.3.1 Site Layout

The building and site layout design should consider all functional aspects of the facility, including requirements for normal operation, anticipated maintenance activities, and future expansion. The following factors should be considered and/or addressed, as applicable, in the design:

.1 Access roads, parking, driveways, and walkways for operations;
.2 Site grading and site drainage;
.3 Facility accessibility and site mobility during all seasons;
.4 Sanitary, storm, power, and telecommunication service connections;
.5 Cross connection control and proper separation of utilities;
.6 Protection of all structures and process from flooding;
.7 Provisions for climate change resilience;
.8 Provisions for waste treatment and disposal requirements;
.9 Provisions for spill containment and management;
.10 Energy efficient design practices to utilize prevailing wind and weather conditions to minimize energy consumption with natural lighting, passive ventilation and energy recovery;
.11 Efficient routing of exposed ducting and cabling within the facility to avoid conflicts and allow ease of access for future maintenance and replacement;
.12 Proper chases or utilidors for current and future process, plumbing, ventilation, and electrical systems;
.13 Climate control of spaces based on the type of occupancy, equipment and materials such that temperature, air flow and humidity are suitable to protect people and property;
.14 Weather protection of equipment and building entrances from snow, rain and ice;
.15 Security-related issues such as site/building access controls, protection of treated/finished water components, site lighting, and alarms; and
.16 The zoning permits that may be needed.

5.3.2 Building Layout and General Considerations

The design of the building should consider the following:

.1 Adequate ventilation;
.2 Adequate lighting;
.3 Adequate heating;

.4 Adequate drainage;
.5 Dehumidification equipment, if necessary;
.6 Accessibility for equipment operation, servicing, and removal;
.7 Accessibility of drill rigs to access well heads;
.8 Flexibility of operation;
.9 Operator safety;
.10 Convenience of operations; and
.11 Placing chemical storage and feed equipment in a separate room to reduce hazards, spills and dust problems. Reference should be made to Chapter 13 – Chemical Application for further guidance on design of chemical systems.

5.3.3 Health and Safety

The building and site layout design should consider the safety of operations personnel and visitors. The design must comply with the *BC Building Code* (BCBC). The design of the building and site layout should consider the following factors:

.1 Emergency egress routes;
.2 Reducing or eliminating confined spaces;
.3 Provision of fall protection including railings, anchor points, and work zone delineation;
.4 Provision of lock-out and tag out provisions for energized equipment or potential energy hazards;
.5 Toxic gas detectors and warning signs;
.6 Noise arresters and noise protection;
.7 Vibration isolators and dampeners;
.8 Warning signs on the doors to chemical rooms;
.9 Emergency flushing/eyewash/safety shower locations and capacity (as per WorkSafeBC requirements);
.10 Provision of fire protection systems including smoke detectors and fire extinguishers;
.11 Reducing the risk of arc flash through design, including ducting and setbacks;
.12 Separation of chemical storage and handling;
.13 Manual overrides for automated controls; and
.14 Chemical spill containment and separation.

The appropriate personal protective equipment (PPE) should be provided for all personnel including; gloves, face shields, goggles, fall arrest, hearing protection, and confined space entry equipment, etc.

5.3.4 Provisions for Future Expansion

Provisions for future plant expansions should consider:

.1 Building siting and topography;
.2 Oversizing of plant piping and conveyance facilities to provide for future projected flow requirements, where treatment will not be negatively affected;
.3 Use of blind flanges for future process expansion connections;
.4 Allocation of additional space in facility superstructures;
.5 Building envelope access points for installation of future equipment;
.6 Provision for future buried or exposed electrical cables between equipment and structures;
.7 Sizing of HVAC and electrical systems (including additional space in MCC/PDC rooms);

.8 Provision of wall castings for future piping penetrations whenever pipes pass through walls of concrete structures; and
.9 Provisions for expansion of the plant waste treatment and disposal facilities, including space for installation of electrical equipment at a later date.

The Designer should review all of the above considerations regarding facility layout with both the drinking water system Owner and the operator at an early stage in the planning and design processes.

5.4 Monitoring Equipment and Laboratory Facilities

Each drinking water system should have equipment to perform the routine performance monitoring necessary to ensure proper operation of the system. Monitoring equipment selection should be based on the characteristics of the raw water source and the complexity of the treatment processes involved. Testing and monitoring should be conducted by appropriately trained individuals. Laboratory test kits which simplify procedures and the qualifications needed to conduct one or more tests may be acceptable.

Water Suppliers must conduct regulatory compliance monitoring (bacteriological) as per Section 11 of the DWPA and Section 8, Schedule A and Schedule B of the DWPR. In contrast with performance monitoring conducted at Water Supplier laboratory facilities, samples for bacteriological compliance monitoring must be analyzed by laboratories (normally third-party) which have been approved by the Provincial Health Officer. A list of approved laboratories can be found on the website of the Provincial Health Services Authority (PHSA). Laboratories may also conduct bacteriological monitoring on site for operational purposes, but these samples cannot be used to meet regulatory monitoring requirements.

Analyses conducted to determine compliance for physical and chemical parameters should be performed in a laboratory certified for analysis of these parameters. Some laboratories are voluntarily certified by the Canadian Association for Laboratory Accreditation (CALA).

Laboratory facilities (e.g. a dedicated laboratory room) is recommended for systems which conduct multiple onsite analyses. The following should be considered when designing a laboratory room:

.1 Sufficient bench space, adequate ventilation, adequate lighting, storage room, laboratory sink, and auxiliary facilities should be provided. Air conditioning may be necessary;
.2 Sample lines may be used to convey a continuous sample stream to the laboratory from the various stages of the treatment process. These sample lines should run continuously to provide representative samples and be kept as short as possible. Consideration for discharging the increased volume of wastewater should be reviewed if a continuous sample stream is to be included in the design;
.3 Sufficient glassware and general reagents should be provided to conduct all the required analyses, as well as appropriate cleaning agents. Sample and reagent storage and refrigeration should also be provided, if required;
.4 An emergency shower/eye wash station should be provided and should be located such that operators have easy access to the station. Stations not connected to a potable water system should have a minimum 15-minute flush capacity. Saline solutions should not be used;
.5 At larger treatment plants, the Designer should consider providing pilot-scale facilities, with sufficient flexibility to alter coagulation, flocculation, filtration and other process operations,

to assist in determining optimum plant operating conditions. If a pilot plant is not currently being considered, providing space for future addition should be considered;

.6 Acid resistant plumbing systems from laboratory or waste drains should be used as required, based on the type of laboratory and reagents used; and

.7 Methods should be provided for verifying adequate quality assurances and for routine calibration of equipment.

Additional details, including specific analytical recommendations, can be found in Chapter 22 – Water Quality Monitoring.

5.5 Personnel Facilities

Personnel facilities should be dictated by the number of personnel expected to be working at one time. At a minimum, it is recommended that provisions be made for storage lockers and change rooms/washrooms with showers. Water efficient fixtures should be used. A lunchroom of adequate size to serve as a meeting or training room for WTP staff as well as a suitable office for WTP supervisory staff and record keeping should be provided. Whenever possible, personnel facilities should be separated from the WTP facilities, but with convenient access to the WTP. Adequate facilities should be included for shop space and storage consistent with the designed facilities.

The provision of drinking water and sanitary facilities for operators may lead to a significant increase in cost for small remote plants. In communities where such facilities may be available elsewhere, the Designer should determine whether such facilities are required and may propose alternatives. Reference should be made to Chapter 21 – Small Systems for further guidance on small system design.

The facility water supply service line and the plant finished water sample tap should be supplied from a source of finished water at a point where all chemicals have been thoroughly mixed, and the required disinfectant contact time has been achieved. Due to high disinfectant residual concentrations at the WTP, bottled water dispensers may be preferred as drinking water for personnel and visitors.

There must be no cross connections between the facility water supply service line and any piping, troughs, tanks, or other treatment units containing wastewater, treatment chemicals, raw or partially treated water.

5.6 Building Services

All buildings must conform to the *BC Building Code*. The following should also be considered for each building:

.1 Adequate and safe heating systems with controls should be provided. In many areas of the plant, sufficient heat need only be provided to prevent freezing of equipment or treatment processes. Buildings should be well ventilated by means of windows, doors, roof ventilators or other means;

.2 Walls, floors, and HVAC systems should be coated in a corrosion resistant material and protected from damage due to humidity;

.3 All rooms, compartments, pits and other enclosures below grade should have adequate forced air ventilation provided when it is necessary to enter them;

.4 Rooms and galleries containing equipment or piping should be adequately heated, ventilated, and dehumidified to prevent excessive condensation. Switches should be provided for convenient control of the forced ventilation;

.5 Buildings should be adequately lit throughout by means of natural light and artificial lighting;

.6 Control switches should be conveniently placed at the entrance to each room or area;

.7 Emergency lighting should be provided;

.8 Communications systems should be provided including connections between buildings;

.9 Power outlets of suitable voltage should be provided at convenient spacing throughout plant buildings to provide power for purposes such as maintenance equipment and extension lighting;

.10 Power outlets located on the outside of buildings may be advantageous. Ground fault interrupter (GFI) type outlets are desirable throughout (where appropriate). Outlets supplied by uninterruptible power supply (UPS) or emergency power systems should be located such that they are easily accessible during a power outage;

.11 Adequate shop space and storage for the designed facilities should be provided; and

.12 A bridge crane, monorail, lifting hooks, hoist or other adequate facilities should be provided for servicing or removing heavy and/or large equipment.

5.7 Mechanical Piping

All mechanical piping in water treatment plants should:

.1 Be designed and manufactured in accordance with ASME, AWWA or CSA standards;

.2 Use seismically appropriate pipe materials and connections for all pipes;

.3 Use compatible flanges or grooved couplings for steel pipe and equipment connections that are equal to or greater than 75 mm in diameter. Steel pipe or equipment connections that are less than 75 mm in diameter should be threaded. Similar units, flange standards and thread standards should be used throughout the facility;

.4 Use fused piping connections, and flanged equipment connections for HDPE pipe;

.5 Use socket welded or threaded piping connections, and threaded or flanged equipment connections for PVC pipe. However, threaded piping is not recommended for small diameter sodium hypochlorite piping;

.6 Use flanged piping connections and equipment connections for FRP pipe;

.7 Be appropriate for the type of liquid to be conveyed. Pipe selection will depend upon economic and corrosion rate factors, as well as the type of equipment used, and connections required. Acceptable process piping/valve materials include polyvinyl chloride (PVC), polyethylene (PE), ductile iron (DI, with proper coating), carbon steel (with proper coating) and stainless steel (with proper passivation). Special consideration is to be given to low and high pH liquids;

.8 Allow for greater potential for deflection in thin wall pipe systems;

.9 Allow for future capacities and ease of extending the piping without major disturbance to the plant;

.10 Have proper isolation through valves, spectacle blinds and pipe sections to allow for repair or replacement;

.11 Provide couplings downstream of isolation valves to allow for maintenance of piping;

.12 Allow for the possibility that piping could be installed during construction when temperature conditions could be substantially different from the design condition (for example, piping could be installed in temperatures anywhere between 40 °C and -20 °C and substantial differences in pipe dimensions could occur). Where piping is cast-in-place, allowance should be made for differential expansion between pipe material and structures. For this reason, the use of polyvinyl chloride (PVC) pipe with cast iron mechanical joint fittings should be avoided;

.13 Be made of similar materials (e.g. pipe appurtenances); otherwise, dielectric couplings should be employed to reduce galvanic corrosion. If pipe with dissimilar materials is connected, insulation kits should be used to reduce galvanic corrosion;

.14 Be provided with drains at all low points and air valves at all high points;

.15 Include cleanouts and flushing facilities for sludge piping;

.16 Allow for proper restraint under all anticipated conditions, particularly where surges may occur, and high transient pressures could result, or where different temperatures occur seasonally. Piping stress analysis should be part of the design of all piping systems (pipe and support) involving high pressure fluids or gases, dangerous chemicals, large diameter above ground pipe, or the potential for transient or temperature derived pressure effects;

.17 Consider supply pressure and employ pressure reducing valves, where necessary;

.18 Avoid using plastic or PVC type pipe for pneumatic systems;

.19 Guard or protect from physical impact, plastic or other pipe materials that may shatter on impact, especially for essential and/or hazardous systems;

.20 Where piping connections are made between adjacent structures, use at least two flexible couplings if any possibility of settlement or differential expansion exists, unless other mitigation is provided to accommodate potential lateral deflections. Particular attention should be given to pipe bedding in areas adjacent to structures to avoid damage due to settlement;

.21 Be arranged so that all valves, flow meters, and other items which may require regular inspection or maintenance are conveniently accessible;

.22 Include sufficient couplings and flanges to allow for easy disassembly and removal of equipment;

.23 Not be subject to contamination and have watertight joints;

.24 Provide sample taps so that water samples can be obtained from each water source and from appropriate locations in each treatment unit operation, and from the finished water. Taps should be consistent with sampling needs and should not be of the petcock type. Taps used for obtaining samples for bacteriological analysis should be of the smooth-nosed type without interior or exterior threads, should not be of the mixing type, and should not have a screen, aerator, or other such appurtenance.

.25 Insulation should be provided where temperatures below 4 °C are anticipated, or a humid environment where condensation on cold pipe surfaces would be expected. Heat tracing should also be provided when there is a risk of freezing.

.26 Designed for the process water piping flow velocities listed in Table 5-1.

Table 5-1 Recommended Maximum Line Velocity

Process	Maximum Velocity (m/s)
Maximum Velocity Limited by Process Considerations	
Flocculated water	0.60
Pre-settled water	0.60
Post-settled water	0.30
Filter influent	0.20
Maximum Velocity Limited by Hydraulic Considerations	
Raw water (pumped)	3.0
Filter effluent	2.0
Wash supply	3.0
Wash drains	2.5
Treated water (pumped)	3.0

5.8 Cross Connections and Backflow Prevention

Within water facilities, considerable potential exists for cross connections between drinking and non-drinking water. Typical examples are drinking water supplies for chemical solution make-up, cooling water supplies to mechanical equipment, seal water supplies to pumps, and filter surface-wash piping. While pump seal water supplies need only be of better sanitary quality than the water pumped, it is frequently more convenient to use the treated water system to provide seal water.

For information on cross connection control, refer to relevant municipal bylaws; the BC Plumbing Code (in particular, Division B, article 2.6.2), the Canadian Standard Association's (CSA) *Selection and Installation of Backflow Preventers/Maintenance and Field Testing of Backflow Preventers (CSA Standard B64.10)*, the *AWWA Manual of Water Supply Practices M14 – Recommended Practice for Backflow Prevention and Cross-Connection Control* and/or the USEPA *Cross-Connection Control Manual, 2003.*

There are several types of backflow prevention devices available including air gaps, double check valve assemblies, reduced pressure principle devices, dual check valves, atmospheric vacuum breakers, and pressure vacuum breakers. Backflow prevention devices should be selected, installed and tested in accordance with the previously mentioned standards or codes.

For applications involving health hazards, only air gaps or reduced pressure principle devices should be used.

5.9 Piping Colour Code

To facilitate identification of piping in plants and pumping stations it is recommended that the colour scheme described in Table 5-2 is used.

Table 5-2 Piping Colour Coding

Chemical Lines	**Colour**
Alum or primary coagulant	Orange
Ammonia	White
Carbon slurry	Black
Caustic	Yellow with green band
Chlorine (gas and solution)	Yellow
Chlorine dioxide	Yellow with violet band
Fluoride	Light blue with red band
Lime slurry	Light green
Ozone	Yellow with orange band
Phosphate compounds	Light green with red band
Polymers or coagulant aids	Orange with green band
Potassium permanganate	Violet
Soda ash	Light green with orange band
Sulfuric acid	Yellow with red band
Sulfur dioxide	Light green with yellow band
Waste Lines	**Colour**
Backwash waste	Light brown
Sewer (sanitary or other)	Dark gray
Sludge	Dark brown
Other	**Colour**
Compressed air	Dark green
Gas	Red
Other lines	Light gray
Water Lines	**Colour**
Finished or potable	Dark blue
Raw or recycle	Olive green
Settled or clarified	Aqua

For liquids or gases not listed above, a unique colour scheme and labeling should be used. In situations where two colours do not have enough contrast to easily differentiate between them, a 150 mm band of contrasting colour should be on one of the pipes at approximately 700 mm intervals. The name of the liquid or gas should also be on the pipe. It is recommended to provide arrows indicating the direction of flow.

5.10 Site, Building, and Digital Security

Security measures are required to help ensure that Water Suppliers can effectively protect the drinking water supply. Design considerations should address physical infrastructure security and facilitate security related operational practices and institutional controls. Because drinking water systems cannot be made immune to all possible attacks, the design should address issues of critical asset redundancy, monitoring, response, and recovery. All public water supplies should identify and address security needs in design and construction for new projects and for retrofits of existing drinking water systems. Reference should be made to the *AWWA G430*, *Security Practices for Operation and Management* and AWWA's *Security Guidance for Water Utilities* document. To ensure highest protection to the public's drinking water, it is recommended that all water systems undertake a Security Vulnerability Self Assessment, at the very minimum, once every five years to identify any weaknesses in water system security and to determine security measures that should be implemented.

The following concepts and items should be considered in the design and construction of new water system facilities and improvements to existing water systems:

.1 Security should be an integral part of drinking water system design. Facility layout should consider critical system assets and the physical needs of security for these assets;

.2 The design should identify and evaluate single points of failure that could render a system unable to meet its design basis. Redundancy and enhanced security features should be considered to eliminate single points of failure when possible, or to protect them when they cannot reasonably be eliminated;

.3 Consideration should be made to ensure effective response and timely replacement of critical components that are damaged or destroyed. Critical components that comprise single points of failure (e.g. high volume pumps) that cannot be eliminated should be identified during design and given special consideration. Design considerations should include component standardization, availability of replacements and key parts, re-procurement lead times, and identification of suppliers, and secure retention of component specifications and fabrication drawings. Readily replaceable components should be used whenever possible and provisions should be made for maintaining an inventory of critical parts;

.4 Human access should be through controlled locations only. Intrusion deterrence measures (e.g. physical barriers such as fences, window grates and security doors; traffic flow and check-in points; effective lighting; lines of sight; etc.) should be incorporated into the facility design to protect critical assets and security sensitive areas. Appropriate and effectively operated detection should be included in the system design to protect critical assets and security sensitive areas. All cameras and alarms installed for security purposes should be connected to SCADA (Supervisory Control and Data Acquisition) where available and include monitors at manned locations. Alternative methods should be considered for primary use where there is no SCADA or SCADA support system;

.5 Vehicle access should be through controlled locations only. Physical barriers such as moveable barriers or ramps should be included in designs to keep vehicles away from critical assets and security sensitive areas. It should be impossible for any vehicle to be driven either intentionally or accidentally into or adjacent to finished water storage or critical components without being provided access by operations staff. Designated vehicle areas such as parking lots and drives should be separated from critical assets with adequate standoff distances to eliminate impacts to these assets from possible explosions of material in vehicles;

.6 Sturdy, weatherproof, locking hardware should be included in the design for the access to tanks, vaults, wells, well houses, pump houses, buildings, power stations, transformers, chemical storage, delivery areas, chemical fill pipes, and similar facilities. Hardened protective covers should be considered for padlocks or similar devices. Vent and overflow openings should be placed in secure areas. When not placed in secure areas, they should be provided with deterrence or intrusion detection equipment;

.7 Computer based control technologies such as SCADA should be secured from unauthorized physical access and potential cyber-attacks. Wireless and network-based communications should be encrypted/firewalled as a deterrence to hijacking by unauthorized personnel. Consideration should be made to designing ISA/IEC 62443-compliant automation systems, and/or including provisions for a CSMS (cybersecurity management system). Vigorous computer access and virus protection protocols should be built into computer control systems. Effective data recovery hardware and operating protocols should be employed and exercised on a regular basis. All automated control systems should be equipped with manual overrides to provide the option to operate manually. The procedures for manual operation including a regular schedule for exercising and ensuring the operator's competence with the manual override systems should be included in facility operation plans. Refer to AWWA's resources on cybersecurity (including the Cybersecurity Risk Management Tool) for more information;

.8 Real time water quality monitoring with continuous recording and alarms should be considered at key locations to provide early warning of possible contamination events; and

.9 Facilities and procedures for delivery, handling and storage of chemicals should be designed to ensure that chemicals delivered to and used at the facility cannot be released, introduced or otherwise used to debilitate a water system, its personnel, or the public. Particular attention should be given to potentially harmful chemicals used in treatment processes (e.g. strong acids and bases, toxic gases, and incompatible chemicals) and on maintenance chemicals that may be stored on-site (e.g. fuels, herbicides, paints, and solvents).

5.11 Flood Protection

Other than surface water intakes, all water supply facilities including pump stations, wells, reservoirs, and water treatment plant access roads should be protected to at least the 200-year flood elevation or maximum flood of record, and any climate risk assessments that have been completed. A minimum freeboard may also be required. Local municipal bylaws and provincial guidelines (e.g. the *BC Flood Hazard Area Land Use Management Guidelines*) should be referred to for the flood construction level. Additionally, the Riparian Areas Protection Regulation and local bylaws should be reviewed when working near a riparian area. Main switch gear electrical controls should be located above grade in areas not subject to flooding. For well floodproofing, reference should be made to the *Drinking Water Protection Act* (section 16), Drinking Water Protection Regulation (section 14) and *Water Sustainability Act* (section 63).

6 Source Water

6.1 General

This chapter provides guidance for the selection and development of source waters for use in drinking water supply and presents topics for Designers to consider when developing a new drinking water source or modifying an existing drinking water source. Development of source water infrastructure can represent a significant investment that will have long term implications to the quality and quantity of water available for use in a water system. Careful consideration of the source water alternatives (e.g. waterbody or aquifer, location, diversion infrastructure, etc.) can reduce the need for engineering or operational controls and ensure the sustainable supply of drinking water.

Provision of clean, safe and reliable drinking water begins with the source water. The term source water refers to any surface water or groundwater supply that is used to provide drinking water under the DWPA. Water Suppliers should aim to obtain source water from the best available source which is economically reasonable and technically possible. When selecting a source water, more than one water source should be evaluated, where feasible. Doing so will help allow for the best water source to be selected, and will document alternative source(s) that can be used as a back-up in cases where the chosen water supply becomes contaminated, unreliable, or otherwise unsuitable.

Prior to developing a new water source, a Water Supplier should demonstrate to the Issuing Official that the source water is appropriate for the intended use, there is adequate quantity of water available to meet current and future water demands, and that withdrawals from the water source are sustainable (see Section 6.1.2 – Source Water Quantity).

When selecting a new water source, Designers should apply a systems approach to assess the impact of seasonal variations on raw water quality and quantity, the benefits of gravity supply to the distribution system, the type and proximity of known contaminant sources, current and anticipated activities within the source area (watershed or capture zone), changing climate conditions, the effect of blending multiple source waters on water chemistry (if applicable), and accessibility to water supply infrastructure.

Consultation should be a key project phase when developing a new source water supply. The relevant First Nations should be consulted where Indigenous rights may be adversely impacted by:

.1 a proposed water supply diversion, storage and use; or
.2 construction, maintenance and operation of the supply system.

6.1.1 Types of Source Water

In B.C., drinking water sources are generally grouped into the following types of source water to assess the level of treatment required for public health protection:

.1 **Surface Water** is defined in the Drinking Water Protection Regulation as water from a source which is open to the atmosphere and includes streams, lakes, rivers, creeks and springs;

.2 **Groundwater** is defined in the *Water Sustainability Act* as water naturally occurring below the surface of the ground. In the *Guidance Document for Determining Groundwater at Risk* *of Containing Pathogens,* groundwater sources are classified based on the following categories:

a. **Groundwater at risk of containing pathogens (GARP)** is defined as any groundwater supply likely to be contaminated from any source of pathogens, continuously or intermittently. Potential sources of pathogens include sewage discharge to land, leaking municipal sewage pipes (especially force mains), agricultural waste stockpiles, runoff intrusion into poorly constructed wells, and surface water;

b. **GARP-viruses only** is defined as any groundwater supply determined to be 'at risk' of containing viruses (i.e. if the DWO has reason to believe that the source is only at risk of containing viruses, and not other pathogens). This would include water supply system wells located within 300 m of a source of probable enteric viral contamination without a barrier to viral transport or other conditions indicating possible viral contamination, therefore requiring treatment of viruses;

c. **Groundwater at low risk of containing pathogens** is defined as groundwater that is considered to be at low risk of containing pathogens as a result of a GARP assessment (i.e. no hazards were identified following a GARP Stage 1: Hazard Screening and Assessment, or the groundwater source was determined to be at low risk following a Stage 2: GARP Determination).

The *Guidance Document for Determining Groundwater At Risk of Containing Pathogens (GARP)* should be referenced when assessing microbial contamination risks to groundwater. The determination of the groundwater category (GARP, GARP-viruses only, or groundwater at low risk of containing pathogens) for a given water source is made by a DWO. This determination becomes the basis for establishing whether disinfection is required and the other measures needed to ensure that public health is protected. Water Suppliers may conduct a self-assessment in consultation with the DWO; and

.3 **Rainwater** is defined as water collected from natural precipitation from a roof or similar structure. Stormwater – precipitation runoff that flows over land and/or impervious surfaces not including roofs (e.g. streets, parking lots, roofs with public access or green roofs) – is not considered as rainwater. Any system used to collect, convey, store, treat and distribute rainwater for use is a rainwater harvesting system. Refer to Chapter 21 – Small Systems for rainwater-specific guidance.

For guidance on pathogen log reduction treatment objectives for different source water types, refer to the *Guidelines for Pathogen Log Reduction Credit Assignment* (BC MOH, 2022).

6.1.1.1 Source Water Assessment

As part of an application for source water approval, a Water Supplier should undertake a source water assessment to understand the characteristics of the source water and threats that may affect the quality and quantity of water. A source water assessment represents only a portion of the overall water system assessment and should be completed prior to the development of source water diversion or extraction infrastructure. The methodology to be used for the source water assessment may vary based on the size, characteristics and complexity of the water system. The source water assessment should accompany an application for source water approval. The Ministry of Health has developed several tools to complete this work.

The Comprehensive Drinking Water Source-To-Tap Assessment (CS2TA) is intended to help water suppliers develop a better understanding of risks to drinking water safety and availability. This is an eight-module step-by-step assessment that evaluates the vulnerabilities that may threaten the safety and sustainability of the water supply and provides risk management actions to address them. Modules 1 and 2 are specific to the source water, while Modules 3, 4, 5 and 6 are specific to the infrastructure and management of the drinking water system. Module 7 outlines the risk assessment process, and Module 8 recommends an approach to manage and mitigate the identified risks.

A source water assessment may be comprised of CS2TA Modules 1, 2, 7, and 8, or as agreed to by the DWO or their designate.

6.1.2 Source Water Quantity

In selecting the source water to be developed, the Designer should determine the water supply requirements to meet current and future water system demands. The assessment of the source water quantity requirements can be separated into two parts, as follows:

.1 Determine the water demands required by water system customers, process water requirements and facility requirements (if applicable) based on current and future design horizons; and

.2 Verify the source water has adequate capacity to meet the water demands determined in point .1 in addition to all other authorizations with precedence, as determined under the WSA, including the environmental flow needs, and that the withdrawals from the source water are sustainable.

The quantity of water required (in point .1) should be determined based on the water system demands (consumption, bulk supply, non-revenue water, etc.), process water requirements (wash water, make-up water, sample waste, etc.), facility domestic usage, and other water demands that can be reasonably anticipated for the water system. For water system planning, the source water should be sized to supply the current and future anticipated maximum day demand (MDD), seasonal average monthly fluctuations and the total annual demand of the water system. For water systems providing fire protection, the source water(s) should have adequate capacity to replenish depleted fire suppression storage within 72 hours (or sooner if required by the local fire authority or local government having jurisdiction over the water system) while concurrently supplying the MDD of the water system. For water systems without storage (free surface or pressure tanks) the source water supply infrastructure should be sized to meet the peak hourly demand plus a suitable safety factor. Further details of source water capacity planning are provided in subsequent sections of this chapter; considerations for small water systems (including rainwater systems) are provided in Chapter 21 – Small Systems.

Water Use During Scarcity in B.C.

If **significant water shortage** (SWS) is in place under the WSA for a designated area and a **critical environmental flow threshold** (CEFT) order is in place for a water source, CEFT has precedence over water rights. A CEFT is a short-term flow threshold, below which significant or irreversible harm to the stream's aquatic ecosystem is likely to occur. Under the "**first in time, first in right**" (FITFIR) system of precedence of rights, the date of precedence establishes who is allowed their full allocation of water first during times of water scarcity or drought. Domestic users will not be prohibited from diverting and using up to 250 litres per day per dwelling for **essential household use** (EHU).

The determination of the source water availability is administered under the *Water Sustainability Act* (WSA) with consideration to all other authorized water rights on the source water and the interconnected surface water and groundwater resource. The WSA endeavours to protect BC's water supply to ensure sustainable management of the Province's water resources today and in the future. Under the WSA, a Water Supplier must hold a Water Licence to divert or use water from a surface water or groundwater source; therefore, water systems must have appropriate Water Licences for their source water supplies. Water Suppliers must apply to the Ministry of Water, Land and Resource Stewardship (WLRS) for a Water Licence for surface or groundwater use through FrontCounterBC's website (www.frontcounterbc.gov.bc.ca).

As part of the Water Licence application process, WLRS conducts a watershed-scale water balance and/or groundwater modelling to consider climate, and groundwater and surface water interaction over the anticipated lifetime of the water supply system. When water balance and environmental flow needs estimates are not available for an area, the Water Licence applicant may be required to carry out this modelling.

A Water Licence is not required for rainwater harvesting.

6.1.3 Source Water Quality

Where possible, source water for drinking water systems should be selected to obtain the highest quality water that is reasonably and economically available and should meet the provincial *Source*

Drinking Water Quality Guidelines (SDWQGs). The SDWQGs are managed and developed by the Ministry of Water, Land and Resource Stewardship as part of the *B.C. Ambient Water Quality Guidelines* (WQG). These guidelines provide maximum acceptable concentrations (MAC) and aesthetic objectives (AO) for chemical, physical and microbiological water quality parameters and apply to ambient or raw water before it is treated and distributed for potable use. Assessment of source water quality against the ambient SDWQGs is a key part of source water protection and the multi-barrier approach to drinking water safety.

The Contaminated Site Regulation (CSR), under the *Environmental Management Act*, sets out requirements for sites which may be contaminated or are known to be contaminated to ensure that groundwater quality at these sites is suitable for specified direct uses (including drinking water) and is of adequate quality to protect adjacent groundwater uses. The CSR and supporting technical guidance outlines screening and sampling methodologies to determine whether there are potential contaminants of concern (PCOCs) in the soil or within the groundwater, and sets requirements for remediation (i.e. numerical standards). Designers must check for any registered contaminated sites, or sites with current or historical activities which could reasonably be assumed to be contaminated, within 500 m of any proposed drinking water source, and should refer to the CSR and supporting technical guidance from the Ministry of Environment and Climate Change Strategy for further details and tools.

Designers need to consider source water quality parameters to determine the level of treatment required to meet the *Design Guidelines*. A source water quality assessment and monitoring program should be conducted to understand the variation in seasonal water quality conditions of a new or modified water source. When developing a new source water, the focus of the sampling program should be on understanding the challenges, risks and seasonal variations. The following Table 6-1 provides a list of parameters that should be considered. The specific parameters to test and frequency of sampling should be selected on a source-by-source basis and should consider the source water type, proximity to potential contaminant sources, current and anticipated land use in the source area, and effects of changing climate conditions.

Table 6-1 Raw Water Characterization Parameters

Field Parameter
Conductivity
Odour [a]
pH
Temperature
Turbidity
Lab Parameter
Microbial [b]
E. coli
Heterotrophic plate count
Iron and sulphate reducers/bacteria
Protozoa (*Cryptosporidium*, *Giardia*)
Total and fecal coliform
Disinfection and DBP Related
Bromide
HAA by-product formation
THM by-product formation
Tannins and lignins
Total organic carbon (TOC)
UV transmittance
Physical
Colour
Total Dissolved Solids (TDS)
Total Suspended Solids (TSS)
Chemical
Alkalinity
Calcium
Chloride
Corrosivity [c]
Cyanide
Fluoride
Hardness
Potassium
Sodium
Sulphate
Sulphide

Lab Parameter (continued)
Nutrients
Ammonia
Nitrate
Nitrite
Organic nitrogen
Phosphorus
Total nitrogen
Metal Scans
Aluminum
Antimony
Arsenic
Barium
Boron
Cadmium
Chromium
Copper
Iron
Lead
Magnesium
Manganese
Mercury
Molybdenum
Nickel
Selenium
Silver
Zinc
Uranium
Additional Tests
Radium/gross alpha beta
Organic Contaminants
Hydrocarbons [d]
Pesticides and herbicides [e]

[a] Qualitative test only. Refer to Chapter 10 – Taste and Odour Control for potential causes and mitigation of water odours.
[b] Although viruses are not commonly quantified, this hazard is assessed in groundwater during GARP determination. Refer to the *Guidance Document for Determining Groundwater at Risk of Containing Pathogens*.
[c] Refer to Chapter 12 – Internal Corrosion Control for information on corrosivity indices.
[d] Measurement of VHw6-10 (volatile hydrocarbons in water, carbon range of C6-10), BTEX (benzene, toluene, ethylbenzene and xylenes), and/or a full VOC scan may be informative depending on site-specific conditions. Refer to the *British Columbia Environmental Laboratory Manual*.
[e] Screening for specific chemicals should be based on local land use. Refer to the *Guidelines for Canadian Drinking Water Quality* for chemicals to consider.

6.2 Surface Water

6.2.1 Source Selection

Surface water sources make up over 75% of the water used for water supply systems in B.C. (*Statistics Canada, 1996*). Surface water sources are typically prone to seasonal variation in quantity and quality. Designers and Water Suppliers should develop surface sources with full knowledge of the anticipated seasonal fluctuations and climate change impacts that may impact the quality and service capacity over time; examples include temperature changes, heavy rainfall events, low rainfall or low snowpack years, anthropogenic activities, wildfires, and drought conditions. Historical water quality and hydrological data should be reviewed to determine the adequacy of the surface water source to meet the current and future needs of the drinking water system.

6.2.1.1 Quantity

The availability of surface water depends on climatic influences, environmental flow needs, existing water use rights, and future impacts of climate change. Designers should assess the capacity of the surface water source to meet the current and future water supply system demands while continuing to satisfy the existing water rights, environmental flows needs and the established minimum flow thresholds.

Source water capacity assessments can be estimated using different methods. Flow mass curves can be generated from streamflow records. Alternatively, a record can be simulated using long-term precipitation data. Where data exists, both methods may be used, and a comparison made between them. Source water source capacity assessments should:

- .1 Include a statistical analysis to determine the 1/20-year return periods within a 95% confidence interval to understand natural fluctuations in water availability;
- .2 Meet the maximum projected water demand of the water supply system as shown by calculations based on a 1/50-year drought or the extreme drought of record, whichever is more extreme, and include consideration of multiple year droughts and changes in expected drought frequency due to climate change;
- .3 Assume a minimum design horizon of 50 years and provide a reasonable surplus for anticipated growth;
- .4 Be adequate to compensate for all losses such as silting, evaporation, seepage, etc.;
- .5 Be adequate to provide ample water for other authorized water users of the source while maintaining the environmental flow needs, as determined under the WSA;
- .6 Use flow mass curves where streamflow data exists to estimate the minimum perennial flow on record, and future minimum flow when considering climate change impacts, and determine a drought return period;
- .7 Consider all available storage in all yield calculations; and
- .8 Consider climate change in future precipitation projections. Refer to Chapter 4 – Climate Change Risk Assessment and Adaptation for details on climate change planning and design practices.

Refer to the *Assessment Methods for Aquatic Habitat and Instream Flow Characteristics in Support of Applications to Dam, Divert, or Extract Water from Streams in British Columbia* and *Development of*

Instream Flow Thresholds as Guidelines for Reviewing Proposed Water Uses for further guidance on assessing surface water source capacities in B.C.

Referral to the Environmental Assessment Office (*EAO, 2019*) is required for surface water supply sources that:

- .1 Divert water at a maximum rate of ≥ 10 million m^3 per year;
- .2 Include modifications that will increase the original design capacities by 35% or greater;
- .3 Result in changes in or about a stream, coastline or estuary and entails dredging, filling or physical disturbance of:
  - a. 1,000 m or greater of linear shoreline, or
  - b. 2 ha or greater of foreshore or submerged land, or a combination of foreshore and submerged land below the natural boundary of a stream, marine coastline or estuary;
- .4 The modification results in an increase of 35% or greater in:
  - a. The length of linear shoreline that is directly disturbed by dredging, filling or other physical action, or
  - b. The disturbed area or a combination of foreshore and submerged land, below the natural boundary of a stream, coastline or estuary.

Refer to the *Environmental Assessment Act* Reviewable Projects Regulation for further details.

6.2.1.2 Quality

A source water assessment should be conducted as defined in Section 6.1.1.1 – Source Water Assessment to understand the factors, both natural and man-made, which may affect water quality in the source water. Specific considerations for surface water sources include, but are not limited to:

- .1 Possible future uses of the watershed;
- .2 The Water Supplier's degree of control over the watershed;
- .3 Degree of hazard to the supply posed by forest fires, or agricultural, domestic, industrial, or recreational activities in the watershed, which may generate toxic or harmful substances detrimental to treated water quality or undermine the integrity of the watershed;
- .4 Waste discharges (point source and non-point sources) and activities in close proximity to the intake protection zone or the watershed;
- .5 Capability of the proposed treatment process to reduce contaminants to meet provincial drinking water treatment objectives;
- .6 Impacts of currents, wind and ice conditions, and other contributing water sources; and
- .7 Potential seiche effects on water quality in lakes.

The determination of representative source water quality should be based on obtaining samples over a sufficient period of time, recommended minimum of one year, to assess seasonal variability in the microbiological, physical, chemical and, when applicable, UV transmissivity and radiological characteristics of the water.

6.2.2 Intake Structure

6.2.2.1 Intake Location

The design objectives for selecting intake location should be to provide adequate quantities and a high and consistent quality of raw water, as confirmed by samples taken over all four seasons at the location and depth(s) of the proposed intake.

When locating the intake, the following should be considered:

.1 The minimum submergence from the top of the intake structure to the minimum recorded water level should be 3 m and the pipe and screen should comply with the *Canadian Navigable Waters Act;*
.2 Historical information on water depths at the proposed location, whether or not the source level is controlled, and, if controlled, whether historical minima occurred before or after control measures were implemented;
.3 The effect of bottom contours, subsoils and available water depths;
.4 Soil conditions including soil porosity and hydraulic conductivity;
.5 Water levels under drought conditions;
.6 Whether there is sufficient distance from shore to avoid water quality disturbances due to wave action or other shoreline disturbances;
.7 The location of present and future planned outfalls from sewage treatment plants and industrial installations, as well as any inshore pollution, especially during high runoff conditions;
.8 The optimum depth(s) to draw water of highest quality;
.9 Water quality information and data on current flows and directions, including potentially infrequent occurrences such as thermoclines or falling plume dispersions;
.10 Potential for the presence of zebra mussels and other molluscs in the source water that may impact intake performances, though these invasive mussels have not yet been found in B.C.'s waters (refer to Section 6.2.4.1 – Mussel Control); and
.11 The influence of contaminant sources.

6.2.2.2 Design of Intake Structures and Pipelines

Due to the high cost and complexity of underwater construction, as well as the impact on the environment, it is suggested that intake size be sufficient for a minimum design period of 50 years. The design of intake structures for surface water supplies should include, but is not limited to, the following:

.1 Withdrawing water from the location of optimal quality. This may include provision to withdraw water from multiple locations within the water column if quality varies significantly with depth and during seasonal events;
.2 Where frazil ice may be a problem, limiting the velocity of flow into the intake structure to less than 0.075 m/sec (during cold weather conditions) and maintaining uniform acceleration of water from inlet to intake pipe. Intake crib materials should be of low thermal conductivity, with racks of smooth materials;
.3 Top entry and side entry designs which may be evaluated on the basis that:
    a. Side entry designs are less likely to be damaged by anchors;
    b. Top entry designs provide greater clearance above the river or lake bottom, and the required inlet area can be more readily attained;
.4 Having a Ground Force Circuit Interrupter (GFCI) protection device as per the BC Electrical

Code on all submerged electrical motors;
.5 Locating river intakes in a stable reach of the channel, where erosion or deposition will not endanger the works and in such a way that the natural regime of the river will not be upset;
.6 Inspection of manholes every 305 m for pipe sizes large enough to permit visual inspection;
.7 Having separate facilities for the release of less desirable water held in storage;
.8 Where shore wells are not provided, having a diversion device capable of keeping large quantities of fish or debris from entering an intake structure;
.9 The intake design and its anchoring should take into account peak wave height and frequency and provide adequate protection against ice scouring and dragging anchors and seismic events;
.10 Identifying intakes with buoys or reflectors where in proximity to shipping or recreational activities. The Designer should be familiar with the requirements as legislated under the *Canadian Navigable Waters Act*;
.11 Using buried surface water collectors (refer to Section 6.2.2.2 – Design of Intake Structures and Pipelines); and
.12 Checking all designs for transient pressure problems and/or vortex generating tendencies, particularly if the intake pipe is long or has high design velocities.

The design of river intakes differs substantially from that for lakes in that a substantial current may exist and anchoring, bottom scouring and siltation considerations will assume greater significance. Where possible, river intakes should ideally be located well upstream of known point sources of pollution. River hydrology should be considered where the riverbed is subject to movement.

6.2.2.3 Design of Intake Screens

The following should be considered when designing an intake screen:

.1 A screen and intake structure design that does not entrain or impinge fish and meets Fisheries and Oceans Canada (FOC) requirements. Refer to the *Interim Code Of Practice: End-Of-Pipe Fish Protection Screens For Small Water Intakes In Freshwater* for intakes up to 150 L/s and consult FOC directly for larger intakes;
.2 Provision of fish ladders or fish passages on streams or rivers where stipulated by FOC;
.3 Screens should be constructed at the end of pipe, intake structure, or in-plant just prior to the raw water pumping facility;
.4 Consideration of the level of redundancy to be based on overall system redundancy, storage and access to alternate source water. Use of at least two screens operating in parallel is recommended;
.5 Mechanically cleaned screens are recommended for larger intake structures (> 150 ML/d) and fixed and mechanically cleaned screens may be used for small and medium capacity facilities;
.6 Locate intake screens and entrance ports a minimum of 0.6 m above the bottom of the streams, lake or impoundment, or as required to prevent sediments from being picked up;
.7 Consideration should be given to providing a means for backflushing or air bursting small intakes, if practical; and
.8 Coarse screens (bar and/or trash racks) may be required upstream of fine screens. Coarse screens should be constructed using 13 to 19 mm bars inclined at 30^{o} from vertical, providing 25 to 75 mm openings.

6.2.2.4 Infiltration Gallery Intake

An acceptable alternative design to a direct intake is an infiltration gallery intake. This type of intake is suitable when the riverbed is composed of gravels and rocks or if the floodplain is demonstrated to have a high-water table that is connected to the nearby watercourse. Infiltration galleries should incorporate either a standby duplicate intake or a submerged intake for use in case of problems with the stream-bed intake.

The Designer should consider the following when designing an infiltration gallery intake:

.1 Protection from ice accumulation;
.2 Protected against persons and domestic pollution, industrial or other harmful wastes or runoff;
.3 Accessibility in all seasons;
.4 Provision for backwashing and/or aeration;
.5 The use of filter cloth;
.6 The use of perforated or slotted plastic;
.7 The intake opening area is sufficient to minimize inlet head loss;
.8 Selection of backfill material in relation to the collector pipe slot size and gradation of the native material over the collector system;
.9 The total orifice area should not exceed 18% to 20% of the total pipe wall area;
.10 The orifices should be sized for an entrance flow velocity of 0.3 m/min or less and be adequate for the selected filter material gradation surrounding the gallery pipe/conduit in order to prevent sand from entering the piping system;
.11 Stainless steel or concrete pipes should be installed with a minimum grade of 500:1 (sloping up toward the collector) and at depths of about 4.0 to 5.0 m below the bottom of streams or lakes; and
.12 The depth of perforated infiltration pipes (to be located as deep as possible in the aquifer so as not to be affected by seasonal fluctuations).

6.2.3 Raw Water Storage

Raw water storage can be useful to manage the quantity and quality of the source water. Raw water storage facilities may be sized to allow retention of intermittent stream or aquifer to balance seasonal inflows with water system demands and provide standby against failure of intake facilities. Water storage facilities may be used to improve water quality by providing pre-sedimentation of solids or to avoid or reduce the impact of source water diversion during periods of poor raw water quality. Storage of source waters is regulated under the WSA and must be licenced under the Water Sustainability Regulation. Impoundments or reservoirs may be used, where authorized, to reduce peak withdrawal rates for a water system and to preserve other authorized water rights.

The Designer should be aware that changes in water quality may occur in impoundments and/or reservoirs, and the intake(s) should be designed accordingly.

Impoundments and reservoirs should be designed with the following considerations:

.1 Should be of sufficient volume to sustain, if possible, a 1/50-year yield without significant drawdown (the volume should be confirmed by a bathymetric survey that is current within the last 20 years);

.2 Should have all necessary permits and approvals for controlling streamflow or installing a structure on the bed of a stream;
.3 Should have fish ladders or fish passages where stipulated by FOC;
.4 The hydraulic structure should be designed to meet the British Columbia Dam Safety Regulation and be in accordance with the latest version of the Canadian Dam Association's *Dam Safety Guidelines;*
.5 The site should be made as secure as is reasonably possible through the use of fencing, signage and patrolling/policing, if necessary;
.6 Minimizing seepage, including the use of liners; and
.7 Safety features for stability and spillway design should be approved by the BC Dam Safety Program.

Referral to the Environmental Assessment Office (*EAO, 2019*) is required for:

.1 Construction of a water storage reservoir:
   a. With a dam 15 m high or greater, measured in accordance with Section 1 (4) of the Dam Safety Regulation, or
   b. Containing 10 million m^3 or greater of water above the natural boundary of the streams that supply the water to the reservoir.
.2 Modifications to an existing water storage reservoir that increases the flooded area of the reservoir, as permitted under the WSA, by 20 ha or greater.

Refer to the *Environmental Assessment Act* Reviewable Projects Regulation for further details.

6.2.3.1 Facility Planning

The Designer should assess the need, location, and sizing of the raw water storage reservoir before proceeding with final design. Reservoir sizing should be determined by assessing the availability of water and the nature of upstream activities. The Designer should also consider any potential adverse effects on the water intake, storage, or treatment facilities; and should include design features to minimize the effects of fluctuating raw water turbidity and impacts to the environment.

6.2.3.2 Site Preparation

When preparing a site for an impoundment or reservoir the following should be completed:

.1 Inclusion of fencing around the reservoir;
.2 Protection from floods during construction; and
.3 Decommissioning of all wells which will be inundated, in accordance with requirements of the Groundwater Protection Regulation.

6.2.3.3 Reservoir Management

Raw water reservoirs should have a reservoir management program that identifies the current condition of the reservoir, the necessary storage capacity, and the necessary management procedures to respond to changes in reservoir conditions. Reservoirs that include a dam, as classified in the Dam Safety Regulation, must meet the requirements set out in the Dam Safety Regulation with respect to construction, monitoring, and reporting practices based on the consequence classification.

Reservoirs should be managed to avoid any difficulties with taste, odour, colour, iron, and manganese in drinking water. In-reservoir management techniques should address problems with algae, weeds, low dissolved oxygen, and loss of storage capacity.

Artificial circulation, aeration, phosphorus precipitation, sediment removal, dilution, and flushing are reservoir management techniques that should be adopted to improve water quality. Use of algaecides is not recommended due to algaecide toxicity and the potential for blue-green algae (cyanobacteria) cells to be ruptured, resulting in the release of cyanotoxins.

The reservoirs should be sized with consideration of potential climate change impacts: for example, increased frequency of droughts, changing patterns of precipitation and snowmelt, and increased water loss due to evaporation as a result of warmer temperatures, will result in changes to water availability. Warmer air temperatures may also result in increased demands on water supplies.

6.2.3.4 Off-Stream Raw Water Storage Reservoir

An off-stream raw water storage reservoir is a facility into which water is pumped during periods of good quality and high streamflow for future release to treatment facilities. Off-stream raw water storage reservoirs should be designed with the following considerations:

.1 Water quality is protected by controlling runoff into the reservoir;
.2 Dikes are structurally sound and protected against wave action and erosion;
.3 Dikes and dam structures meet the relevant requirements of the Dam Safety Regulation;
.4 Intake structures and devices meet the requirements of Section 6.2.2 – Intake Structure;
.5 The point of influent flow is separated from the point of withdrawal to prevent short-circuiting;
.6 Separate pipes are provided for influent to and effluent from the reservoir;
.7 A bypass line is provided around the reservoir to allow direct pumping or gravity flow to the treatment facilities;
.8 Redundancy with a minimum of two cells to enable one cell to be taken offline for filling or maintenance. Each cell should be sized to retain about 75% of the annual raw water needs and be sized to satisfy long-term drought conditions;
.9 Control structures should enable the plant operator to isolate each cell, to drain each cell, and to enable the cells to be operated in series or in parallel;
.10 Each cell should be deep enough to restrict light penetration within the depth of the reservoir to discourage the development of ideal habitats for aquatic plant growth;
.11 Inside slopes of the cells should be armoured, where required, to prevent erosion. The impact of ice formation on winter storage should be accounted for in the design; and
.12 Safety features should be incorporated to prevent animals or unintended human entry into the reservoir and to provide for safe egress.

6.2.4 Source Water Pre-Treatment

Pre-treatment at the intake should consider mussel control, intake chemical treatment and pre-sedimentation. For design guidance on pre-sedimentation, refer to Chapter 7 – Pre-sedimentation, Coagulation, Flocculation and Clarification.

6.2.4.1 Mussel Control

Invasive mussels (i.e. zebra and quagga mussels) have the potential to obstruct public water supply intakes and cause loss of intake capacity, as well as contribute to taste and odour problems. These mussels have not yet been found in B.C. water supplies, although there is a high risk of their introduction to water systems. Water Suppliers should periodically assess the condition of their intakes to determine if mussels are or potentially may be present and implement a system of control.

The most accepted and currently recommended forms of chemical treatment for public water supplies are the use of oxidants such as chlorine, chlorine dioxide, potassium permanganate and ozone. Chemical dosages are typically applied at the intake through solution piping and a diffuser to prevent the formation of mussel colonies within the intake and piping. The type of chemical selected and frequency of application will depend on the type of existing chemical treatment facilities, mussel breeding season, potential for disinfection by-product formation, and other pre-treatment objectives such as taste and odour control, safety and cost. Refer to Section 6.2.4.2 – Intake Chemical Treatment.

In addition to the chemical methods described above, intake screens are also available that are manufactured with special alloys that prevent mussel growth on the intake itself.

The Designer may consider the provision of a suitable alternate intake, as periodic alternating use/zero flow conditions has been demonstrated to control mussel infestation, where economical.

Further information on zebra mussel prevention and management can be found in the AWWA Manual of Water Supply Practice *M7 - Problem Organisms in Water: Identification and Treatment.*

6.2.4.2 Intake Chemical Treatment

If it is determined that chemical treatment is warranted to address taste and odour control or the control of mussels and other nuisance organisms at the intake, the following should be considered in the design of the chemical system:

- .1 Chemical treatment should be in accordance with Chapter 13 - Chemical Application;
- .2 Plant safety items, including but not limited to ventilation, operator protective equipment, eyewashes/showers, cross connection control, etc., should be provided;
- .3 Solution piping and diffusers should be securely anchored. Piping and diffusers should have appropriate valving and should be installed within the intake pipe or in a suitable carrier pipe;
- .4 Provisions should be made to prevent chemical dispersal into the water environment outside the intake. Diffusers should be located and designed to protect all intake structure components;
- .5 A spare solution line should be installed to provide redundancy and to facilitate the use of alternate chemicals;
- .6 The chemical feeder should be interlocked with plant system controls to shut down automatically when the raw water flow stops;
- .7 Provisions should be included for obtaining raw water samples not influenced by chemical treatment;
- .8 Means to provide adequate flushing should be provided; and,
- .9 When alternative control methods are proposed, appropriate piloting or demonstration studies may be required.

6.3 Groundwater

Groundwater makes up nearly 25% of the total source water used for drinking water supply in B.C. Groundwater and aquifers can be a productive source of high quality water, often requiring minimal treatment for potable use. Groundwater supplies are often utilized by small and medium-sized water systems or as a secondary source of water.

In B.C., the Groundwater Protection Regulation (GWPR), under the WSA, ensures that activities related to the use of wells and groundwater are performed in a sustainable and environmentally safe manner. The GWPR regulates minimum standards for well construction, maintenance, deactivation and decommissioning. The GWPR also identifies the types of qualified people certified to drill wells, install well pumps, and perform related services. When developing a groundwater source, the GWPR must be followed and the reference material below consulted:

- .1 *Groundwater Protection Regulation: Guidance Manual (ENV & FLNRORD, 2019);*
- .2 *Groundwater Protection Regulation Handbook (BC Groundwater Association, 2017);*
- .3 *Guidance for Technical Assessments in Support of an Application for Groundwater Use in British Columbia (ENV & FLNRORD, 2020)*; *and*
- .4 *AWWA Standard A100 – Water Wells* and *AWWA Manual M21 – Groundwater.*

This section provides a high level overview of planning and design considerations when developing a new groundwater source or modifying an existing groundwater source for a water supply system. In all cases, the requirements of the *Water Sustainability Act* and the Groundwater Protection Regulation related to groundwater protection must be met, as well as the applicable portions of the *Drinking Water Protection Act* (Sections 16 and 23), Health Hazard Regulation (Section 8, under the *Public Health Act*), Sewerage System Regulation (Section 3.1) and Municipal Wastewater Regulation (Section 82). Designers should also consult relevant Ministry of Water, Land and Resource Stewardship policies and guideline documents associated with groundwater protection requirements.

6.3.1 Source Selection

6.3.1.1 Quantity

The Designer should determine groundwater supply capacity requirements based on meeting the MDD of the water system with the largest producing well out of service. The required groundwater supply capacity can then be compared to the estimated long-term well yield capacity. The Designer should use a pumping test or hydrogeologic analysis conducted by or under the direct supervision of a Qualified Professional to estimate the long-term well yield capacity.

Water Suppliers must obtain a Water Licence prior to using a water supply well. The *Guidance for Technical Assessments in Support of an Application for Groundwater Use in British Columbia* provides guidance on the appropriate level of analysis that is required to make a decision on a Water Licence application. Water Licence applications undergo a technical review by the Ministry of Water, Land and Resource Stewardship to make sure there is enough water to not affect the existing water rights of others or harm the water supply and aquatic ecosystem. Other government agencies, affected landowners and licensees may be notified of the application and given the chance to respond; more details are provided in the *Water Applicant's Agency Resource Guide*. First Nations in the area may also be consulted.

Technical assessment requirements in support of Water Licence applications vary based on the quantity of water use and the potential to impact the availability of water to other wells, streams, and groundwater sources. The technical assessment levels range from Level 1 to Level 4, where Level 4 requires the most extensive reporting to support the application to license a water supply well. The results of a technical assessment are presented in a technical assessment report that is sealed by a Qualified Professional. A technical assessment report is intended to address the following considerations related to a new water supply well: groundwater availability and production capacity, impacts to existing users, hydraulic connection to surface waters, and other relevant issues (e.g. salt water intrusion, aquifer supply limits, flowing artesian conditions).

Pumping tests are required for Level 3 and Level 4 technical assessments. Refer to Section 6.3.1.6 – Pumping Test for more information.

Referral to the Environmental Assessment Office (*EAO, 2019*) is required for water supply wells with:

.1 Capacities of 75 L/s or greater that are operated continuously or intermittently for greater than one year; or
.2 Modifications that will increase the original design capacities by 35% or greater.

Refer to the *Environmental Assessment Act* Reviewable Projects Regulation for further details.

6.3.1.2 Quality

An assessment should be made of the factors, both natural and anthropogenic, which may affect water quality in the well and aquifer. Such an assessment may include obtaining samples over a sufficient period of time to assess the microbiological and physical characteristics of the water, including dissolved gases, and chemical and radiological characteristics. A GARP assessment should be conducted prior to the development of a groundwater supply source.

Groundwater quality monitoring should be conducted to:

.1 Show the suitability of the raw water source for potable use by comparing the results to the GCDWQ and the *Source Drinking Water Quality Guidelines*;
.2 Demonstrate the need for further treatment to meet the GCDWQ and provincial water quality objectives (i.e. *Drinking Water Treatment Objectives (Microbiological) for Ground Water Supplies in British Columbia*, Ministry of Health, 2015);
.3 Provide indications of well vulnerability to pathogens, and associated disinfection requirements;
.4 Identify other parameters that require treatment (if any);
.5 Show any changes that may occur as a result of pumping; and
.6 Provide evidence of contaminant sources that were not identifiable as part of the well siting study.

If GCDWQ values are exceeded, the hydrogeologist should indicate if this represents one or more of the following:

.1 A naturally occurring condition within the aquifer related to:
  a. The aquifer material (e.g. gypsum, arsenic, iron, manganese, uranium);
  b. Drawdown effects (e.g. hardness, dissolved solids, redox changes);
.2 Groundwater-surface water interactions (e.g. stream, river, lake, wetland or seawater

intrusion);

.3 Point-source contaminant sources (e.g. service stations, dry cleaning stores, landfills, on-site sewage systems);
.4 Non-point source contaminant sources (e.g. agriculture, road salting); and/or
.5 Inadequate well development (see Section 6.3.3 – Groundwater Source Construction-Related Contaminants).

The results of this assessment should be included in a well construction report sealed by a Qualified Professional.

6.3.1.3 Number of Wells

Ideally, a minimum of two sources of groundwater should be provided. Active wells may not be used at equal frequencies, depending on yield and water quality; less active wells should be flushed or operated for a minimum of two hours every seven days to avoid stagnation.

6.3.1.4 Siting of Wells

Siting of water supply wells must be conducted in accordance with GWPR. A desktop study should be completed prior to exploratory drilling to collect available background data from sources such as iMapBC or the BC Water Resources Atlas, GWELLS database, eLicensing, hydrogeological reports, provincial groundwater monitoring data, Environmental Monitoring System Data and geological mapping. The local Environmental Health Officer should be consulted with on the location of the proposed well. The well siting study should consider:

.1 Topography and drainage, including climate change impacts;
.2 Accessibility of the site by the drill rig and equipment;
.3 GARP hazard screening and assessment;
.4 Aquifer type;
.5 Aquifer hydraulic properties and distribution;
.6 Potential well depth;
.7 Geology mapping;
.8 Existing water well records;
.9 Existing monitoring well records;
.10 Beneficial confining units;
.11 Baseline/background groundwater quality;
.12 Expected groundwater flow directions and groundwater flow divides;
.13 Proximity and potential connection to surface water and potential to deplete the surface water or impact stream baseflow;
.14 Proximity and potential connection to contaminant sources;
.15 Existing allocation restrictions and environmental flow needs of the potentially connected surface water;
.16 Impacts from a nearby controlled dam;
.17 Proximity to the coastline and potential for saltwater intrusion;
.18 Land uses in source water zones;
.19 Risk of encountering flowing artesian conditions (refer to Section 6.3.1.7.3 – Flowing Artesian Wells);
.20 Distance from existing production wells, both private and domestic; and
.21 Cost of transmission and pumping of the groundwater.

6.3.1.4.1 Contaminant Setbacks

Well setbacks from contamination sources must also be considered in the siting of the well. Under Section 8 of the Health Hazards Regulation (HHR), Part 1 of the Sewerage System Regulation (SSR), Section 82 of the Municipal Wastewater Regulation, and the Section 18 of the GWPR, wells must have at least the horizontal setbacks from sources of contamination as defined in Table 6-2; however, for larger community water wells, larger setbacks may be required as determined by the size of the capture zone. In addition to these setbacks, the Designer should review local municipal bylaws.

Table 6-2 Well Setbacks from Possible Contamination Sources

Setback [2]	Contamination	Reference
6 m	Private dwelling	Health Hazards Regulation
15 m	Domestic sewage holding tank	Sewerage System Regulation
30 m	Any probable source of contamination	Health Hazards Regulation
30 m	Sewage system, including septic tank with daily flow less than 22.7 m^3/day	Sewerage System Regulation
50 m	Shorelines or saltwater body	GWPR Handbook
60 m	Discharge from municipal wastewater with maximum daily flow between 22.7 m^3/d and 37 m^3/d	Municipal Wastewater Regulation
60 m	High pumping rate community well [1] - sewage system, including septic tank with daily flow less than 22.7 m^3/day	Sewerage System Standard Practice Manual
60 m	Underground stormwater infiltration facility	GWPR Handbook
90 m	Discharge from a municipal wastewater system with a maximum daily flow equal to or greater than 37 m^3/day and the well is within a **confined** aquifer	Municipal Wastewater Regulation
90 m	High pumping rate community well [1] in an unconfined aquifer - sewage system, including septic tank with daily flow less than 22.7 m^3/day	Sewerage System Standard Practice Manual
120 m	Any cemetery or dumping ground, unless contamination of the well would be impossible because of the physical conformation	Health Hazards Regulation
300 m	Discharge from a municipal wastewater system with a maximum daily flow greater than 37 m^3/day and the well is within an **unconfined** aquifer	Municipal Wastewater Regulation

1. High pumping rate community well - for the purpose of determining horizontal setbacks, this means a well or well group serving more than 500 people or if it is pumped for more than three months at a rate of more than 190 L/min.
2. Larger setbacks may be required as determined by the size of the capture zone.

In addition to the setbacks defined above, water supply wells should be hydraulically up-gradient from potential sources of contamination, where possible. Well capture zones should not encompass potential sources of contamination. Separation distances should be established by a Qualified Professional based on the time of travel to the well, the type of aquifer, depth of the well and the persistence of the contaminant source. Future land use and long term wellhead protection should also be a factor when selecting a suitable location. Land uses of concern include:

- .1 Agricultural sources (runoff from pastures or feed lots, fertilized fields, manure storage areas and intensive pesticide use areas);
- .2 Landfills or waste management facilities;
- .3 Cemeteries;
- .4 Archaeological and culturally significant areas;
- .5 Bulk storage of liquids (service stations, dry cleaners, bulk plants, heating oil);
- .6 Roads and highways (road salt runoff, accidental chemical releases);
- .7 Mines and quarries (stored mine water, acid mine drainage, heavy metals from tailings, mine dewatering activities);
- .8 Wastewater treatment facilities; and
- .9 Industrial activities (manufacturing or processing facilities).

The *Guidance Document for Determining Ground Water at Risk of Containing Pathogens* (GARP) by the BC Ministry of Health should be referred to when assessing the level of potential risk that a groundwater source may become, or may already be, contaminated by pathogens. EGBC's Professional Practice Guidelines *Assessment of Groundwater at Risk of Containing Pathogens (GARP)* should also inform groundwater assessments.

6.3.1.4.2 Hydraulic Setbacks

Water supply wells should be sited to minimize impacts to existing groundwater users and the proposed wells must be sited so that that the horizontal setback distance is not less than 15 m from any part of the proposed wells to an existing water supply well, in accordance with the GWPR (section 18). In situations where large quantities of groundwater are required, it may be necessary to locate new wells within different catchment areas to avoid exceeding the aquifer recharge rate or causing stream depletion.

Proximity to streams and lakes can affect a well's vulnerability to pathogens. The degree of interaction between well field pumping and stream base flows should be addressed through well location, casing length, monitoring of groundwater and streamflow responses, and water quality monitoring.

6.3.1.5 Exploration Program

A groundwater supply exploration program will help to confirm the quantity and quality of groundwater available within a target area. A Qualified Professional should lead this type of work. The program scope will be determined based on the desktop study and by previous testing work within the area, potential supply sources and water supply requirements.

The minimum test hole diameter should be 150 mm in areas that have not been previously investigated to allow for pumping tests. Depending on the well setting and goals of the investigation, test holes with a minimum diameter of 200 mm may be more appropriate, as larger diameter pumps are often required to test at higher pumping rates. If a 150 mm diameter test well is used, it can be retained as a monitoring well or equipped with a pump and used as a backup or lower rate production well.

During construction of each exploration well, a detailed log must be made in accordance with the GWPR. Preliminary water quality sample(s) should be taken and analyzed for the full suite of health and aesthetic related parameters to confirm the presence of suitable water quality (refer to Table 6-1). If the well has not been developed, turbidity can affect the analytical results of unfiltered samples. Filtered samples may be more appropriate for turbid samples collected at this early stage of exploration.

The completion of exploratory wells allows for the assessment of aquifer characteristics, and will ultimately allow for proper production well design, spacing of wells and pump selection.

The GWPR must be followed for the siting and construction requirements for water wells. Specific requirements concerning the casing and annular seal, setbacks, driller and assessor qualifications, and yield assessment should be consulted prior to any intrusive work. Refer to the *Guidance for Technical Assessments in Support of an Application for Groundwater Use in British Columbia*.

6.3.1.6 Pumping Test

A pumping test is a type of flow test that is used to estimate well performance, well yield, the zone of influence of the well and aquifer characteristics. A pumping test is generally required to support a Water Licence application as part of the technical assessment. This technical assessment should also meet the requirements consistent with the level of proposed pumping and aquifer type. Refer to the *Guidance for Technical Assessments in Support of an Application for Groundwater Use in British Columbia (Version 2)* for more information.

In a pumping test, the well is pumped under controlled conditions and the water level in the well and other nearby wells is measured over time to determine drawdown. Pumping tests are commonly used to:

.1 Determine the maximum long-term yield for a well (i.e. specific capacity of the well after 100 days of pumping);
.2 Assess the impacts of the proposed well on neighbouring wells or water bodies; and
.3 Obtain aquifer properties, such as permeability and boundary conditions.

Additional details about pumping tests can be found in *Guide to Conducting Pumping Tests* by the Province of British Columbia, Agriculture and Agri-Food Canada, and the British Columbia Groundwater Association.

6.3.1.7 Additional Considerations

6.3.1.7.1 Saltwater Intrusion

Saltwater intrusion can occur due to either natural processes or anthropogenic activities. As per Section 58 of the WSA, a person must not operate a well in a manner that causes intrusion of saline groundwater or saltwater into an aquifer.

Areas at highest risk of saltwater intrusion include locations:

.1 Close to the coast;
.2 Where there is a low to moderate slope;
.3 On peninsulas or in areas with a limited source area for groundwater recharge;
.4 Where there is a high density of wells;
.5 Where there are high rates of pumping from a single well or from multiple wells in a coastal

area;

.6 Where the static (non-pumping) groundwater level is at or below sea level; and
.7 In fractured bedrock aquifers due to heterogeneity and the linear nature of fracturing.

Best practices when planning or developing a water supply well in areas at high risk of saltwater intrusion include, but are not limited to:

.1 Well siting: Avoid drilling in locations immediately adjacent to the coast. The GWPR Handbook recommends drilling at least 50 m beyond the coast;
.2 Well depth: Avoid drilling excessively deep within areas proximal to the coast. The depth to the freshwater-saltwater interface varies locally;
.3 Well alteration: Avoid using technologies such as hydrofracturing in areas < 100 m from the coast to reduce the risk of opening fractures that are directly connected with the sea;
.4 Well testing: Avoid pumping at higher flow rates or for longer than is necessary;
.5 Well monitoring: Monitor for specific conductivity or salinity during drilling. If there is a significant increase in the measurements during drilling, consider stopping, and testing the chloride concentration of the groundwater. If a saline zone has been encountered it may be necessary to seal the well below a certain depth;
.6 Closing unstable or unused wells;
.7 Qualified Professional: Consult a Qualified Professional to help assess saltwater intrusion risk and plan for and interpret water quality test and monitoring results.

Saltwater intrusion is indicated by elevated concentrations of chloride and high electrical conductivity of groundwater compared to average conditions in the area. These salinity indicators are easy to measure. Groundwater wells with the following characteristics may be considered to be affected by saltwater intrusion, according to the *Best Practices for Prevention of Saltwater Intrusion*:

.1 Chloride concentration greater than 150 mg/L;
.2 Specific conductivity greater than 1000 µs/cm; and
.3 TDS greater than 700 mg/L.

For coastal British Columbia, a groundwater well should only be pumped if it is capable of producing water of this quality or better.

If a well is severely impacted by saltwater intrusion, it may be necessary to discontinue using it for a period of time, and use alternate sources, to give the well time to recover, or the well may need to be decommissioned permanently. Refer to the WSA for the regulations regarding well operation and saltwater intrusion.

The Designer should refer to *Best Practices for Prevention of Saltwater Intrusion,* and advisories for coastal areas for further guidance on saltwater intrusion (located here: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/groundwater-wells-aquifers/groundwater-wells/information-for-well-drillers-well-pump-installers/well-drilling-advisories).

6.3.1.7.2 Subsurface Filtration (Riverbank Filtration)

Subsurface filtration is a naturally occurring process that filters surface water as it passes through river or lakebed sediments, lake/riverbank substrate, and into an aquifer before being drawn up by a well. Subsurface filtration is best suited to systems that are located adjacent to rivers with reasonably good surface water quality and that plan to use subsurface filtration as one component of their treatment process. For certain systems, subsurface filtration can be an efficient, cost-effective pre-treatment option to improve water quality or control the extent of sudden changes in raw water temperature and quality after a storm event; however, only certain subsurface conditions provide improved quality.

The Designer should consider the type of bed and aquifer material present, the dynamics of groundwater flow, and the potential for scouring of riverbed materials at any potential riverbank filtration site. The degree to which any particular contaminant will be removed via bank filtration depends on site-specific conditions and may vary over time. A similar raw water characterization as for surface water may apply. Subsurface filtration must be demonstrated through one of the acceptable methods described in the Ministry of Health's *Drinking Water Treatment Objectives (Microbiological) for Ground Water Supplies in British Columbia*:

.1 Well/surface water separation;
.2 Subsurface filtration study; or
.3 Demonstration of performance

A subsurface filtration study or demonstration of performance must be conducted by a Qualified Professional.

Sampling frequency and analysis should be developed to assess the water quality and effectiveness of the subsurface filtration process; turbidity sampling intervals are specified for pathogen log reduction credit maintenance in the Ministry of Health's *Guidelines for Pathogen Log Reduction Credit Assignment.* Both the *Guidelines for Pathogen Log Reduction Credit Assignment* and *Drinking Water Treatment Objectives (Microbiological) for Ground Water Supplies in British Columbia* should be referenced if proceeding with subsurface filtration.

6.3.1.7.3 Flowing Artesian Wells

The provincial regulatory requirements for controlling flowing artesian wells are outlined in Section 77 of the *Water Sustainability Act.* EGBC has issued a *Flowing Artesian Wells and Excavations Practice Advisory* to provide direction on responsibilities for anticipating and managing flowing artesian conditions during well design and construction. Additionally, the Ministry of Environment and Climate Change Strategy has published *Flowing Artesian Wells,* which provides general guidance for working with flowing artesian wells.

If artesian conditions are encountered when constructing or supervising construction of a well, the qualified well driller or Qualified Professional must ensure the artesian flow is controlled and advise the well owner (and the land owner, if applicable) of the steps taken to do so. If the flow cannot be controlled, the person responsible for drilling the well should advise the Ministry of Water, Land and Resource Stewardship Regional Hydrogeologist and must comply with any directions given.

A flowing artesian well is considered "under control" when the entire flow is through the production casing to the wellhead and the flow can be stopped or directed indefinitely without leaking on the surface of the ground and with no leakage into any other aquifer penetrated by the well.

Pre-screening the geology and hydrogeology of a project site minimizes the chance that uncontrolled flowing artesian conditions will be encountered unexpectedly during borehole drilling or while excavating in soil or rock. When artesian conditions are anticipated based on pre-screening, alternate well design practices should be applied to control the artesian flow.

The well driller should take precautions to prevent a well from flowing out of control, particularly in areas that have a history of flowing wells. The Ministry of Water, Land and Resource Stewardship maintains a database of artesian wells on its Well Drilling Advisories website (https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/groundwater-wells-aquifers/groundwater-wells/information-for-well-drillers-well-pump-installers/well-drilling-advisories) that should be reviewed.

6.3.2 Well Construction

In B.C., the construction of a new well is regulated under the GWPR. The well driller must be certified and ensure that the well is constructed to meet the minimum requirements as defined in the GWPR. A well identification plate and a well construction report is required for all new wells. If the well is to be decommissioned, a well decommission report is required at that time as defined in the GWPR. All wells should be straight and meet plumbness requirements, as specified by the AWWA.

6.3.2.1 Casing

Well casings should be designed as follows:

.1 Materials should be new or like new and:
  a. Approved or certified by the Canadian Standards Association (CSA), Underwriters' Laboratories of Canada, ASTM International, or NSF International;
  b. Strong enough to withstand pressures or forces exerted on them during installation and well operation;

.2 The well and casing diameters should be based on the intended use (production or observation well), anticipated flow rates, pumping equipment specifications, wellhead completion appurtenances, and screen-liner requirements;

.3 The well casing should protrude at least 0.3 m above the ground surface, and the ground should be sloped away from the well to prevent ponding of water around the well;

.4 Production well diameters for water supply wells should be a minimum of 200 mm, to provide sufficient size for pumps and monitoring devices, and contingency for possible future liner installation;

.5 Well casings with 150 mm diameter may be suitable for monitoring wells and smaller capacity water supply wells;

.6 Well casing may be constructed of steel or HDPE. PVC (minimum DR 21) should only be used when approved by the Issuing Official and should be of NSF 61 certified material. In all cases, the casing material should have a minimum weight and thickness to withstand the forces it is subject to;

.7 HDPE casing material may be considered in applications where permeation by hydrocarbons or degradation of other PVC or steel materials may occur; and

.8 The use of any nonferrous material as well casing is subject to the approval of the Issuing Official.

6.3.2.2 Casing Vent

Provisions should be made for venting the well casing to the atmosphere. The vent should terminate in a downturned position, at or above the top of the casing or pitless unit, no less than 300 mm above grade or floor, in a minimum 38 mm diameter opening covered with a 24 mesh, corrosion resistant screen. Consideration should also be given to install the screen above the snow levels. The pipe connecting the casing to the vent should be of adequate size to provide rapid venting of the casing. Where vertical turbine pumps are used, vents into the side of the casing may be necessary to provide adequate well venting; installation of these vents should include a fine mesh vermin screen. Venting of wells located inside a pump house must ensure that the vent is directed outside the building to prevent the build-up of harmful gasses inside the pump house building.

6.3.2.3 Well Cap

The well cap is a secure cap or lid that prevents vermin, contaminants, debris or other foreign objects or substances from entering the interior of the production casing and includes a sanitary well seal. Part 4 of the GWPR must be followed when designing a well cap. The following should be considered:

- .1 All wells, temporary or permanent, should be effectively located/sealed against the entrance of water and contaminants;
- .2 Venting and electrical penetrations to be above the 1:200 flood elevation or highest historic flood level, whichever is highest; and
- .3 At all times during the progress of work, the contractor should provide protection to prevent tampering with the well or entrance of foreign materials.

6.3.2.4 Surface Seal

Surface seals are installed in the annular space around the outside of the outermost casing and between multiple casings and extend up to or just below the surface of the ground. Surface seals are intended to:

- .1 Prevent the entry of contaminants and foreign matter;
- .2 Be permanent, watertight and continuous;
- .3 Be reinstated and extended to within 0.3 m of the ground surface when disturbed by pitless unit installation or extension above the finished grade surface; and
- .4 Be made of non-toxic materials.

Division 3 – Surface Seals of the GWPR includes detailed surface seal requirements.

6.3.2.5 Water Level Measurement

Provisions should be made for monitoring and measurement of water levels in the completed well. This is typically done using pressure transducers or sounding tapes in sounding tubes within stilling wells or conduits inside the well case.

6.3.2.6 Pitless Unit or Pitless Adaptor

The pitless unit or adaptor is a device attached to a casing for the underground conveyance of water from the well. Pitless units or adaptors should be installed below the frost line.

Pitless units should:

- .1 Be shop-fabricated from the point of connection with the well casing to the unit cap or cover;
- .2 Be welded to the well casing;
- .3 Be of watertight construction throughout to prevent entrance of contaminants;

.4 Be of materials and weight at least equivalent and compatible to the casing;
.5 Have a field connection to the lateral discharge from the pitless unit of threaded, flanged or mechanical joint connection; and
.6 Terminate at least 300 mm above final ground elevation or 1 m above the 200-year flood level or the highest known flood elevation, whichever is higher.

The design of the pitless unit should make provision for:

.1 Access to disinfect the well;
.2 An access tube within which water levels can be independently measured;
.3 Facilities to measure water levels in the well;
.4 A cover at the upper terminal of the well that will prevent the entrance of contamination;
.5 A contamination-proof entrance connection for electrical cable;
.6 An inside diameter as great as that of the well casing, up to and including casing diameters of 300 mm, to facilitate work and repair on the well, pump, or well screen.

6.3.2.7 Pumps

Pump specifications for a newly designed well should be based upon analysis of the hydraulic testing results, the recommended pumping rates (i.e. short and long-term) and pump intake setting. Factors that should be included in the selection of an appropriate pump size include:

.1 Well and/or casing diameter;
.2 Recommended pumping rate for sustainable well operation;
.3 Calculated or observed water level from pumping test(s);
.4 Total dynamic head and vertical lift requirements;
.5 Friction/head losses;
.6 Service pressure; and
.7 Long-term power requirements.

The design criteria for well pumping stations generally follow those presented for raw surface water pumping in Section 18.3 – Raw Water Pumping Stations. Water supply wells should be equipped with either submersible or vertical turbine line shaft pumps. Well pumps are required to be installed by a certified pump installer as defined in the GWPR.

Oversizing a pumping system will result in an excessive pumping rate. In turn, the excessive pumping rate can cause critical fracture zones to de-water, resulting in sudden declines in pumping levels and potential damage to the well or pump.

Line shaft pumps and submersible pumps are two common types of well pumps.

.1 Line shaft pumps should:
  a. Have the casing firmly connected to the pump structure or have the casing inserted into a recess extending at least 13 mm into the pump base;
  b. Have the pump foundation and base designed to prevent water from coming into contact with the joint;
  c. Be water lubricated. If oil lubricated pumps are proposed, food grade lubricant should be used;
.2 Submersible pumps should:
  a. Be water lubricated;

b. Not have mercury seals. Mercury seals are not permitted;
c. Have the top of the casing effectively sealed against the entrance of water under all conditions of vibration or movement of conductors or cables; and
d. Have the electrical cable firmly attached to the riser pipe at 6 m intervals or less.

In addition, the following special considerations apply for well pumping stations:

.1 Provide a pump pedestal for dry mounted vertical turbine pump assemblies and large diameter inline submersible pump assemblies (i.e. greater than 200 mm diameter discharge). The pump pedestal should be designed to support the full weight of the pump and riser piping and to prevent load transfer to the well casing(s);
.2 A water-tight seal should be provided between the pump base plate (or submersible discharge head) and the pump pedestal, and between the well casing and the pump discharge column to prevent the entrance of contaminants;
.3 Provide for adequate means for removal of the pump for maintenance purposes including crane pad laydown area, roof hatch access, or lifting equipment and riser pipe decoupling appurtenances.
.4 A flow measurement device should be provided.

6.3.2.8 Well Riser and Discharge Piping

Well piping systems – including riser, column and/or discharge pipes as applicable – should:

.1 Be designed to minimize friction loss;
.2 Have control valves and appurtenances located above the pump house floor;
.3 For pitless units, include a buried well isolation valve located adjacent to the well casing;
.4 Be protected against the entrance of contamination;
.5 Be equipped with a check valve in or at the well, a shutoff valve, a pressure gauge, and a means of measuring flow;
.6 Be equipped with a smooth nosed sampling tap located at a point where positive pressure is maintained, but before any treatment chemicals are applied. The sample tap should be at least 0.5 m above the floor to facilitate sample collection;
.7 Avoid the use of return pipes that permit water to be recirculated down the well, which could cause contamination of the well;
.8 Where applicable, be equipped with an air release-vacuum relief valve located upstream from the check valve, with exhaust/relief piping terminating in a down-turned position at least 0.5 m above the floor and covered with a 24-mesh corrosion resistant screen;
.9 Include provision to permit future testing of the well, including a means to pump to waste in case of poor water quality during the test;
.10 Be valved to allow isolation of the well for test pumping and control of each well;
.11 Have all exposed piping, valves and appurtenances protected against physical damage and freezing;
.12 Be properly anchored to prevent movement and be properly supported to prevent excessive bending forces;
.13 Be protected against surge or water hammer;
.14 Conform to the latest standards issued by the ASTM, AWWA and NSF/ANSI, where such standards exist, or in the absence of such standards, conform to applicable product standards;
.15 Be constructed so that it can be disconnected from the well or well pump to allow the well

pump to be removed;

.16 In particular, the riser piping (submersible pump application) or column piping (vertical line-shaft pump application) inside the well should:

a. Be constructed with fittings, brackets, tape or other appurtenances which meet NSF/ANSI Standard 61 *Drinking Water System Components – Health Effects*, where applicable;
b. Be capable of supporting the weight of the pump, piping, water and appurtenances, and be capable of withstanding the thrust, torque and other reaction loads created during pumping. The actions of fatigue from repeated starting and stopping of the pump should be considered when choosing pipe and fittings;
c. Be fitted with guides or spacers to center piping and well pump in the casing; and
d. Be constructed of non-corrosive materials.

6.3.2.9 Dug Wells

Dug wells are typically not recommended. Their shallow depth makes them vulnerable to contamination and higher fluctuations in water level due to drought or local changes in drainage.

However, in some instances dug wells can provide water, for example, when a shallow aquifer is the only viable potable water source. The GWPR must be followed when constructing a dug well. Additional information can be found in the brochure *Best Practices for Dug Wells.*

6.3.3 Groundwater Source Construction-Related Contaminants

Inadequate well development and flushing following construction may result in high turbidity or detection of chemical residuals used in the well drilling process. Collecting initial water quality samples at the end of the pump test will help ensure that sample results reflect the water quality in the aquifer and are not the result of well construction. A damaged or poorly designed screen may also result in high turbidity levels observed in a water supply well.

The Designer should be aware of the risks posed by certain construction materials and practices. Low-level detection of organic contaminants may be the result of residuals associated with well development and construction. It is possible to introduce organic contaminants such as tetrahydrofuran and 2-butanone (components in PVC glue) and toluene (a component in lubricants) during well construction. Such construction-related contamination, even in very small concentrations, may require increased water quality monitoring and/or treatment.

High turbidity in a new well or spring is often an indicator of one or more consequential issues, including:

.1 **Poor source development:** Inadequate well cleaning following construction may result in high turbidity and indicate the need to redevelop the source;

.2 **Iron or manganese:** These common inorganic contaminants will cause turbidity and, in most cases, require treatment to remove them from newly developed sources if they exceed the GCDWQ MACs and/or aesthetic objectives; and

.3 **Groundwater under the direct influence of surface water.** High turbidity measured in wells developed close to lakes, rivers, and springs may indicate direct surface water influence. A GARP Assessment should be completed.

6.3.4 Commissioning of a New Well

Commissioning of new wells should take place following connection to the distribution system and installation of all well appurtenances. Operation and performance of all well system components should be checked against the system design. During commissioning, further yield and time-drawdown data may be collected to support calculated sustained yields and predicted pumping levels, and/or to confirm groundwater quality results. These results may be used to finalize the operational groundwater monitoring plan.

The water level and water quality responses of each well should be clearly documented during the commissioning process. A recommended procedure for a multiple well system is as follows:

.1 Operate the first well for one to three days or until steady state drawdown is achieved;
.2 Turn on and operate the remaining wells with continued monitoring of water level changes in all wells; and
.3 After all wells have been turned on, operate the system for a period of time that is sufficient to confirm all of the predicted parameters.

All new production wells or well fields should be monitored closely during the initial year of operation. The water level, flow rate and water quality data should be reviewed by a qualified hydrogeologist, and recommendations made for adjustments or further monitoring as warranted.

Upon completion, all wells should be disinfected with a chlorine solution to remove microbial pathogens that may have been introduced during well construction. As per Section 30 of the GWPR, 'the person responsible for drilling, altering, developing or rehabilitating a water supply well must, promptly after performing the activity, disinfect the groundwater in the well to destroy micro-organisms introduced by the activity.' This can be completed by following the *Water Well Disinfection Using the Simple Chlorination Method* or AWWA methods (i.e. AWWA C654).

When following the AWWA method, chlorine should be applied to ensure that a concentration of 50 mg/L is present in the well for a period of twelve hours. Dosage should be computed on the basis of the water required to provide mixing throughout the entire well volume. Effective disinfection requires that a conductor pipe is used to pump the solution to the bottom of the well. After sufficient holding time, the chlorinated water should be circulated within the well casing and pump column, and then the well should be pumped to waste to remove the chlorinated water. Bacteriological evaluation should be conducted to verify disinfection.

Disinfection agents are potentially hazardous compounds. Proper storage, training, and handling are required for all disinfection compounds.

6.3.5 Wellhead Protection

The *Well Protection Toolkit* (Ministry of Environment and Climate Change Strategy, Ministry of Health and Ministry of Municipal Affairs, 2004) outlines a six-step process for the development and implementation of a well protection plan to prevent contamination of well water supplies. Protecting source water through a well protection plan is one of the barriers in the multi-barrier approach to drinking water protection.

The *Well Protection Toolkit* presents the well protection planning process through the following six steps:

.1 Form a community planning team;
.2 Define the well protection area;
.3 Identify potential contaminants;
.4 Develop management strategies;
.5 Develop contingency plans; and
.6 Monitor results and evaluate the plan.

A source water assessment comprised of selected *Comprehensive Source-to-Tap Assessment* (CS2TA) modules is also recommended to inform well protection plans. Refer to Section 6.1.1.1 – Source Water Assessment for further details on CS2TA guidance and other considerations for groundwater protection measures that may be employed to ensure the long term integrity of the water supply well. In some instances, a regional-level aquifer based protection plan may be warranted to protect the ground water supply.

6.3.6 Observation or Monitoring Wells

It is recommended that a municipal well field completion include a provision for routine surveillance of water levels and water quality in both the pumping well and the host aquifer. Monitoring wells are defined as a class of well under the GWPR: they are used for collecting water samples and monitoring the water depth in the aquifer. The GWPR requires that all permanent monitoring wells have construction and decommissioning reports, however these are not required for temporary monitoring wells. The *Guidance for Technical Assessments in Support of an Application for Groundwater Use in British Columbia* should be referred to for further direction on observation wells.

The required number and location of monitoring wells should be based on hydraulic testing results. The distance should be determined based on the aquifer type by a Qualified Professional. At least one monitoring well should be located at the mid-point of all production wells for surveillance of long term and seasonal water level responses within the aquifer.

If applicable, a monitoring well should be located between the pumping well(s) and any perceived contaminant risk. Where dewatering of domestic wells is of concern, a monitoring well resembling the domestic well design should be established between the pumping well(s) and the domestic well(s) of concern. Alternatively, the nearest domestic wells may be incorporated into the well field monitoring strategy.

Monitoring wells should be:

.1 Equipped with an automatic logging pressure transducer;
.2 Constructed in accordance with the requirements for permanent wells if they are to remain in service after completion of a water supply well, and;
.3 Protected at the upper terminal to preclude entrance of foreign materials.

6.3.7 Deactivating or Decommissioning Wells

An open or unused well is a potential liability to any well field and to the well owner. A well must be decommissioned (taken permanently out of service) within five years of being deactivated. The GWPR describes the requirements for deactivating or decommissioning a well.

When a water supply well is decommissioned, a well decommission report must be completed. The requirements of the report are defined in Schedule 4 of the GWPR.

7 Pre-sedimentation, Coagulation, Flocculation and Clarification

7.1 General

This chapter describes design considerations for drinking water treatment processes which reduce suspended and colloidal solids in water: pre-sedimentation, coagulation, flocculation and clarification. The selection of a particular treatment technology and/or technology train will depend on an evaluation of the nature and quality of the water to be treated, seasonal variations in raw water quality, and the desired quality of the finished water.

7.1.1 General Design Considerations

When selecting and sizing pre-sedimentation, coagulation, flocculation and clarification processes, the Designer should:

.1 Determine the required throughput (volume of water to be treated);
.2 Evaluate the raw water quality, including temperature, turbidity, total suspended solids, pH and other parameters affecting the performance of the process;
.3 Determine the key components to be removed and the target performance required. In general, sedimentation processes are well suited for high turbidity surface waters while dissolved air flotation is well suited for surface waters with lighter particles, such as those with high concentrations of algae or organic carbon. Consideration should also be given to the use of pre-sedimentation;
.4 Determine the type, concentration, and dosage of coagulants and flocculants, and the required reaction times;
.5 Consider the impact of upstream and downstream processes;
.6 Determine the optimum surface loading rate (also called overflow or hydraulic loading rate) and size of clarification unit(s) based on findings from the points above;
.7 Consider the following recommended minimum provisions:
   i. Provide a minimum of two units of each coagulation, flocculation, and sedimentation tank (or two clarifiers) where possible. Where only one tank is available, sufficient finished water storage or provisions to produce water should be provided to maintain a continuous supply of water while the tank is out of service;
   ii. Allow units to be taken out of service without disrupting operation. Drains or pumps should be sized to allow for dewatering in a reasonable period of time;
   iii. Allow measurement and modification of flows to each train or unit;
   iv. Permit operation of the units either in series or in parallel where softening is performed, and in other circumstances where clarification is performed;
   v. Minimize hydraulic head losses between units to allow future process changes without the need for re-pumping; and
   vi. Be started manually following shutdown.

7.2 Pre-sedimentation and Hydrocyclones

Pre-sedimentation may be required for source waters with high suspended solids, turbidity, and/or organics. Pre-sedimentation may be performed seasonally, such as during spring freshet, or continually during the year for increased clarification and/or filtration efficiency. Coagulants and/or oxidizing agents may also be added.

When designing pre-sedimentation systems, the following should be considered:

.1 Pre-sedimentation basins should have hopper bottoms or continuous mechanical sludge removal mechanisms, and arrangements for dewatering. The design should provide a means of maintaining and cleaning basins without interruption;
.2 The inlet should be designed so that incoming water is dispersed across the full width of the line of travel as quickly as possibly. Short-circuiting should be prevented;
.3 Provisions should be provided to bypass the pre-sedimentation basins; and
.4 Sufficient detention time should be provided to meet target effluent water quality. As a general guideline, three hours detention is the minimum recommended period. However, this should be confirmed through bench or pilot testing.

Hydrocyclones can be used as an alternative to pre-sedimentation to remove suspended solids using centrifugal force. Hydrocyclones are effective in removing suspended particles from water where the specific gravity (density) of the particles is heavier than the water; removal efficiency increases as particle density increases. Raw water enters at the top of the cone-shaped separator, creating a vortex. The centrifugal forces cause the denser particles to separate to the bottom. Hydrocyclones are pre-manufactured and often proprietary equipment; for further guidance, the manufacturer should be consulted.

7.3 Coagulation

Coagulation refers to the combined processes of rapid mixing and chemical precipitation of dissolved and particulate matter from water through “particle destabilization”. Particle or charge destabilization occurs by neutralizing the negatively charged particles in the water by adding inorganic salts (positively charged metal ions such as aluminum and iron) or organic polymers.

Enhanced coagulation refers to the process in which coagulant is added to optimize the removal of natural organic matter, with the goal of reducing or eliminating DBP formation. Enhanced coagulation is now nearly ubiquitous in conventional water treatment, as turbidity removal alone is no longer the primary focus of surface water treatment facilities.

Sweep coagulation refers to the process in which a sufficiently high concentration of coagulant is added to precipitate metal hydroxides, which enmesh floc particles into larger agglomerates during flocculation.

Flocculation is the process following coagulation which uses gentle stirring to bring suspended particles together so they will form larger aggregate particles, called flocs. Organic polymers are often used at this stage to provide bridging of floc particles, which tends to form even larger floc agglomerates.

The targeted floc type and characteristics depend on the type of downstream process employed. The floc characteristics will depend on the types of colloidal and/or suspended solids in the water; water temperature and pH; the type and dosages of coagulants and coagulant/flocculant aids (if used); the rapid mixing procedures; flocculation methods, intensities, and time; and overall flow regime through the system.

Consideration should be given to optimizing chemical feed point locations. This may including provision of multiple injection locations for the coagulant, coagulant/flocculant aid, and/or pH adjustment chemicals in relation to the rapid mixing process, residence time, and chemical reaction rates. Alternatively, validation of the optimum chemical reaction times and efficiencies may be determined through bench scale or pilot testing.

The type of coagulant and coagulant/flocculant aid polymers selected depend upon a number of factors including incoming water quality, downstream unit treatment processes, treatment objectives, and economics. Designers should consider pilot and bench scale testing, comparable industry practice, and treatment equipment vendor requirements or conditions when selecting coagulation chemicals. For example, use of polymers may not be compatible with certain filtration processes such as polymeric hollow fibre membranes.

7.3.1 Rapid Mix Unit

The rapid mix unit is where coagulant(s) and raw water are subject to a short duration, high intensity mix to encourage coagulant dispersion and hydrolysis reactions (for metal salts). The rapid mix unit can either be a separate process tank or an in-line mixing system. The following should be considered:

.1 The detention time in the mixing zone should be minimized and limited to under 30 seconds;
.2 The detention time (t) and mixing intensity (G value) are dependent on the chemicals added, water temperature, pH, and other water quality parameters. Jar testing should be conducted to determine system specific values. Table 7-1 can be referred to as guidance for design values;
.3 Powered mixers are generally preferred. Static mixers should only be considered where flow is relatively constant and high enough to maintain the required turbulence for chemical reactions to occur. The Designer should be aware that minor reductions in flow through static mixers may significantly reduce the mixing efficiency delivered. This may reduce operational flexibility and chemical reaction efficiency, particularly at low throughputs; and
.4 The rapid mix process should be placed as close to the flocculation zone as possible.

Table 7-1 Coagulation Design Values (ACWWA Water Supply Guidelines, 2020)

Mixer Type	Mixing Intensity (G value) (s^{-1})	Detention Time, t (s)	Gt
In-line mixers	700 to 1,500	0.5 to 1.0	500 to 1,500
In-line sidestream pump mixer	700 to 1,500	0.5 to 1.0	500 to 1,500
In-line mechanical mixer	3,000 to 5,000	0.5 to 1.0	2,000 to 3,000
Paddle-type rapid mixer	600 to 1,000	10 to 60	6,000 to 25,000

7.3.2 Coagulant Chemical Injection

The following should be considered when designing coagulant chemical injection:

.1 Chemicals injected to a rapid mix unit should be injected at a point closest to the inlet of the unit;
.2 Flocculant aids should not be injected into a rapid mix unit unless an additional rapid mix unit for the flocculent aid is provided;

.3 The Designer should be aware that solids-forming reactions may plug the chemical injector/diffuser and should make appropriate provisions for removal and cleaning;
.4 Coagulant and flocculant aid concentration and detention times should be derived from jar/pilot testing;
.5 The nozzle velocity of a chemical injector into a rapid mix unit should not exceed 3.0 m/s;
.6 3 to 5 minutes detention time should be allowed between coagulant addition and upstream chemical addition, or as otherwise demonstrated through pilot testing. This includes chemicals used for alkalinity or pH adjustment, powdered activated carbon (PAC) and potassium permanganate ($KMnO_4$); and
.7 Primary coagulants should not be mixed using in-line devices such as pumps, weirs, valves, etc., as they do not provide controlled mixing.

7.3.3 Enhanced Coagulation

Disinfection by-products (DBPs) are the result of reactions between disinfectants and natural organic matter (NOM). Reducing NOM, as measured by total organic carbon (TOC), can reduce DBP formation.

Enhanced coagulation refers to removal of TOC by adding sufficiently high concentrations of coagulant and is recommended for treatment plants using surface water or GARP. Generally, TOC removal requires higher coagulant concentrations than for turbidity removal. Coagulants including alum, iron salts, polyaluminum chloride, and cationic polymers have been shown to be effective for enhanced coagulation. If aluminum-based coagulants are used, the Designer should take steps to reduce the amount of residual aluminum below the relevant Health Canada operational guidance value for finished water, particularly for water with elevated pH.

Table 7-2 shows recommended TOC removal prior to the point of continuous disinfection in relation to the source water alkalinity and TOC concentrations. Generally, TOC removal becomes more difficult as alkalinity increases and TOC decreases. In higher alkalinity waters, pH depression to a level at which TOC removal is optimal (e.g. pH between 5.5 and 6.5 for alum) is more difficult and is not be easily achievable. Use of pH control can improve TOC removal, however, it will also impact downstream processes. These impacts should be carefully considered before pH control can be implemented. Potential impacts include:

.1 A lower alum dose resulting in a low amount of sludge produced at the plant;
.2 A lower settled-water pH, which will require a higher dose of alkaline chemicals such as lime to increase the pH of the finished water to levels acceptable per local regulations or as needed for corrosion control;
.3 Increased TDS in the finished water due to acid and caustic addition; and
.4 Increased operating costs arising from pH adjustment.

Table 7-2 TOC Removal Requirement by Enhanced Coagulation (From Alberta 2012, Table 2.2)

Influent TOC (mg/L)	Alkalinity (mg/L as $CaCO_3$)		
	0-60	60-120	>120
0-2	No action	No action	No action
2-4	40%	30%	20%
4-8	45%	35%	25%
>8	50%	40%	30%

7.4 Flocculation

Flocculation is the process of enhancing agglomeration of small floc particles into larger flocs, which are more easily settleable, floatable and/or filterable. This is done by gently stirring through hydraulic or mechanical methods. The mixing should be thorough enough to provide opportunities for the particles to collide but also gentle enough to prevent the flocculated particles from breaking apart.

Flocculation aids may also be used. Flocculation aids are secondary coagulation chemicals which assist in floc formation, including organic charged and neutral compounds, and activated silica.

7.4.1 Basin Design

The following should be considered in flocculation basin design:

.1 A minimum of two separate flocculation tanks should be provided where possible so that maintenance can be performed without disrupting plant operation;
.2 Each tank should be divided into at least two stages (i.e. series compartments) with tapered flocculation (i.e. diminishing velocity gradient) to prevent short-circuiting and floc destruction;
.3 A drain and/or pumps should be provided for dewatering and sludge removal;
.4 The inlet and outlet of each tank should be designed to minimize short-circuiting and floc destruction;
.5 A superstructure (enclosure or cover) over the flocculation basin is recommended to prevent ingress of rainfall, dust or other debris; and
.6 To assist in observing floc formation, effective size, and density, consideration should be given to providing access and adequate lighting.

7.4.2 Detention Time and Flow through Velocity

The detention time for flocculation depends on the raw water characteristics (including water temperature, turbidity, colour, etc.) and downstream treatment processes. A summary is provided in Table 7-3.

Table 7-3 Flocculation Detention Time

Downstream Process	Water Temperature	Flocculation Detention Time [1]
Sedimentation	Summer temperatures	25 – 30 min
	< 5 °C	30 – 40 min or more
Flotation	Summer temperatures	5 - 10 min
	< 5 °C	20 or more
Direct filtration	All	≤ 15 min

[1] Even shorter times may be adequate for coagulation/flocculation for membrane filtration. However, if the flocculation time prior to membrane filtration is too short, or control of pH, alkalinity and buffering capacity of the water is inadequate when using aluminum based coagulants, dissolved aluminum concentrations in the permeate may exceed the GCDWQ operational guideline and/or may prematurely foul the membrane.

7.4.3 Mixing Equipment

Mechanical mixing equipment with paddles driven by variable speed drives is preferred. External, non-submerged motors and bearings are recommended. All submerged parts should be corrosion resistant for long-term use in coagulated water. When designing mixing equipment, the key parameters to consider include:

.1 G value: velocity gradient, also called mixing intensity or root mean square velocity (in s^{-1});
.2 t: residence time within flocculation chamber(s) (in s); and
.3 Gt: The product of velocity gradient and residence time (dimensionless).

The following should be considered regarding the G and Gt values:

.1 Generally, G values of 10 to 80 s^{-1} are needed for flocculation. However, the G value is temperature dependent. The mixing should be sufficient to allow particles to collide but gentle enough to prevent floc shearing. The peripheral speed of paddles should range from 0.15 to 0.9 m/s;
.2 Lower velocity gradients should be applied for fragile colour floc. Higher velocity gradients are needed for flocculated suspended material (turbidity) or where direct filtration is the next downstream process; and
.3 Optimum G and Gt should be determined by pilot testing. Jar testing can also be used if the volume, paddle size and speed are known.

Mixing can also be done hydraulically using baffles. Design of the baffles should take into consideration the flow range, provide a sufficient G value and also consider the Gt. Baffles or hydraulic flocculators should only be used in systems where anticipated flow variations are small.

7.4.4 Location

When selecting the location of the flocculation basin, the Designer should consider:

.1 Placement of the flocculation basin as close to the downstream process as possible;
.2 Flocculated water should never be pumped between the flocculation basin and downstream process as this will break the floc;

.3 The velocity of the flocculated water through the piping or conduits to the downstream process should be no less than 0.15 m/s and no greater than 0.45 m/s. Changes in direction of the piping or conduits should be minimized to prevent turbulence; and

.4 Polymer flocculation aids and activated silica should not be subjected to high shear mixing. Provisions should be made for separate addition downstream of coagulant mixing. A delay period of 3 to 5 minutes detention time between processes is recommended.

7.5 Clarification

Clarification is the process that allows separation of particles by gravity settling or flotation for removal and typically precedes filtration. Clarification technologies can be divided into five general categories: horizontal flow sedimentation basins, upflow clarifiers, adsorption clarifiers, ballasted sand processes and flotation processes.

7.5.1 General Settling Tank and Clarifier Design Considerations

7.5.1.1 Surface Loading Rate

The key parameter in sedimentation basin design is the surface loading rate, also known as overflow rate or hydraulic loading rate. Surface loading rate is measured as a velocity as shown in the equation below. This equation is applicable to both horizontal sedimentation basins and upflow clarifiers.

$$Surface\ Loading\ Rate\ (V_o)\left[\frac{m}{h}\right] = \frac{Flow\ of\ Water\ (Q)\left[\frac{m^3}{h}\right]}{Surface\ area\ of\ settling\ basin\ (A)[m^2]}$$

Particles with a settling velocity (Vs) greater than the surface loading rate (Vo) will settle out, while other particles will settle at a ratio of $\frac{Vs}{Vo}$. Reference values for settling velocities of selected floc types are shown in Table 7-4. The optimum surface loading rate depends on the technology chosen, the target performance in terms of suspended solids (measured as turbidity), the nature of flocculated material, and temperature. Bench or pilot testing is recommended to determine the settling velocities of particles as velocities are impacted by water type, temperature, chemistry and the presence of different coagulation chemicals, and other environmental conditions.

Table 7-4 Settling Velocity of Selected Floc Types (Crittenden et al., 2012)

Floc Type	Settling Velocity (m/h) at 15 °C
Small fragile alum floc	2 – 4.5
Medium-sized alum floc	3 – 5
Large alum floc	4 – 5.5
Heavy lime floc (lime softening)	4.5 – 6.5
Iron floc	2 – 4
Polyaluminum chloride (PACl) floc	2 – 4

7.5.1.2 Basin Design

The following general basin design considerations should be made for clarification processes:

.1 A minimum of two trains should be provided. Where only one sedimentation basin is available, sufficient finished water storage or provisions to produce water without sedimentation should be provided to maintain a continuous supply of water while the basin is out of service;
.2 Basins, piping and appurtenances should be constructed from corrosion resistant materials;
.3 Open ports, submerged ports, and similar entrance arrangements are required. A baffle should be constructed across the basin close to the inlet end and should project below the water surface such that influent water is distributed evenly across the entire basin and at uniform velocities;
.4 Basins should be designed such that short circuiting does not occur;
.5 Outlet weirs or submerged orifices should be designed to:
   a. Not exceed discharge velocities of 250 m^3/day/m of the outlet launder or orifice circumference;
   b. Have a maximum submergence depth of 1.0 m;
   c. Not exceed a submerged orifice entrance velocity of 0.15 m/s. The use of submerged orifices is recommended in order to provide a volume above the orifices for storage when there are fluctuations in flow;
.6 An overflow weir or pipe should be provided to establish the maximum water level desired on top of the filters. The overflow should discharge by gravity with a free fall at a location where the discharge can be observed;
.7 A superstructure to house the sedimentation units is recommended;
.8 Basins should be designed with a drain or sump;
.9 Bottom slopes should be no less than 8% sloping toward the drain, if mechanical collection is not installed;
.10 Mechanical sludge collection is recommended, and bottom slopes may be less than <1% in this case. Flat bottoms are recommended for travelling siphon or scraping mechanisms. Where sludge hoppers are used, the hopper design should be consistent with the flow characteristics of the sludge produced; and
.11 Handrails should be provided around the basins and ladders should be provided for access into the basins.

7.5.1.3 Sludge Systems

When selecting a sludge system, the Designer should consider the following factors:

.1 The type of sedimentation technology chosen and the provision of high-rate settlers;
.2 The nature and quantity of suspended solids in raw water;
.3 Coagulant(s) and coagulation/flocculation aid(s) used; and
.4 Climate (ice formation).

Further information on system specific sludge removal requirements are provided in Chapter 14 – Waste Residuals Handling and Treatment. General considerations for sludge removal systems include:

.1 Sludge pipes should be not less than 75 mm in diameter and arranged to facilitate cleaning;
.2 The entrance of sludge withdrawal piping should be designed to prevent clogging. Designers should be aware that sludge loadings may be unevenly distributed in the tank. Specifically, conventional (horizontal) sedimentation basins may have significantly higher sludge concentrations at the basin inlet than elsewhere;

.3 Valves should be located on the outside of the tank for accessibility. All valve operators which are not within buildings should be tamper proof with provision for locking;
.4 Operators should be able to observe and sample sludge withdrawn from the unit;
.5 Flushing lines should be provided to backflush sludge lines; and
.6 Sludge disposal should be by an approved method.

7.5.1.4 Superstructure

A superstructure (i.e. cover or enclosure) over the settling tank/clarifier should be provided. The following should be considered:

.1 A cover may be adequate if there is no mechanical equipment in the tank(s) and adequate monitoring is provided under all expected weather conditions;
.2 Roof drainage should also be provided and should not discharge into the tank;
.3 Consider the potential for ice formation within the settling tank which may fall and damage submerged equipment if the water level is dropped; and
.4 Consider Brownian motion, particularly for tanks that are located outdoors. When the surface of the tank is warm, and the bottom is cold, thermal currents occur. This results in settled solids moving back into the supernatant.

7.5.1.5 Health and Safety

Relevant municipal, provincial and federal regulations should be adhered to. This includes:

.1 Provision of ladders, ladder guards, railing, handholds and entrance hatches where applicable, including on the inside walls of basins above the water level;
.2 Consideration of confined space requirements;
.3 The incorporation of fall arrest systems that are easily accessible;
.4 Tank openings that are curbed and covers that have a locking device; and
.5 Consideration for a sealable, small opening into tanks for venting and testing purposes.

7.5.2 Horizontal Sedimentation

Horizontal sedimentation basins rely on gravity to remove solids. Water to be treated moves horizontally and sedimentation occurs over the length of the basin. Gravity sedimentation is best suited for source waters that experience high turbidity and suspended solids. Flocculation is necessary prior to gravity sedimentation to develop floc that will settle. Gravity sedimentation is generally less effective on lower throughputs.

7.5.2.1 Turbulence and Stability

Flow characteristics (i.e. laminar or turbulent flow) and stability need to be considered when designing horizontal sedimentation basins. Flow characteristics are determined by the dimensionless Reynolds number. Stability is characterized by the Froude number (Fr). Design criteria for Re and Fr are provided in Table 7-5. A large Reynolds number indicates high turbulence; a low Froude number implies that the water flow is not dominated by horizontal flow, and back-mixing may occur.

Reynolds number is determined by the following equation.

$$Re = \frac{v_f R_h}{\nu}$$

Where Re = Reynolds number based on hydraulic radius, dimensionless
v_f = average horizontal fluid velocity in tank (m/s)
R_h= hydraulic radius, $\frac{A_x}{P_w}$ (m)
A_x = cross-sectional area (m^2)
P_w = wetted perimeter (m)
ν = kinematic viscosity (m^2/s)

Froude number is determined by the following equation.

$$Fr = \frac{{v_f}^2}{gR_h}$$

Where Fr = Froude number, dimensionless
v_f = average horizontal fluid velocity in tank (m/s)
R_h= hydraulic radius (m)
g = acceleration due to gravity, 9.81 m/s^2

A summary of the design criteria for horizontal settling basins is shown in Table 7-5.

Table 7-5 Horizontal Sedimentation/Settling Tank Design Criteria

Parameter	Typical Values	Notes
Surface loading rate	< 1.0 to 2.4 m/h	Low rates should be used for colour removal and high rates for turbidity and suspended solids removal. Rate may need to be reduced by 15 -25% in plants smaller than 10,000 m^3/d to maintain desired performance. Sizing should consider the lowest water temperature.
Mean horizontal flow velocity	0.3 to 1.1 m/min	
Max water entrance velocity	0.6 m/s	Flow straightening baffles should be considered as a part of the inlet.
Water depth	3 to 4.5 m	
Length to width ratio	Min 4:1	
Water depth to length ratio	Min 1:15	
Weir loading	9 to 13 $m^3/(m\cdot h)$	
Detention time	2 – 4 h	
Froude number (Fr)	Fr > 10^{-5}	From Kawamura, 2000
Reynolds number (Re)	Re < 20,000	From Kawamura, 2000

The water exiting the settling basin should be uniformly collected by either a submerged pipe (orifice) or across a weir positioned perpendicular to the flow direction. The velocity of the exit flow will depend on the individual design. Submerged orifices are recommended to provide a storage volume in the sedimentation tank above the orifices to accommodate fluctuations in flow. Submerged orifices should not be located more than 1 m below the water level. An overflow for each tank should be provided when submerged orifices are used.

7.5.2.2 Inlets and Outlets

Inlets and outlets should be designed to distribute water evenly across the basin and minimize short-circuiting. Velocities should be kept uniform.

An inlet zone should be allowed for in the design with a perforated baffle plate to provide flow straightening. The inlet zone will provide an area of varying turbulence based on the influent flow, which provides mixing for the flocculant aid. The flow straightening baffle wall straightens the flow to reduce the turbulence within the sedimentation zone to ensure the required Reynolds and Froude numbers are achieved.

Drainage systems that allow the basin to drain within a reasonable time period (ex. 8 h) should be provided.

7.5.2.3 Sludge Systems

Settled particles form a sludge at the bottom of the basin which must be removed. The sludge system should include the following components:

.1 Sludge collection – ensure collection of sludge throughout basin;
.2 Sludge removal – piping to remove sludge from the basin or clarifier; and
.3 Sludge disposal – waste sludge should be disposed appropriately per regulations.

Sludge collection systems should provide full tank coverage. A summary of the different sludge collection system types and design considerations for conventional sedimentation tanks is shown in Table 7-6.

Table 7-6 Sludge Collection Systems and Design Considerations

Sludge Collection System Type	Design Considerations
Manual sludge removal	- Tank bottom should be sloped toward inlet (1:100). - Flushing lines should be provided.
Travelling siphon or scraping mechanisms	Tank bottom should be flat.
Pumping from sludge hoppers	Hopper design should be consistent with flow characteristics of sludge.

7.5.3 Tube or Plate Settlers

Tube and plate settlers are used to reduce the vertical sedimentation path of the floc particles and thereby reduce the settling time required.

Tube settlers use multiple adjacent tubular channels which increase the effective settling surface area. The tubes help accumulate smaller particles until the particles become large enough to move down the tube uniformly. Tube settlers are typically sloped at 60°. The size and shape of the tubes vary by manufacturer.

Plate settlers (also known as lamella settlers) use a series of inclined plates, typically angled at 55° to 60°. Solids fall to the plate surface, where they slide down by gravity.

There are two different design approaches for tube or plate settlers:

.1 A lamella plate clarifier is typically a rectangular tank with upflow characteristics. Plates or tubes are installed across the complete surface area; and
.2 Horizontal flow tanks typically have the tubes or plates located at the outlet end of the basin, where the flow goes up to discharge over the weir or launder collection area.

When designing tube or plate settlers, the design criteria from Table 7-7 should be considered.

Table 7-7 Tube or Plate Settling Design Criteria

Parameter	Typical Value	Note
Surface loading rate	Tube settlers < 4.8 m/h Plate settlers < 1.2 m/h	Assumes effective settling area is the footprint area (i.e. before the plates or tubes are installed).
Incline angle of tube or plate settlers	55 to 60°	Tube settlers are typically angled at 60°.
Distance between tube or plate	50 mm	
Average flow velocity	0.15 to 0.2 m/min	Typical values for alum floc.
Recommended entrance velocity	0.6 m/min	
Weir loadings	3.7 to 7.5 $m^3/m \cdot h$	

Additional consideration should be given to:

.1 Settling velocity and characteristics of suspended solids;
.2 Sludge removal equipment to be installed under the settler unit;
.3 Spacing of launders to be installed above the settler unit which meet weir loading criteria;
.4 Provisions for cleaning and/or removal of plates or tubes and sludge removal. Flushing lines with appropriate backflow prevention device should be provided;
.5 Drain piping from settler units should allow for quick flush of settler units to prevent flooding;
.6 The support system should be able to carry the weight of the settler modules when the basin is drained plus any additional weight to support maintenance personnel and equipment; and
.7 Provisions should be made to allow the water level to be dropped, and a water or air jet system for cleaning the settler modules.

7.5.4 Ballasted Flocculation and Separation

Ballasted flocculation is a high rate settling process that uses heavy particles (ballasts) to seed floc formation and accelerate the flocculation and sedimentation processes. A means to clean and recycle the sand ballast for reuse in the process should be provided. Ballasted flocculation systems are proprietary and much of the design criteria relies on equipment supplier input.

The surface loading rates of ballasted flocculation systems are very high, typically between 20 to 50 m/h. The detention time for flocculation and sedimentation is very short because of the high surface loading rates. This allows ballasted systems to have smaller spatial footprints than conventional systems. Due to the very short detention time, the overall reaction time to influent quality changes is very short, which is why the process is best suited to treat surface water with a consistent water quality. This process is very effective at removing high turbidity and has also been shown to effectively remove *Giardia lamblia* cysts, but not *Cryptosporidium* oocysts.

The Designer may consider ballasted flocculation, particularly for situations where space is limited, for the clarification process in the main treatment train or where backwash water is to be clarified before recycling. However, ballasted flocculation should not be used upstream of membrane filtration. The effluent of ballasted flocculation and sedimentation processes always contains a polymer residual, and during influent quality fluctuations, the polymer dosage is increased to compensate for the short reaction times. The residual polymer has led to filter blinding on some sites.

7.5.5 Adsorption Clarifiers

Adsorption clarifiers are proprietary systems that use a combination of hydraulic flocculation, roughing filtration, and rapid rate filtration. Flocculation occurs as the coagulated water passes through the granular media, which is often a buoyant plastic media. The agglomerated flocs are then adsorbed by the media.

Adsorption clarifiers are more applicable for higher quality surface waters with low turbidity, iron, manganese and colour. The following general guidelines should be considered in evaluating adsorption clarifiers:

.1 The surface loading rate of adsorption clarifiers are typically in the range of 19.5 to 25.5 m/h;
.2 The flocculation time provided in these systems is generally limited, which may be a concern at low water temperatures;
.3 Air scour should be provided to clean the filters; and
.4 Pilot testing should be conducted.

7.5.6 Upflow Clarifiers

Upflow clarifiers provide coagulation, flocculation, and sedimentation in a single unit. The common types of upflow clarifiers are solids contact and sludge blanket clarifiers. These are often proprietary settling units that have their basic sizes and associated equipment pre-established by the manufacturers based on flow.

Solids contact clarifiers have an inverted cone in the centre which contains the zone of coagulation and zone of high solids concentration. Raw water is drawn into the mixing zone where coagulation and flocculation take place. Water then passes into the settling zone, where the solids settle to the bottom and clarified water flows over a weir. The solids are drawn back into the mixing zone to recirculate the large floc.

Sludge blanket clarifiers also include an inverted cone within the unit. The coagulated and flocculated water enter the bottom of the clarifier and passes through a suspended layer of previously formed floc. The cone shape of the clarifier decreases the rise rate of the water from the bottom to the top as the cross-sectional area increases. When the rise rate of the water equals the downward velocity of the solid particle, the particle becomes suspended. As the water containing flocculated solids passes through this sludge blanket, the particles agglomerate to form large floc that eventually falls to the bottom of the clarifier.

These clarifiers should be considered where water characteristics (particularly temperature) and flow rates are relatively constant, and operation is continuous.

Table 7-8 Upflow Clarifier Design Criteria

Parameter	Typical Value	Note
Surface loading rates	1.2 to 2.4 m/h	Surface loading rates up to 6.0 m/h can be used. Supporting data such as calculations or bench/pilot testing results should be used to justify rates higher than 2.4 m/h. Higher rates are attainable in clarifiers that include plate or tube settlers. When selecting loading rates, low rates are preferable for colour removal and higher rates for turbidity removal.
Flocculation and mixing time	≥30 minutes	If applicable, flocculation equipment should be adjustable, and the clarifier design should provide for coagulation in a separate chamber or baffled zone within the unit.
Detention period	2 – 4 hours	
Weir loading	≤120 L/min/(m of weir length)	From 10 States Standards (2018).

In addition to the design criteria in Table 7-8, the following factors should be considered in evaluating proprietary clarifiers:

.1 Clarifiers should be designed for the maximum uniform flow rate and should be adjustable to accommodate changes in flow and water characteristics;
.2 Effective mixing devices should be provided to ensure good mixing of the previously formed sludge particles and the newly coagulated/flocculated water, and to prevent solid deposition in the mixing zone;
.3 Some proprietary clarifiers may require coagulant to be added in a separate rapid mix unit upstream of the clarifier to ensure even coagulant distribution;

.4 Overflow weir or orifices should be provided so that the water on the surface of the clarifier unit does not travel more than 3 m horizontally to the collection trough. Weirs should be adjustable. The design of the weirs and orifices should produce uniform rise rates for the entire surface area of the tank;
.5 Recirculation impellers should have an adjustable speed ratio of 1 to 4;
.6 Rake speed should be variable from 0.3 to 4.0 m/min;
.7 The design should allow sludge recirculation to continue when raw water flow stops;
.8 Adequate piping should be provided with suitable sampling taps located to permit the collection of samples from various depths of the units. Sampling taps should be located at the sludge withdrawal level and preferably spaced at 0.6 m intervals from the basin bottom to 0.6 m below the effluent level;
.9 The raw water inlet valve should be of the slow opening type, operating over not less than one minute to prevent disruption of the floc blanket; and
.10 Discharge from blow-off outlets and drains should be treated as wastewater.

7.5.6.1 Sludge Systems

In addition to the sludge removal system described in Section 7.5.1.3 – Sludge Systems, an internal or external sludge concentrator should also be provided to produce a concentrated sludge with minimum water content. Solids concentration of waste sludge should be greater than or equal to 3% by weight. Total water losses should not exceed 5%.

For sludge blanket clarifiers that decant into concentrator cones, sludge should be removed through 50 mm hoses. Because the sludge blanket forms in the middle of the clarifier, it has a higher water content and is less thick compared to sludge that settles at the bottom. The water on top of the sludge blanket also provides hydraulic head to help push the sludge through the hose.

7.5.6.2 Enclosure

A clarifier should either by located within the plant or covered with a separate cover that allows personnel to visually inspect the treatment. Appropriate weather proofing of equipment and consideration for ice blockage of orifices should be provided if the proposed clarifier is open top.

7.5.7 Dissolved Air Flotation

Dissolved air flotation (DAF) involves the use of microbubbles to remove floc particles. The bubbles are generated by saturating a recycled stream of water with pressurized air. The saturated recycle stream then enters a proprietary DAF nozzle where it is depressurized to form microbubbles, also known as whitewater. The bubbles bind to the flocculated particles and float them to the surface, where they are removed by a surface scraper system. The clarified water flows under a baffle wall or through a plenum, which then flows up to the overflow weir, which maintains the hydraulic level within the DAF tank.

The DAF process is effective at treating waters with high colour, low turbidity, high natural organic matter, or high algae content. The detention time and loading rates depend on the water being treated, the contaminants being removed, chemicals used, and the design of the DAF process. Designers may also consider using DAF on a seasonal basis (i.e. during algae blooms) because of its fast start-up time.

Table 7-9 DAF Design Criteria

DAF Design Criteria	Typical Values	Note
Conventional DAF surface loading rate	10 to 12 m/h	Conventional DAF has also demonstrated significant removal of *Giardia lamblia* cysts.
High rate DAF surface loading rate	20 to 40 m/h	Performance of high rate DAF should be confirmed with pilot studies.
Tank length	≤ 12 m	Length to width ratio typically between 1 – 2.
Tank depth	1.5 to 3.0 m	Greater depths should be used for high algae loads.
Air saturated recycle flow ratio	Between 5 to 12% of inlet flow	
Saturation pressure	415 to 725 kPa (60 to 105 psi)	
Bubble diameter	Between 10 and 100 µm	

In addition to the design criteria listed in Table 7-9, the following should be considered:

.1 Flow velocities should be limited to prevent scouring of the float from below;
.2 An inlet baffle should be provided to create a contact zone to provide sufficient floc/bubble contact time without short circuiting;
.3 The angle of the baffle should be between 60° to 90°, depending on loading rate;
.4 The air flow should be adjustable, and the air injection designed to ensure an even distribution of air across the inlet baffle;
.5 The recycle flow should be introduced at such a location to ensure even distribution of the released air at the tank influent;
.6 The clarified water should be collected at the bottom of the clarifier; and
.7 An overflow pipe or weir should be provided to control the water level in the DAF unit.

8 Filtration

8.1 General

This chapter describes design considerations for filtration treatment processes which remove particulate matter from water by passing the water through porous or non-porous filter media, such as granular media or membranes. The selection of a particular filtration treatment technology and/or technology train will depend on an evaluation of the nature and quality of the water to be treated, seasonal variations in raw water quality, and the desired quality of the finished water.

Filters should be designed to achieve individual filter effluent turbidity that meets the *Guidelines for Canadian Drinking Water Quality* and the BC Ministry of Health's *Guidelines for Pathogen Log Reduction Credit Assignment*, other than during the filter ripening period when the effluent should be directed to waste (filter-to-waste).

To meet the provincial dual treatment objective, a filtration process should be assigned pathogen log reduction credits. Pathogen log reduction credit assignment is based on the specified filtration treatment process being fully operational and the applicable pathogen log reduction credit assignment criteria being met. Refer to the *Guidelines for Pathogen Log Reduction Credit Assignment* for more information.

Acceptable filtration processes for pathogen log reduction credit assignment include:

- .1 Rapid rate gravity filtration, which includes inline filtration, direct filtration, and conventional filtration;
- .2 Slow sand filtration;
- .3 Membrane filtration, which includes microfiltration, ultrafiltration, nanofiltration and reverse osmosis;
- .4 Biologically active filtration;
- .5 Diatomaceous earth filtration;
- .6 Cartridge filtration; and
- .7 Subsurface filtration, see Section 6.3.1.7.2 – Subsurface Filtration (Riverbank Filtration) for more information.

Pressure filtration - which is not eligible for pathogen log reduction credits - is also discussed within this chapter because it may be used as pre-treatment or for some types of contaminant-specific treatment (for example, iron and manganese removal). Bag filters may be used as pre-treatment but are also not assigned pathogen log reduction credits.

8.1.1 Filtration Selection

The application of any type of filtration should be supported by water quality data representing a reasonable period of time (i.e. seasonal) to characterize variations in water quality. Pilot treatment studies may be required to demonstrate the applicability of the proposed filtration method. Pilot testing guidance can be found in Chapter 3 – General Design Guidance.

The most appropriate filtration technology will vary depending on source water quality, the availability of skilled operators, land and energy requirements, costs, availability of replacement parts for proprietary technology, and other resource considerations. For all filtration facilities, filter-to-waste capability should be provided in anticipation of a less-than-optimum filtered water quality at the start of a filtration cycle. Table 8-1 provides treatment limitations for the different types of filtration technologies given source water quality. Pre-treatment processes can allow for greater levels of coliform, colour, or turbidity than listed below.

Table 8-1 General Source Water Limitations for Filtration Technologies

Filtration Technology	Turbidity (NTU) [1]	Total Organic Carbon (mg/L) [2]	Total Coliform (#/100 mL) [1]	Colour (TCU) [1, 2]
Conventional filtration	<3,000	No limit	< 5,000 – 20,000	< 75
Direct filtration	< 15	< 3	< 500	< 40
In-line filtration	<5		< 500	< 5
Slow sand filtration [3]	< 10	< 2 [6]	< 800	< 5
Diatomaceous earth filtration	< 5		< 50	< 5
Pressure filtration [4]	**DO NOT USE FOR PATHOGEN LOG REDUCTION CREDIT**			
Cartridge filtration [3]	< 5		See [5]	See [5]
Membrane filtration [7]	See [5]	< 2	See [5]	See [5]

[1] Recommended water quality limitations are derived from a combination of sources, including Washington State (2019) and Alberta Environment and Sustainable Resource Development (2012).
[2] Higher TOC and colour values may be treatable based on specific pre-treatment technologies and unit processes.
[3] These limits are for applied filter turbidity. The treatment process can handle higher source water turbidity values if additional pre-treatment is provided.
[4] Pressure filters may be used for iron and manganese removal but will not be assigned any pathogen log reduction credits.
[5] Special studies are required to determine limitations, which are equipment specific.
[6] Higher TOC values require pilot testing. Application of ozone (≤ 1 mg/L) or other oxidants (i.e. potassium permanganate) upstream of filter may improve biodegradability of organics.
[7] NF and RO membranes may be used to treat high TOC and colour source waters.

Applicable to all treatment design, the Designer should consider how the design will affect the classification of the treatment system under the Environmental Operators Certification Program (EOCP) and inform the water supplier of the necessary operator certification level and training requirements.

8.1.2 Preliminary Design

During the preliminary design phase, Designers should conduct a historical summary of meteorological conditions and of raw water quality with special reference to fluctuations in quality, and possible sources of contamination. The following raw water parameters should be evaluated:

.1 Colour;
.2 Turbidity;
.3 Bacterial concentration;
.4 Microscopic biological organisms, which can include *E. coli*, total coliform and fecal coliforms;
.5 Temperature;
.6 Total solids;

.7 pH;
.8 Alkalinity;
.9 General inorganic chemical characteristics; and
.10 Additional parameters as necessary.

The preliminary design phase should also including developing a draft description of methods and work to be done during a pilot plant study or, where appropriate, an in-plant demonstration study.

8.2 Rapid Rate Gravity Filtration

Rapid rate gravity filtration, including in-line, direct, and conventional filtration, is primarily used to remove turbidity after coagulation and flocculation in large water treatment plants. Numerous texts and standards cover the design of rapid rate filtration in detail, including:

.1 *AWWA Standard B100: Standard for Granular Filter Media* (AWWA 2016a);
.2 *Water Treatment Plant Design: Ch. 9. High-Rate Granular Media Filtration* (AWWA/ASCE 2012b);
.3 *Recommended Standards for Water Works. Section 4.3.1 Rapid Rate Gravity Filters* (Ten State Standards 2018); and
.4 *Integrated Design and Operation of Water Treatment Facilities* (Kawamura 2000).

Designers should review these references and other resources as part of their evaluation of rapid rate filtration for any source. Deep bed rapid rate gravity filters generally refers to rapid rate gravity filters with filter material depths equal to or greater than 1,200 mm. For these systems, filter media sizes are typically larger than those listed in Section 8.2.8 – Filter Media. Final filter design should ideally be based on pilot plant studies.

8.2.1 Types of Rapid Rate Gravity Filtration

The pre-treatment process used prior to filtration can further classify rapid rate filtration as follows:

.1 **In-line filtration** - includes a short period of coagulation and rapid mixing prior to filtration. It does not include extended flocculation with the use of basins or clarification. In-line filtration should only be used to treat water sources with low turbidity and low concentrations of natural organic matter;
.2 **Direct filtration** - includes coagulation and flocculation prior to filtration without prior solids removal through clarification. Nonetheless, direct filtration systems should be designed such that a solids separation process could be installed at a later date; and
.3 **Conventional filtration** - includes coagulation, flocculation, and clarification prior to filtration.

Figure 8-1 illustrates a typical flow diagram for in-line, direct and conventional filtration. Refer to Chapter 7 – Pre-sedimentation, Coagulation, Flocculation and Clarification for design of chemical mixing, flocculation and clarification. Additionally, refer to Chapter 13 – Chemical Application for design of chemical systems.

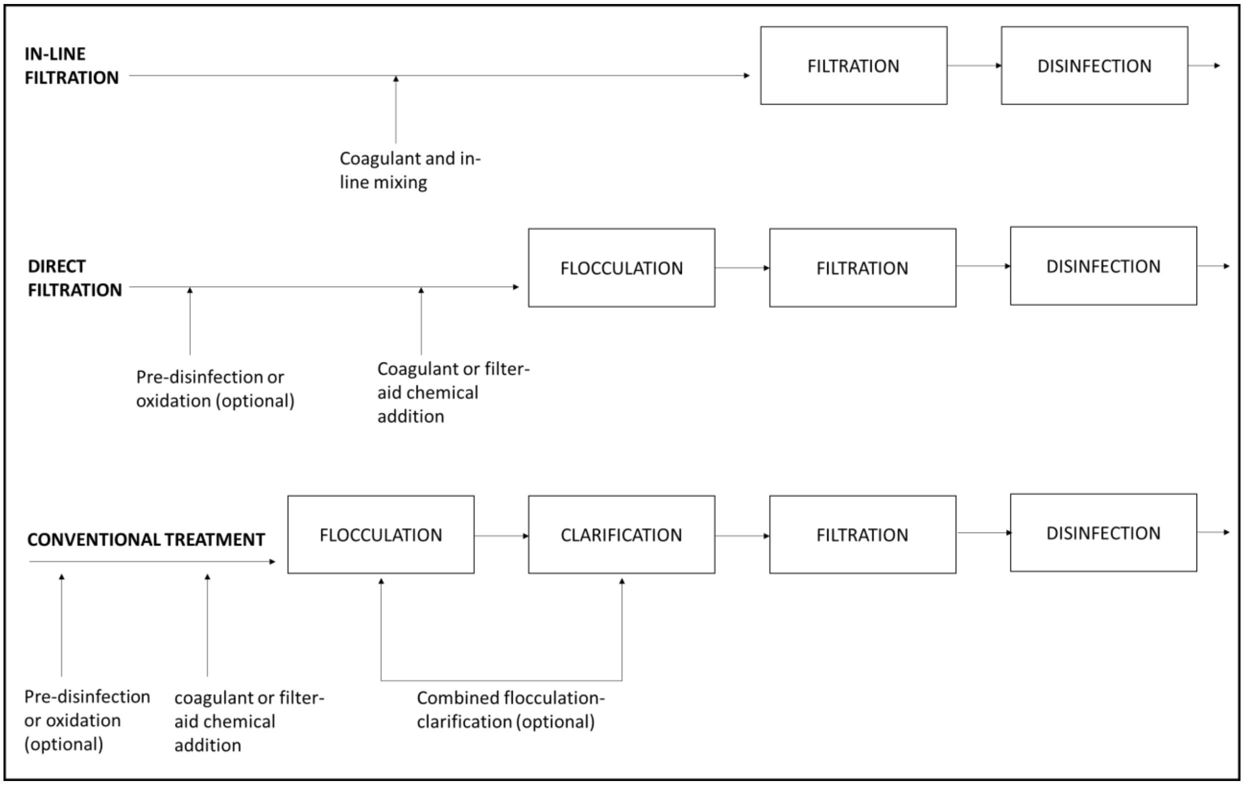


Figure 8-1 Typical flow diagram of rapid rate filtration systems

8.2.2 Rapid Media General Design Considerations

8.2.2.1 Number and Redundancy

The Designer should consider the following when deciding the number of filters in the plant:

.1 A minimum of two filtration units should be provided for redundancy;
.2 Where only two units are provided, each unit should be capable of meeting the facility design capacity (normally the projected maximum daily demand) at the approved filtration rate;
.3 Where more than two filter units are provided, the filters should be capable of meeting the plant design capacity at the approved filtration rate with the largest filter removed from service;
.4 The number of filters and area of each filter bed should be designed such that the filtration rate can remain the same or not increase substantially (less than 10% gradual change in hydraulic loading) during the backwashing of the filters to prevent the possibility of turbidity breakthrough; and
.5 Where declining rate filtration is provided, the variable aspect of filtration rates, and the number of filters should be considered when determining the design capacity for the filters.

8.2.2.2 Structural Details and Hydraulics

The filter structure should be designed with the following considerations:

.1 Effluent piping designed hydraulically for flows of up to 50% in excess of the filtration design capacity to accommodate potential peak demands, provided that the water quality is not compromised;
.2 Effluent piping arranged to prevent backflow of air into the filter;
.3 Vertical walls within the filter;
.4 No protrusion of the filter walls into the filter media;
.5 Covered by superstructure;
.6 Head room to permit normal inspection and operation;
.7 Minimum depth of filter box of 2.5 m;
.8 Minimum water depth over the surface of the filter media of 900 mm;
.9 Trapped effluent to prevent backflow of air to the bottom of the filters;
.10 Prevention of floor drainage to the filter with a minimum 100 mm curb around the filters;
.11 Prevention of flooding by providing overflow;
.12 Maximum velocity of treated water in pipe and conduits to filters of 0.6 m/sec;
.13 Cleanouts and straight alignment for influent pipes or conduits where solids loading is heavy, or following lime-soda softening;
.14 Wash water drain capacity to carry maximum flow;
.15 Walkways around filters, to be not less than 600 mm wide;
.16 Safety handrails or walls around all filter walkways; and
.17 Construction to prevent cross connections and common walls between potable and non-potable or filtered and unfiltered water. Tanks containing untreated or partially treated water should not be located adjacent to a structure containing treated water with a single wall separation. Refer to Chapter 5 – Facility Recommendations for cross connection and backflow prevention considerations and Chapter 17 – Water Storage for considerations for water storage tanks.

8.2.2.3 Appurtenances

The following appurtenances should be provided for every filter:

.1 Influent and effluent sampling taps;
.2 An indicating loss of head gauge or transmitter;
.3 Indicating flow meter and flow control to each filter/train;
.4 For surface water or GARP with two or more filters, on-line turbidimeters should be installed on the effluent line from each filter such that:
   a. All turbidimeters should consistently determine and indicate the turbidity of the water in NTUs;
   b. Each turbidimeter should report to a recorder that is designed and operated to allow the operator to accurately determine the turbidity at least once every 5 minutes;
   c. Graphical display capability should be provided for turbidity data;
   d. Turbidimeters on individual filters should be designed to accurately measure low-range turbidities and have an alarm that will sound when the effluent level approaches 0.3 NTU. The readout should be data-logged continuously and should be connected to SCADA systems;
   e. It is recommended that turbidimeters be placed in a location that also allows measurement of turbidity during filter to waste;
   f. Reference should be made to Chapter 22 – Water Quality Monitoring for further guidance on turbidity monitoring;

.5 A flow rate controller capable of providing gradual rate increases when placing the filters back into operation;
.6 Wall sleeves providing access to the filter interior at several locations for sampling or pressure sensing;
.7 A 25 to 38 mm pressure hose equipped with a shutoff nozzle or valve and storage rack at the operating floor for washing filter walls;
.8 Automatic shutoff valves on each filter effluent to prevent the filters from draining down after the plant is shut off; and
.9 Access to particle counting equipment (portable or online) may be considered as a means to enhance monitoring and overall treatment operations.

8.2.3 Filter-to-Waste Provisions

Water treatment plants should be designed with a filter-to-waste provision. Refer to Section 5.8 – Cross Connections and Backflow Prevention for considerations and resources.

Piping for filter-to-waste is to be designed at full filter flow capacity and include precautions to prevent backflow from the filter-to-waste stream to any component of the potable water supply system.

During the filter-to-waste mode, the filter may be operated at high hydraulic loading rates and wasted water turbidity should be measured daily until it reaches an acceptable level.

8.2.4 Rate of Filtration

The rate of filtration should be determined through consideration of such factors as:

.1 Raw water quality;
.2 Degree of pre-treatment provided;
.3 Filter media;
.4 The total required area of the filter bed;
.5 The available hydraulic loss during filtration;
.6 The anticipated terminal head loss prior to turbidity breakthrough in the filter bed;
.7 The anticipated filter run;
.8 Water quality control parameters;
.9 Competency of operating personnel; and
.10 Other factors as necessary.

For traditional dual media filter designs, a maximum filtration rate of 14.8 m/h is recommended. In any case, the filter rate should be proposed and justified by the Designer prior to the preparation of final plans and specifications. For all filter designs, filtration rates greater than 14.8 m/h should be confirmed through pilot testing. Pilot testing in cold water conditions is also advisable to establish acceptable rates.

8.2.5 Flow Control

There are three basic modes of filtration control:

.1 Constant rate filtration:
   a. Constant rate filtration is the most commonly used method. In this method, the rate of filtration is maintained by a flowmeter and a modulating butterfly valve on the effluent side. As the head loss increases in the media, the valve is gradually opened to maintain

the pre-determined filtration rate;

.2 Declining rate filtration:

a. In declining rate filtration, filter influent enters a specially designed manifold to provide an equal head to all filters. As such, filtration rate declines with increasing head loss in the media. This method requires a special care in start-up of filters and limits operating flexibility which can be a significant issue for larger plants; and

.3 Influent flow splitting:

a. In influent flow splitting, filter influent flow into each filter is maintained by an adjustable weir at the entrance of the cell. As head loss increases, the cell water level will rise within the cell. Filtration is terminated when the water level reaches an elevation below the influent weir to prevent flooding.

For all methods, flow control should provide equal flow distribution among the individual filters and accommodate rising head loss through each individual filter run. The Designer should consider cost, complexity and reliability when selecting a control strategy.

8.2.6 Head loss and Control

.1 Filters should be designed with a maximum permissible head loss typically in the range from 0.3 m (clean bed) to 2.5 m. Excessive head loss can cause air binding and/or channeling and deterioration of filter performance;

.2 Filters should be designed to have at least 1.0 m of water above the media and in the case of high rate filtration, this value should not be less than 1.5 m. Filters may be designed with significantly different values on a site-specific basis;

.3 Some elements of filter design are proprietary in nature, and the performance of designs which deviate significantly from these guidelines should be demonstrated based on relevant references and/or piloting; and

.4 Filter run times should be designed between 12 and 72 hours and, where possible, should be between 24 and 48 hours. Longer filter run times may be considered provided that it is adequately demonstrated that it will not result in adverse impacts on water quality, and operation and maintenance of the filter.

8.2.7 Backwash Water Troughs

Backwash water troughs should be constructed to have:

.1 The bottom elevation above the maximum level of expanded media during washing;

.2 A 50 mm freeboard at the maximum rate of wash;

.3 The top edge of each trough to be at the same elevation (adjustable weirs are recommended);

.4 Spacing so that each trough serves the same number of square meters of filter area;

.5 Trough spacing of 1.8 to 3 m for dual media with anthracite or granular activated carbon (GAC);

.6 Troughs should be located so that they do not obscure observation of filters or affect accessibility; and

.7 Maximum horizontal travel of suspended particles to reach the trough not to exceed 1.0 m.

8.2.8 Filter Media

All filter materials should meet the current applicable AWWA standards for filtering materials and storing and handling information, including *AWWA B100 – Granular Filter Media* and *AWWA B604 – Granular Activated Carbon*. The selection of media type, size (effective particle size and uniformity coefficient), distribution, depth and L/d ratio (L=depth, d=filter media effective particle size) should be such that, in operation, the filter reaches its design terminal head loss at approximately the same time as either turbidity or colour breakthrough occurs, based on whichever is the controlling process parameter. The media selection also depends on the concentration and type of suspended solids to be removed by the filter. Media selection is complex and should, therefore, only be undertaken by competent professionals.

Filter media is typically clean silica sand or other natural or synthetic media free from detrimental chemical or bacterial contaminants and having the following characteristics, unless otherwise demonstrated by pilot testing or comparable reference installation:

- .1 Typically, a total depth between 600 and 760 mm;
- .2 A uniformity coefficient of the smallest material greater than 1.65;
- .3 A minimum depth of 300 mm of media with an effective size range no greater than 0.45 mm to 0.55 mm;
- .4 Types of filter media:
  - a. Anthracite - filter anthracite should consist of hard, durable anthracite coal particles of various sizes. Blending of non-anthracite material is not acceptable. Anthracite should have an:
    - i. Effective size of 0.45 mm - 0.55 mm with uniformity coefficient not greater than 1.65 when used alone;
    - ii. Effective size of 0.8 mm - 1.2 mm with a uniformity coefficient not greater than 1.7, when used as a cap;
    - iii. Effective size for anthracite used as a single media on potable groundwater for iron and manganese removal only should be a maximum of 0.8 mm (effective sizes greater than 0.8 mm may be approved based upon on-site pilot plant studies or other demonstration);
    - iv. Specific gravity greater than 1.4;
    - v. Acid solubility less than 5%;
    - vi. A Mohs scale of hardness greater than 2.7;
  - b. Sand Filter – sand should have:
    - i. An effective size of 0.45 mm to 0.55 mm;
    - ii. A uniformity coefficient of not greater than 1.65;
    - iii. A specific gravity greater than 2.5;
    - iv. An acid solubility less than 5%;
  - c. High Density Sand - high density sand should consist of hard, durable, and dense grain garnet, ilmenite, hematite, magnetite, or associated minerals of those ores that will resist degradation during handling and use, and should:
    - i. Contain at least 95% of the associated material with a specific gravity of 3.8 or higher;
    - ii. Have an effective size of 0.2 to 0.3 mm;
    - iii. Have a uniformity coefficient of not greater than 1.65;
    - iv. Have an acid solubility less than 5%;
  - d. Granular Activated Carbon (GAC) - granular activated carbon as a single media may be considered for filtration only after pilot or full-scale testing. The design should include

the following:

i. The media should meet the basic specifications for filter media as given in .1 through .3 above. Alternate media sizes may be allowed where pilot or full-scale tests have demonstrated that treatment goals can be met under all conditions;
ii. There should be provisions for a free chlorine residual and adequate contact time in the water following the filters and prior to distribution (see Chapter 11 – Disinfection);
iii. There should be means for periodic treatment of filter material for control of bacterial and other growth;
iv. Provisions should be made for removal/replacement or regeneration; and

e. Other media types or characteristics may be considered based on experimental data and operating experience.

8.2.9 Filter Underdrains and Strainer Systems

The underdrain system (or filter bottom) should provide an even rate of filtration over the entire area of the filter and, if used, uniform distribution of backwash water and/or scouring air. Underdrain systems come in many forms including perforated pipe, false bottom with strainers, nozzle based, block underdrain, precast concrete underdrains, folded plate underdrain, and some proprietary types.

The selection of an underdrain design will be dependent on filter size, filter media characteristics, and the type of filter washing system implemented. Departures from these standards may be acceptable for high rate filters and for proprietary bottoms. Porous plate bottoms should not be used where iron or manganese may cause clogging or with waters softened by lime.

The design of manifold-type collection systems should:

.1 Minimize loss of head in the manifold and laterals;
.2 Ensure an even distribution of wash water and an even rate of filtration over the entire area of the filter;
.3 Provide the ratio of the area of the final openings of the strainer systems to the area of the filter at about 0.003 (typical range 0.0015 – 0.005);
.4 Provide the total cross-sectional area of the laterals at about twice the total area of the final openings;
.5 Provide the cross-sectional area of the manifold at 1.5 to 2 times the total area of the laterals;
.6 Lateral perforations without strainers should be directed downward;
.7 Allow for cushioning of the air inflow surge at blower start-up as well as even distribution of air scouring over the whole floor area; and
.8 Depending on the underdrain design, support media may be required. Refer to Section 8.2.10 – Support Media.

8.2.10 Support Media

Support media for underdrains, when required, should conform to the following criteria:

.1 Torpedo sand - A 76 mm layer of torpedo sand should be used as a supporting media for filter sand where supporting gravel is used, and should have:
a. an effective size of 0.8 mm to 2.0 mm;
b. a uniformity coefficient < 1.7; and

.2 Gravel - gravel, when used as the supporting media, should consist of cleaned and washed, hard, durable, rounded silica particles and should not include flat or elongated particles. The coarsest gravel should be 62 mm in size when the gravel rests directly on a lateral system and should extend above the top of the perforated laterals. Not less than four layers of gravel should be provided in accordance with the following size and depth distribution:

Size (mm)	Depth (mm)
62 – 38	125 – 200
38 – 19	75 – 125
19 – 12	75 – 125
12 – 5	50 – 75
5 – 2.5	50 – 75

Reduction of gravel depths, number of layers, and other size gradations, along with substitution of support media type may be considered with justification when proprietary filter bottoms are specified.

8.2.11 Surface Wash or Subsurface Wash

Surface or subsurface wash facilities are required except for filters used exclusively for iron, radionuclides, arsenic or manganese removal, and may be accomplished by a system of fixed nozzles or a revolving-type apparatus. All devices should be designed with:

.1 Provisions for water pressures of at least 310 kPa (45 psi), with a typical range of 483-690 kPa (70-100 psi);
.2 A properly installed vacuum breaker or other approved device to prevent back siphonage if connected to the filtered or finished water system;
.3 The following provides a typical flow range for different types of wash:
   a. Fixed nozzles: 7.5-10 m/h;
   b. Revolving single arm: 1.2-1.75 m/h;
   c. Dual arms: 3.25-3.75 m/h; and
.4 Air wash can be considered based on experimental data and operating experiences.

8.2.12 Backwash

Provisions should be made for washing filters as follows:

.1 A minimum backwashing rate of 37 m/h, consistent with water temperatures and specific gravity of the filter media. A rate of 50 m/h or a rate necessary to provide for a 25-50% expansion of the filter bed is recommended. A reduced rate of 25 m/h may be acceptable for full depth anthracite or granular activated carbon filters; for systems using air scour see Section 8.2.13 – Air Scouring;
.2 Filtered water should be used for backwashing and provided at the required rate by a minimum of two backwash water pumps (one duty and one standby). The use of high-pressure sources with pressure reducing valves is not recommended as failure of pressure reducing valves may disrupt filter media which would then need to be re-stratified;
.3 Backwash water pumps in duplicate unless an alternate means of obtaining backwash water is available;

.4 Provision for water pressures of at least 310 kPa (45 psi) or as specified by the manufacturer;
.5 Sufficient volume of water should be provided for backwashing all filters every 24 hours. An equivalent volume of equalization may be required for plants that store their backwash prior to treatment and/or ultimate disposal;
.6 Not less than 15 minutes wash of one filter at the design rate of wash, and a minimum 10 minutes of backwash water for systems that use air scour;
.7 A backwash water regulator or valve on the main backwash water line to obtain the desired rate of filter wash with the backwash water valves on the individual filters open wide;
.8 A flow meter, preferably with a totalizer, on the main backwash water line or backwash waste line, located so that it can be easily read by the operator during the washing process;
.9 Design to prevent rapid changes in backwash water flow;
.10 Backwash should be operator initiated; alternatively, automated systems should be operator adjustable; and
.11 Appropriate measures for cross connection control and prevention against back-siphonage if connected to the treated water system.

8.2.13 Air Scouring

Air scouring can be considered in place of surface wash, with the following criteria:

.1 The air should be free from contamination. Oil-free compressors should be used;
.2 Air flow should be 0.9 - 1.5 $m^3/min/m^2$ of filter area when the air is introduced in the underdrain; a lower air rate should be used when the air scour distribution system is placed above the underdrains;
.3 A method for avoiding excessive loss of the filter media during filter backwashing should be provided;
.4 Air scouring should be followed by a fluidization wash sufficient to re-stratify the media;
.5 Air scour distribution systems should be placed below the media and supporting bed interface; if placed at the interface the air scour nozzles should be designed to prevent media from clogging the nozzles or entering the air distribution system;
.6 Piping for the air distribution system should not be flexible hose (which may collapse when not under air pressure) nor a relatively soft material (which may erode at the orifice opening with the passage of air at high velocity);
.7 Air delivery piping should not pass down through the filter media nor should there be any arrangement in the filter design which would allow short circuiting between the applied unfiltered water and the filtered water;
.8 Consideration should be given to maintenance and replacement of air delivery piping;
.9 The backwash water delivery system should meet the requirements in Section 8.2.12 – Backwash; however, for systems with air scour, backwash rates of 5-10 m/h and 20-25 m/h are common for typical depth and deep bed filters respectively;
.10 The filter underdrains should be designed to accommodate air scour piping when the piping is installed in the underdrain; and
.11 Air scouring controls should allow the operator to control the air flow rates and duration. Rate of flow indicators for air and water should be provided.

8.3 Slow Sand Filtration

Slow sand filtration refers to the process in which water is gravity filtered at very low rates through a sand bed in which a biologically active layer forms on the top of the media. This biologically active layer is commonly referred to as a *Schmutzdecke*. The use of this technology should require prior engineering studies to demonstrate the adequacy and suitability for the specific raw water supply. Extensive raw water quality and piloting data should be obtained and should cover a period of at least one year to capture all of the seasonal water quality fluctuations. Pilot testing should meet the requirements of Section 3.6 – Pilot Test Recommendations.

8.3.1 Number and Redundancy

Refer to Section 8.2.2.1 – Number and Redundancy.

8.3.2 Structural Details and Hydraulics

Slow sand filters should be designed so as to provide:

.1 A cover;
.2 Headroom to permit normal movement by operating personnel for scraping and sand removal operations;
.3 Adequate access hatches and access ports for handling of sand and for ventilation;
.4 An overflow at the maximum filter water level;
.5 Protection from freezing;
.6 Means for cleaning and/or scraping of sand; and
.7 Filter-to-waste (a minimum two days flow should be considered).

8.3.3 Filter-to-Waste Provisions

During the filter ripening period, following the start-up of a new filter or a re-built filter bed, filtered water may be of very poor quality. The ripening period typically ranges from about one week to several months. The filters will not meet the minimum performance requirements during the ripening period and the water produced during this period should be wasted. Water treatment plants should be designed with this filter-to-waste provision. Precautions should be made to prevent backflow from the filter-to-waste stream to any component of the potable water supply system.

During the filter-to-waste mode, the filter may be operated at high hydraulic loading rates and wasted water turbidity should be measured daily until it reaches the acceptable level.

8.3.4 Rates of Filtration

The permissible rates of filtration should be determined by the quality of the raw water and should be on the basis of experimental data derived from the water to be treated. The nominal rate may be 0.04 to 0.40 m/h, with somewhat higher rates acceptable with the demonstration of effective performance. Water supply to the *Schmutzdecke* should maintain adequate dissolved oxygen (DO > 6 mg/L), as metals can be mobilized under low DO conditions.

8.3.5 Filter Media

All filter materials should meet the current applicable AWWA standards for filtering materials and storing and handling information and the following should be considered:

.1 Filter sand should be placed on graded gravel support layers (see Section 8.3.6 – Support Media).
.2 Sand bed depth should be generally between 1 - 1.3 m at the start of operation, although deeper beds may be used if desired;
.3 The effective size should be between 0.15 mm and 0.30 mm. Larger sizes may be considered; a pilot study may be required;
.4 The uniformity coefficient should not exceed 2.5;
.5 The sand should be cleaned and washed free from foreign matter and dust/fine particles to avoid long start-up times; and
.6 The sand should be re-bedded when scraping has reduced the bed depth to no less than 480 mm. Where sand is to be reused in order to provide biological seeding and shortening of the ripening process, re-bedding should use a "throw over" technique whereby new sand is placed on the support gravel and existing sand is replaced on top of the new sand.

8.3.6 Support Media

The supporting gravel should be similar to the size and depth distribution provided for rapid rate gravity filters, refer to Section 8.2.10 – Support Media.

8.3.7 Underdrains

Design of the underdrains should consider the following:

.1 Each filter unit should be equipped with a main drain and an adequate number of lateral underdrains to collect the filtered water;
.2 The underdrains should be placed as close to the floor as possible and spaced so that the maximum velocity of the water flow in the underdrain will not exceed 0.23 m/sec;
.3 The maximum spacing of laterals should not exceed 1.0 m if pipe laterals are used;
.4 The underdrain system should ensure uniform flow through the overlying sand bed by having a uniform distribution and sufficient number of collection orifices. The designed head loss within the underdrain pipe should be negligible relative to head loss through the orifice. The diameter and spacing of the underdrain pipes and the diameter of the orifices should be determined using hydraulic calculations. The recommended drain orifice diameter is 6.35 mm;
.5 Air release holes or slits should be included at the top near the midpoint of the main drain and each lateral. Alternatively, slotted drainpipe may be used where the width of the slots is in the 2-4 mm range, provided the head loss through the slots is determined to be much greater than the laterals and main drains; and
.6 Underdrains material should be PVC or other noncorrosive material meeting *NSF/ANSI Standard 61: Drinking Water System Components – Health Effects*.

8.3.8 Depth of Water on Filter Beds

Influent water should be introduced to the supernatant water with enough clearance above the sand to prevent turbulence scouring of the sand surface. Design should provide a depth of at least 1.8 to 2.0 m of water over the sand. Head loss should be between 0.1 m (i.e. clean bed) and 2.0 m (i.e. final bed).

8.3.9 Control Appurtenances

Each filter should be equipped with:

- .1 Influent and effluent sampling taps;
- .2 An indicating loss of head gauge or other means to measure head loss;
- .3 An indicating rate-of-flow meter. A modified rate controller that limits the rate of filtration to a maximum rate may be used. However, equipment that simply maintains a constant water level on the filters is not acceptable, unless the rate of flow onto the filter is properly controlled. A pump or a flow meter in each filter effluent line may be used as the limiting device for the rate of filtration only if other options are not viable and requires approval;
- .4 Provisions for filtering to waste with appropriate measures for cross connection control;
- .5 An orifice, venturi meter, or other suitable means of discharge measurement installed on each filter to control the rate of filtration;
- .6 An effluent pipe designed to maintain the water level above the top of the filter sand; and
- .7 A movable weir plate that can be raised or lowered during operation to control tailwater. Refer to Section 8.3.11 – Tailwater Control.

8.3.10 Scraping and Ripening

Slow sand filters should be scraped as required based on filter breakthrough or maximum head loss. After scraping, the de-watered filter should be backfilled with treated water. Provision should be made in the design to backfill the filter through the underdrain system; backfilling from the top can result in entrapment of air bubbles which may cause air binding and disruption of the flow. Slow sand filters should be allowed to ripen for enough time to ensure the target filtered water turbidity levels are achieved.

The frequency of scraping and ripening duration will vary with sand depth and raw water quality and can be more accurately determined during piloting. Filter harrowing (raking) as an intermediate maintenance activity between scrapings may prolong the life of the media and considerations to allow harrowing should be made during design of the filter basin and piping.

Slow sand filters should be operated to waste after scraping or re-bedding during a ripening period until the filter effluent turbidity falls to consistently below the water quality treatment objectives.

8.3.11 Tailwater Control

Filter effluent water (also called tailwater) passes through a finished water storage tank, normally located adjacent to the slow sand filter. Weirs are recommended over effluent control valves to control the tailwater elevation in the finished water storage.

The design of the system should have a movable weir plate that can be raised or lowered during operation. Immediately after scraping the filter, it is recommended that the water level is raised by 0.3 m to dissipate the kinetic energy of the influent flow and prevent disruption of the filter bed.

This can be achieved by increasing the head loss through the filter via raising the tailwater elevation. The weir plate should be adjustable enough so that it can be lowered to the elevation of the surface of the sand bed once the head loss across the sand bed is greater than 0.3 m.

8.4 Membrane Filtration

This section provides general design criteria that apply to all membrane systems. Membrane filtration systems are typically proprietary technologies with fiber and module designs differing significantly between manufacturers. As such, the manufacturer should be consulted for specific design requirements.

Membrane systems are classified based on their approximate pore size ranges. These categories are as follows:

.1	Microfiltration (MF):	> 0.1 µm pore size (typically 0.1 - 10 µm);
.2	Ultrafiltration (UF):	0.01 - 0.1 µm pore size;
.3	Nanofiltration (NF):	0.001 –0.01 µm pore size; and
.4	Reverse osmosis (RO):	0.0001 µm pore size.

Where µm = micrometre = 1×10^{-6} metres = 1×10^{-3} millimetres.

Many membranes, especially those used in ultrafiltration, are also characterized in terms of molecular weight cut-off (MWCO), which is defined as the molecular weight where 90% of removal across the membrane occurs. MWCO is measured in Daltons (atomic weight units) and is used where measurement in microns is insufficient to accurately describe removals of dissolved constituents.

Membrane filtration systems are used in a range of drinking water treatment applications, including the removal of fine particles through ultrafiltration (UF) and microfiltration (MF) to the removal of solutes through reverse osmosis (RO) and nanofiltration (NF). In B.C., UF and MF are the most commonly used membrane systems for drinking water applications. NF and RO are less commonly found. Current RO applications are typically limited to brackish groundwater, seawater sources, and membrane softening.

Membrane replacement represents a major component in the overall cost of water production. The life expectancy of a particular membrane under consideration should be evaluated during the pilot study or from other relevant available data. Membrane life may also be reduced by operating at consistently high fluxes.

Numerous texts and standards cover the design of membrane filtration in detail, including:

.1 *Membrane Filtration Guidance Manual* (USEPA 2005);
.2 *AWWA B110: Standard for Membrane Systems* (AWWA 2016c); and
.3 *AWWA Manual M53 Microfiltration and Ultrafiltration Membranes for Drinking Water* (AWWA 2016d).

For pathogen log reduction credit assignment, the Designer should refer to the *Guidelines for Pathogen Log Reduction Credit Assignment* and the latest edition of the USEPA Membrane Filtration Guidance Manual or ANSI/NSF Standard 419.

8.4.1 Pre-treatment

Depending on the source water, pre-treatment requirements for membrane treatment may be considered. Generally, the feed water should be very low in organic and inorganic colloidal substances, metal oxides (particularly iron and manganese), and biological substances to minimize premature fouling of the pores. In addition, most membranes will not tolerate high/low pH water or free chlorine. A number of pre-treatment unit processes that may be evaluated for integration with membrane filtration systems include:

.1 **Pre-screening:** Pre-screening of any membrane system to protect the membranes from damage by debris. The required screen size and/or strainer should be dictated by the requirements of the membrane manufacturer (typically 50 – 500 µm);

.2 **Oxidation:** Oxidation to be integrated with membrane processes to assist with organics, including both total organic carbon (TOC) and dissolved organic carbon (DOC), and taste and odour reduction. It is recommended that the oxidation process be introduced as far upstream of the membrane process as possible. However, the possibility of DBP formation should be reviewed.

The Designer should obtain agreement for the use of a particular oxidant from the membrane manufacturer. In the case of using oxidation for the removal of divalent iron and/or manganese, sufficient contact time should be allowed for chemical reaction completion and precipitate formation upstream of the membrane filter;

.3 **Adsorption:** Adsorption processes are normally used downstream of the membrane process for removal of organics (TOC and DOC) and taste and odour causing compounds. When carbon adsorption processes are considered upstream of membrane processes, pilot tests should be carried out for the specific membrane and carbon grade to assess the potential reduction in membrane life due to the presence of abrasive carbon fines. When biological filtration is planned upstream of membrane filtration, optimization of pilot biological filtration over a minimum period of 4 months should be conducted before commencing membrane pilot work on the biological filter effluent; and

.4 **Coagulation:** Coagulation upstream of the membrane process is not typically needed for effective pathogen removal. In some cases, this is implemented for pin floc formation. Coagulant use may lead to additional expense and residuals handling costs and may require conditioning of the raw water to be effective. Where coagulant is needed, such as for example, for colour or dissolved organic carbon removal, the coagulation process will add additional solids loading and may plug the membrane pores, leading to extra cleaning requirements. Furthermore, the use of coagulant needs to be optimized to prevent high dissolved aluminum concentrations in the treated water. Where coagulation is needed for a substantial part of the operating year, operating cost and life cycle analysis should be evaluated and understood for the system.

When pre-treatment is required, the Designer should consider the effects of upstream processes on the membrane system. For example, many membranes have restricted tolerance for exposure to chlorine, the use of which may be needed for mussel or taste and odour control. Other processes such as biological filters and contactors can significantly affect membrane cleaning requirements and life. Many of these processes are difficult to pilot accurately. The Designer should consider the applicability and reliability of pilot results and consider placing these processes downstream in the treatment train where possible.

8.4.2 Number and Redundancy

Since most membranes are modular in nature, redundancy should be provided such that any component failure critical to continued operation should have a means for back-up, replacement or repair in sufficient time so as not to interrupt the system water supply demand. The following considerations may be incorporated into the design:

- .1 A minimum of two trains with 100% capacity each. Alternatively, isolatable membrane modules to be provided;
- .2 A minimum of one redundant feed, suction, and cleaning pumps (installed or shelf spare) is provided;
- .3 When determining the total amount of membrane area and number of membrane trains to meet system demands, the effect of the following should be considered:
  - a. Membrane age;
  - b. Irreversible fouling;
  - c. Reduction in membrane area due to fibre plugging/repairs;
  - d. Low temperature;
  - e. Train out of service;
  - f. Changes in source water quality;
- .4 When a train is off-line for cleaning, the remaining trains will need to be capable of operating at a higher flux rate for the duration of the cleaning cycle in order to meet system demands. Where possible, this should be avoided as operating at high flux rates may significantly accelerate deterioration of the membrane performance. The need for redundant trains and equipment should also be considered when selecting the number and size of trains;
- .5 Provision for future expansion should be considered in the anticipation of population growth;
- .6 Automated monitoring and control systems should be provided with back-up power and operational control systems consisting of the following:
  - a. Dual running PLCs with synchronized programs and memory, or spare PLCs loaded with the most current program;
  - b. Spare input/output (I/O) cards of each type;
  - c. A minimum of two human machine interfaces (HMI); and
  - d. Backup power.

8.4.3 Membrane Configurations

Membrane systems come with a wide variety of configurations depending on membrane type and material, and mode of filtration. This section only provides a general overview of the commonly used membrane systems in drinking water applications. The Designer is responsible for ensuring that the selected membrane system meets the design and manufacturer’s operating requirements for the particular application.

Membranes come in different shapes and geometries which include, but are not limited to: hollow fibre, multi-bore fibre, tubular, flat sheet, and spiral-wound. Hollow-fibre and tubular membranes are the most commonly used type in MF/UF drinking water treatment applications, with tubular membranes being more common in small systems due to its low packing density and niche on tolerance of high cross-flow velocity (MWH, 2005). Flat sheet membranes in a spiral-wound configuration are most commonly used for NF and RO drinking water treatment applications.

A membrane system is further defined by the direction of filtration through the membrane, as follows:

.1 **Dead-end:** In dead-end filtration, the feed stream is directed toward and perpendicular to the membrane surface, as such water is filtered in the same direction as the feed.
   - This often results in a greater solids accumulation during the filter run and lower average flux values, when compared to that achieved in crossflow filtration; and

.2 **Crossflow**: In crossflow filtration, the feed stream is directed parallel to the membrane surface, and water is filtered in a perpendicular direction from the feed.

Each of the above membrane types can be bundled into a several membrane modules to meet the desired demand. The membrane modules are typically configured into two systems and Table 8-2 provides a comparison of the two systems.

.1 Low Pressurized Filtration System:
   a. Low pressure membrane systems use pressurized vessels to house the membrane, such that a positive pressure is applied to the feed side of the membrane to provide the driving force for the liquid to permeate through the membrane. External membranes can have either an “inside-out” or “outside-in” flow path. “Inside-out” means the feed water is conveyed into the centre of the membrane (lumen) and is filtered through the membrane surface on the channel inside diameter (ID), whereas outside-in has the feed water conveyed to the outside of a membrane fibre with filtrate passing through the membrane surface on the fibre outside diameter (OD); and

.2 Submerged Filtration System:
   a. Submerged membrane systems combine both the raw feed and membrane modules in one tank with an outside-in flow path. A negative pressure or suction is applied to the permeate side of the membrane to provide the driving force for the liquid to permeate through the membrane.

Table 8-2 Low Pressurized Filtration Compared to Submerged Filtration

Parameters	Low Pressurized Filtration Systems	Submerged Filtration Systems
Pressure	Upstream positive pressure pump (HGL)	Downstream pump (suction)
Flow configuration	Typically, dead-end	Typically, crossflow, leading to less fouling and less backwashing
Footprint	Slab on grade skids	In-slab tanks

8.4.4 Membrane Materials

Membranes can be made from either organic polymers or inorganic materials. Material selection depends on the type of membrane, quality of water and the desired finished water quality. Properties of various membrane materials are provided in Table 8-3.

Table 8-3 Properties of Various Membrane Materials

Material	pH Range	Tolerance to Chlorine (mg/L)	Maximum Temperature (°C)
Cellulose acetate [1]	3 to 6	~1	180
Polyamide [1]	2 to 12	<0.1	80
Polysulfone [1]	1 to 13	~100	150
Polyvinylidene fluoride [1] (PVDF)	2 to 10	>100	75
Aluminum oxide [2], SiC, TiO_2 (ceramic)	0 to 14	>100	>100

Note: [1] Organic; [2] inorganic

While organic membranes are more commonly used in water treatment, inorganic membranes resist compaction, high temperature, and extreme pH values and can operate under a broad range of temperatures. The major drawback of inorganic membranes is their high density and cost.

Membranes can consist of hydrophilic or hydrophobic materials (AWWA, 1992), which can have an effect on fouling; material selection should be considered with the type of feed water.

8.4.5 Rates of Filtration

The design flow rate per membrane train is a function of the total membrane surface area in the module and the flux rate selected. In determining the design flow rate, the Designer should consider:

- the loss of feed water used for backwashing and chemical cleaning;
- the lost production while a unit or train is out of service for chemical cleaning; and,
- the filtration flux (which is governed by the transmembrane pressure (TMP), fouling mechanism of the membrane, as well as its surface area).

The Designer should sufficiently size the membrane system to consider the above factors and meet the desired output. The flux rate should be selected in consultation with the membrane manufacturer and the characteristics of the source water being treated in order to achieve operation at a stable flux rate. Optimum flux rates should be selected based on pilot results considering the required design production rates with both cold and warm water. Cold water can significantly reduce the flux rate of a membrane system; hence the seasonal demands should be carefully evaluated.

Table 8-4 presents typical operating conditions of membrane systems. As the presented parameters are highly application specific, unique operating conditions should be developed through pilot testing and consultation with the manufacturer.

Table 8-4: Typical Design Criteria (sourced from Atlantic Canada)

Design Parameter	Microfiltration	Ultrafiltration	Nanofiltration	Reverse Osmosis
Flux rate (L/m^2/h)	34-170	34-170	14-34	10-34
Transmembrane pressure, TMP (kPa)	20-600	30-700	310-1,000	2,000-10,000
Recovery	90-98%	85-95%	60-75%	50-60%
Temperature range (°C)	0-35	0-35	0-35	20-35
Cleaning frequency (days)	14-90	14-90	14-180	30-360

Recovery is defined as:

$$Recovery = \frac{net\ filtrate\ production}{total\ feed} \times 100\%$$

Where net filtrate production is total filtrate production less the filtrate used for backwashing and discharged as filter-to-waste.

Membrane cleaning for reversible fouling is typically achieved through frequent backwashing and routine recovery chemical cleaning. The frequency of cleaning is highly dependent on the feed water type, filtration flux, as well as proprietary aspects of the chosen membranes. Backwashing typically occurs 1 to 4 times per hour to maintain a sustainable flux up to a certain TMP. When TMP becomes too high to maintain, recovery chemical cleaning is conducted to restore membrane permeability. The typical frequency for chemical cleaning is provided in Table 8-4. Removal rating refers to the molecule cut-off size that a membrane can reject, typically represented in microns and/or molecular weight in Daltons (Da). Refer to Section 8.4.8 – Backwash and Chemical Cleaning for further discussion on cleaning.

8.4.6 Integrity Testing

Membrane systems should be designed with a means to directly measure membrane integrity to validate the filtration efficacy (i.e. confirming the extent of membrane tears or holes remain below certain threshold to satisfy the prescribed treatment credits). Integrity testing is a requirement if the membrane process is to be considered for pathogen log reduction credits (refer to the *Guidelines for Pathogen Log Reduction Credit Assignment*). An integrity testing program should be developed in accordance with the latest edition of the USEPA's *Membrane Filtration Guidance Manual* or the guidance set out in *ANSI/NSF Standard 419 – Public Drinking Water Equipment Performance - Filtration*.

There are two basic types of integrity testing:

.1 Continuous indirect integrity testing:
   a. Indirect integrity testing methods using water quality parameters such as turbidity, particle counts, DOC and/or conductivity should be routinely performed and should be on-line where possible. A filter-to-waste option should be considered in the event of a membrane integrity breach. An alarm should be provided with

continuous indirect integrity testing; and

.2 Periodic direct integrity testing:

a. Direct integrity tests are typically conducted through a pressure decay test, vacuum hold, bubble point, marker solution or sonic testing.
   i. NF/RO is typically used for solids reduction, not for pathogen removal; as such, direct integrity testing is not normally provided. In the absence of direct integrity testing for NF/RO membranes, molecular markers such as Rhodamine WT or dyes may be considered with justification.

b. The required frequency of direct integrity testing will depend on the quality of the influent raw water and the robustness of the membranes. In any case, a direct integrity test should be conducted immediately following a clean-in-place (CIP) to ensure none of the fibers or seals were damaged by the cleaning solutions.

The direct integrity test upper control limit must be identified in the integrity testing program. If the upper control limit is exceeded, the direct integrity test will be reported as “failed” and the affected unit must be removed from service for further diagnostics and repairs. The plant operation manual should indicate how operators will be notified of a failed direct integrity test, how the test results data are to be saved, and any automatic shutdown procedures resulting from the failed test.

8.4.7 Filter-to-Waste Provisions

Depending on the membrane technology used, a means to filter-to-waste may be required for on-line testing during production in the event of a membrane integrity breach. Refer to Section 8.2.3 – Filter-to-Waste Provisions for general design considerations.

8.4.8 Backwash and Chemical Cleaning

The Designer should consider that chemical cleaning of membranes is required at regular intervals to slow the deterioration of available flux due to permanent fouling. Failure to apply cleaning chemicals in an optimal manner can lead to rapidly declining membrane performance and a need for early membrane replacement. Backwashing (back-pulsing) and chemical cleaning frequencies, durations and procedures should be obtained from the membrane manufacturer, based on pilot study data or similar application data.

Chemical cleaning, also known as clean-in-place (CIP), is a cleaning process in which membranes in a water treatment system are not removed from their housings (pressure vessels) or the system and are cleaned by being exposed to cleaning solutions. This is typically done using a pre-defined soaking period to dissolve the foulant rather than recirculating the cleaning solution through the cleaning system and membranes. Membrane cleaning chemicals may be highly aggressive and excessive cleaning may shorten effective membrane life. The membrane manufacturer should provide appropriate cleaning instructions to balance performance, degradation and the costs of cleaning for each specific installation.

The Designer should consider the following while designing backwash and chemical cleaning systems:

.1 The objective of the chemical cleaning process should be to restore the membrane performance to the same flux at the same transmembrane pressure (TMP) and temperature as the original design;
.2 To ensure a successful cleaning operation, cleaning chemicals should be matched to the nature of site-specific foulants and membrane material limitations.
.3 Cleaning chemicals should be NSF/ANSI Standard 60 certified;
.4 The ability to soften/demineralize and heat the water used to make up membrane cleaning solutions should be provided where required;
.5 The membrane treatment system and chemical cleaning processes should be separated using a double block and bleed arrangement. Care should be taken in the cleaning process to prevent contamination of both the raw and finished water system.
.6 Chemical cleaning systems should be designed to allow easy draining and flushing between uses to avoid cleaning solutions from being in contact with the piping systems for long periods of time;
.7 Chemical cleaning equipment should be located as close as possible to the membrane units;
.8 Provision for neutralization should be included for the spent cleaning chemicals for the membrane system. Chemical waste neutralization can be conducted in-situ or in a dedicated tank, depending on the application; and
.9 A means to flush the system to waste following chemical cleaning should be provided to prevent contamination of finished water.

8.4.9 Monitoring Equipment

8.4.9.1 *Flow Metering Systems*

Flow meters should be provided to directly or indirectly continuously monitor:

.1 The main raw water supply line (or individual train raw water supply lines) to measure the feedwater volume entering the membrane system and for flow pacing of any pre-treatment chemicals;
.2 Individual permeate lines from each membrane train to measure the filtration rate and volume of each train, and pace post disinfection chemicals;
.3 Individual reject or concentrate lines from each train to measure the flow rate and volume of waste stream water for calculating the overall recovery rate of the train;
.4 Individual backwash lines (or use of the permeate flow meters) to measure the backwash flow rate and volume;
.5 The combined filter effluent line and/or the distribution main header leaving the plant;
.6 Dosing of pre-treatment chemicals; and
.7 Total raw and filtrate flow for determination of system/unit production rate and recovery.

8.4.9.2 *On-line Metering*

The Designer should consider the following while designing on-line metering:

.1 An on-line turbidimeter should be provided on the common feed water line to the membrane trains;
.2 The filtrate from each membrane unit (synonymous with “train”, “skid”, and “rack”) should be independently monitored on a continuous basis when operating. On-line turbidimeter instruments should therefore be provided on the permeate discharge from each membrane train;

.3 The provision of particle counters may be considered on a per train basis. Sample point connections should be provided at each rack or cassette for connection of a portable particle counter to aid in troubleshooting in the event of a fibre breakage; and

.4 Provisions should be made for pH and chlorine residual measurement, either on-line or at convenient sample points, on each membrane CIP tank to monitor the cleaning solution concentrations. When protein fouling from biofilm on the membrane requires the use of protease enzyme solutions, strength measuring techniques, as recommended by the manufacturer, should be applied.

8.4.9.3 *Other Monitoring Systems*

Additional considerations for other monitoring systems include:

.1 Pressure gauges and transmitters should be provided on each membrane train to measure transmembrane pressures for monitoring the rate of fouling and to initiate chemical cleaning, and backpulse pressures to avoid over pressurization and damage to the membrane fibres; and

.2 Direct integrity testing results should be continuously monitored and recorded.

8.4.9.4 *Alarms*

Systems should be provided with alarms, communication systems, and automatic shutdown processes. At a minimum, the following alarms should be provided:

.1 High raw and filtrate turbidity;
.2 Pump failure;
.3 Direct integrity test failure (upper control limit exceedance);
.4 High TMP;
.5 Program Logic Controller (PLC) failure;
.6 Membrane unit shutdown;
.7 Clear well level high and low;
.8 Equipment failure;
.9 High and low chlorine residual;
.10 Low chemical level;
.11 Power failure; and
.12 Building low temperature.

8.4.10 Ancillary Equipment

The Designer should specify or ensure that the membrane manufacturer contractual commitment includes the following ancillary equipment:

8.4.10.1 *Feed Water or Permeate Pumps, Blowers & Compressors*

Where pumps, air blowers and compressors are employed, the number of duty pumps, air blowers and compressors required will depend on the number of process trains selected and the anticipated range of flows. A standby unit should be available for any process train in the event one of the duty units is out of service for maintenance or repair. For small systems with adequate storage, the use of “shelf-spares” in place of standby units may be considered acceptable. The Designer should also consider the efficiency of pumping and blower equipment, as these are energy intensive processes and operation may be continuous or semi-continuous.

8.4.10.2 *Isolation Valves & Unions*

The size of the individual modules is such that it is often impractical to isolate individual membrane modules. Instead, isolation valves are to be provided to isolate individual trains and membrane assemblies, or subsections of the membrane assemblies.

8.4.10.3 *Piping and Automated Valves*

Some membrane systems operate over a wide range of pressures and have a significant number of automated valves. Select piping materials, restraints, and actuator speed controls suitable for the intended materials, service and to prevent water hammer. The Designer should ensure that the valves and piping are suitable for a wet and chlorine-heavy environment. Valves and actuators should be suitable for multi-cycle operation rather than modulation/shut-off only, where required.

8.4.10.4 *Chemical Feed Systems*

Chemical feed systems should have standby pumping units. Refer to Chapter 13 – Chemical Application for the storage and safe handling of chemicals. The Designer should also consult the manufacturer regarding the design of HVAC systems, the provision of means for access to, removal of and repair of membrane modules, valves and instrumentation.

8.4.11 Cross Connection Control

Cross connection control considerations should be incorporated into the system design, particularly with regard to chemical feeds and the waste piping used for membrane cleaning (particularly clean-in-place), the waste stream and concentrate. Refer to Section 5.8 – Cross Connections and Backflow Prevention for backflow prevention options and resources.

8.4.12 Residuals

The Ministry of Environment and Climate Change Strategy should be consulted, as early as possible, when considering the use of membrane technologies, to determine environmentally acceptable options for disposal of waste streams from both pilot scale and full-scale membrane plants. Neutralization of the cleaning solutions should be provided, either directly in the process tank where the CIP has taken place, or the solutions should be transferred into a holding tank to ensure sufficient time for neutralization and monitoring prior to disposal. Refer to Chapter 14 – Waste Residuals Handling and Treatment for reference to residuals handling.

8.5 Biological Filtration

Biological treatment within a filter (i.e. a biofilter) at a drinking water treatment facility is an operational practice of managing, maintaining, and promoting biological activity on granular media in the filter to enhance the removal of organic and inorganic constituents before treated water is introduced into the distribution system. This section is specific to aerobic biofiltration. Anaerobic/anoxic biofiltration is not widely used in B.C., however, it may be used for specific dissolved contaminants including nitrate, perchlorate, selenite, chromate and VOCs. Aerobic biofiltration is typically used for the removal of iron, manganese or ammonia. Refer to the *Ten States Standards* for further details (policy statements) on anoxic biofiltration and biofiltration for groundwater.

Typical objectives of biofiltration include the following:

.1 Reduction of specific inorganic contaminants and/or natural organic matter;
.2 Increased disinfectant stability;
.3 Taste and odour (T&O) control;
.4 Reduction of substrates for microbial regrowth in the distribution system; and
.5 Control of disinfection by-product (DBP) precursors.

Naturally occurring biomass is allowed to accumulate by limiting or eliminating the pre-disinfectant residual, most commonly chlorine, in the filter influent or in the backwash water. For biological degradation of organics and inorganics to take place in aerobic biofilters, there needs to be sufficient oxygen in the filter influent to maintain the biomass. Design of biologically active filters should ensure that aerobic conditions are maintained at all times. Bio-filters that are taken off-line or put in standby can turn anoxic leading to water quality and taste & odour issues.

Biological filtration may include the use of ozone as a pre-oxidant to break down more complex organic matter into biodegradable organic matter. If ozone is placed upstream of a granular media filter, some recalcitrant organics may be degraded to more readily biodegradable compounds. Additionally, the dissolved oxygen concentration in the filter influent will be elevated. Typically, any filter downstream of ozonation will be an aerobic biological filter.

It is important to note that biological activity within a filter can have adverse effects on turbidity and microbial pathogen removal, head loss development, filter run times and distribution system corrosion. To mitigate these effects, consideration should be given to providing regular and frequent backwashing cycles as described in Section 8.5.6 – Backwash.

Biofiltration uses media to provide surface area onto which bacteria can adhere and grow. Common media includes sand, anthracite, granular activated carbon (GAC) and expanded clay. GAC media may be used to support denser biofilms due to its high surface area and tends to provide greater biological activity than sand or anthracite in cold water application. In very cold water conditions (< 5 °C) the metabolic rate and biological activity can slow to very low rates.

8.5.1 Filter Design

Biofilters are typically rapid rate gravity filters in surface water treatment plants where the primary objective is particle control. In such filters, biological treatment is always the secondary objective. Design criteria presented in Section 8.2 – Rapid Rate Gravity Filtration for rapid rate gravity filters should be applied with consideration for filtration rate, media type and depth to support the biological activity and particle capture. Pressure filtration should not be used for biological filtration, except where biological filtration is targeting specific contaminants for removal (e.g. iron, manganese).

8.5.2 Empty Bed Contact Time

Constituent removal is strongly impacted by the length of time that the water is in contact with the microbial community in the filter. Empty bed contact time (EBCT) is defined as the volume of the filter bed occupied by the media (including porosity volume) divided by the flow rate. Empty bed contact time should be determined by a pilot study based on treatment objectives. Filter media depths greater than 760 mm may be allowed if supported by the results of a pilot study. A longer empty bed contact time may be required when the water is cold (e.g. less than 15 °C). Empty bed contact times typically range between 5 and 20 minutes.

8.5.3 Media Selection

Sand, anthracite, and granular activated carbon (GAC) can be used as filter media for aerobic biofiltration. Granular activated carbon media is commonly used due its large surface area to volume ratio. Use of media with an effective size of less than 0.45 mm should be avoided.

8.5.4 Filter Bottoms and Strainer Systems

Filter bottoms with small openings may be prone to clogging. Porous plate bottoms should not be allowed. Evidence that the proposed filter bottom has successfully been used in the past with biofilters or pilot testing of the proposed underdrain may be required. Section 8.2.9 – Filter Underdrains and Strainer Systems also applies for biological filtration.

8.5.5 Pre-treatment

Pre-treatment prior to biofiltration such as coagulation, clarification, filtration or water pre-conditioning should take into consideration the effect on the downstream biofilter performance.

Chemical addition (such as ozone or peroxide) upstream of a rapid rate filter may promote biological activity on the granular filter media and increase the dissolved oxygen concentration; however, sufficient mixing and reaction time should be provided to avoid adverse effects on the microorganisms. Additional chemicals may be added to promote biological oxidation, biological activity, or reduce head loss. Refer to Chapter 7 – Pre-sedimentation, Coagulation, Flocculation and Clarification for design considerations.

If performance of the biofilter is not meeting desired goals, testing for a DO, ORP or micronutrient limitation should be conducted. DO, pH and micronutrient dosing may be applied to achieve optimum conditions for biofiltration (i.e. phosphoric acid for phosphorus, ammonia for nitrogen, etc.). If head loss is significant, a low dose of a pre-oxidant should be considered. Designers may refer to *Biofiltration Guidance Manual for Drinking Water Facilities* by the Water Research Foundation for more information.

8.5.6 Backwash

Backwashing design should follow Sections 8.2.12 – Backwash and Section 8.2.13 – Air Scouring, and include the following:

- .1 The ability to add chlorine or other approved chemicals to the backwash;
- .2 Backwash air scour system;
- .3 Filter-to-waste piping; and
- .4 Backwash waste residuals management.

The particular backwash strategies can have a significant effect on the performance of a biofilter. Combined air and water backwash is often used to provide sufficient scouring energy to detach excess biomass from the media surface, while sub-fluidization has been used to shorten the filter ripening time after backwash. Non-chlorinated backwash water is usually needed to preserve high levels of biological activity after backwashing. Filter effluent may have decreased biological stability (i.e. increased heterotrophic plate counts) and may require treatment.

8.5.7 Monitoring and Control

In addition to the laboratory equipment listed in Section 5.4 – Monitoring Equipment and Laboratory Facilities, test equipment for the following parameters should be provided for online measurements:

.1 Dissolved oxygen concentration at the influent and effluent of the filter;
.2 Oxidation-reduction potential; and
.3 Temperature.

Test equipment for the following parameters can be provided for offline measurements:

.1 Biological indicator organisms (total coliform, heterotrophic plate count, etc.);
.2 The contaminant targeted for biological treatment; and
.3 Additional parameters as required.

Biofiltration and the associated pre- and post-treatment and residuals treatment may require advanced operator skill and training. Consideration should be made for the EOCP classification of the water treatment plant design and the resulting Operator certification that will be required.

8.6 Diatomaceous Earth Filtration

The use of diatomaceous earth filters may be considered for application to surface waters with low turbidity and low bacterial contamination. The Designer should refer to the *AWWA Manual of Water Supply Practices M30 – Precoat Filtration* and the *Guidelines for Pathogen Log Reduction Credit Assignment* for more information on the design and pathogen log reduction credit assignment criteria for diatomaceous earth filtration processes.

8.6.1 Conditions of Use

Diatomaceous earth filters should not be used for the following conditions:

.1 Colour removal for high total colour exceeding 5 TCU;
.2 Turbidity removal where either the gross quantity of turbidity is high (exceeds 5 NTU), or the turbidity exhibits poor filterability characteristics; and
.3 Filtration of waters with high algae counts.

8.6.2 Types of Filters

Pressure or vacuum diatomaceous earth filtration units will be considered for approval. However, the vacuum type is preferred as it permits observation of the filter surfaces: this allows the operator to determine whether there is proper cleaning, damage to a filter element, and adequate coating over the entire filter area.

8.6.3 Treated Water Storage

Treated water storage capacity in excess of normal requirements should be provided to:

.1 Allow operation of the filters at a uniform rate during all conditions of system demand at or below the approved filtration rate, and;

.2 Guarantee continuity of service during adverse raw water quality conditions without by-passing the system.

8.6.4 Number of Units

At least two units should be provided. Where only two units are provided, each unit should be capable of meeting the plant design capacity (normally the projected maximum daily demand) at the approved filtration rate. Where more than two filter units are provided, the filters should be capable of meeting the plant design capacity at the approved filtration rate with the largest filter removed from service.

8.6.5 Pre-coat

.1 Application - A uniform pre-coat should be applied hydraulically to each septum by introducing a slurry to the tank influent line and employing a filter-to-waste or recirculation system; and

.2 Quantity - Pre-coat should use 0.98 kg diatomaceous earth/m^2 of filter area, or an amount sufficient to apply a 3.175 mm-thick coating.

8.6.6 Body Feed

A body feed system to apply additional amounts of diatomaceous earth slurry during the filter run is required to avoid short filter runs or excessive head losses.

.1 Quantity - The rate of body feed is dependent on raw water quality and characteristics, and should be determined in the pilot plant study;

.2 Operation and maintenance can be simplified by providing accessibility to the feed system and slurry lines; and

.3 Continuous mixing of the body feed slurry is required.

8.6.7 Filtration

.1 Rate of filtration - The recommended nominal rate is 2.4 m/h, with a recommended maximum of 3.7 m/h; however, filtration rates should be confirmed through pilot testing. The filtration rate should be controlled by a positive means;

.2 Head loss - The head loss should not exceed 210 kPa (30.5 psi) for pressure diatomaceous earth filters, or a vacuum of 38.1 cm of mercury (-51 kPa or -7.4 psi) for a vacuum system;

.3 Recirculation - A recirculation or holding pump should be employed to maintain differential pressure across the filter when the unit is not in operation in order to prevent the filter cake from dropping off the filter elements. A minimum recirculation rate of 0.24 m/h should be provided;

.4 Septum or filter element - Filter elements should be structurally capable of withstanding maximum pressure and velocity variations during filtration and backwash cycles and should be spaced such that no less than 2.5 cm is provided between elements or between any element and a wall; and

.5 Inlet design - The filter influent should be designed to prevent scour of diatomaceous earth from the filter element.

8.6.8 Backwash

A satisfactory method to thoroughly remove and dispose of spent filter cake should be provided.

8.6.9 Appurtenances

The following should be provided for every filter:

.1 Sampling taps for raw and filtered water;
.2 Loss of head or differential pressure gauge;
.3 Rate-of-flow indicator, preferably with totalizer;
.4 A throttling valve used to reduce flow rates below normal during adverse raw water quality conditions;
.5 Evaluation of the need for body feed, recirculation, and any other pumps, in accordance with Chapter 18 – Pumping Facilities;
.6 Provisions for filtering to waste with appropriate measures for backflow prevention, refer to Section 5.8 – Cross Connections and Backflow Prevention; and
.7 A continuously monitoring turbidimeter with recording on each filter effluent, as required for the assignment of pathogen log reduction credit.

It is recommended that the following be provided:

.1 A 2.54 - 3.81 cm diameter pressure hose and storage rack at the operating floor for washing the filter;
.2 Access to particle counting equipment as a means to enhance monitoring and overall treatment operations; and,
.3 A flow rate controller capable of providing gradual rate increases when placing the filters back into operation.

8.7 Cartridge and Bag Filtration

Cartridge filtration is a pressure-driven physical separation process that removes particles greater than 1 µm using a porous filtration medium. Cartridge filters are typically made of a semi-rigid or rigid wound filament that is housed in a pressure vessel in which water flows from the outside of the cartridge to the inside. Cartridge filtration systems can be constructed with either single or multiple filters within one pressure vessel.

Cartridge filtration is ideally suited for small drinking water systems with low flow requirements. The use of cartridge filters should be limited to source water (or pre-treated influent) having a maximum turbidity of 5 NTU and maximum colour of 5 TCU. To reduce the frequency of filter replacement, cartridge filters are typically used in series with decreasing pore sizes.

When using cartridge filters of appropriate pore size, these filters can effectively remove particles from water in the size range of *Cryptosporidium* oocysts (2-5 microns) and *Giardia* cysts (5-10 microns). Cartridge filters with a rating of ‘1 micron absolute’ may be eligible for pathogen log reduction credits; refer to the *Guidelines for Pathogen Log Reduction Credit Assignment* for more details.

It should be noted that the particulate loading capacity of these filters is low, and once expended, the cartridge filter should be discarded and replaced. With this in mind, the operational and maintenance cost of cartridge replacement should be considered during system design.

Cartridge filters can be supplied with media for removal of specific water quality parameters, such as activated carbon for taste and odour control, or oxidizing/catalytic media for iron, manganese or hydrogen sulphide removal.

Bag filters are typically constructed of a woven bag or fabric filtration medium that is placed in a pressure vessel. As water flows from the inside of the bag to the outside, contaminants are filtered out of the water. Bag filters are not eligible for pathogen log reduction credits but may be used as pre-treatment for other unit processes.

Refer to the latest edition of the USEPA's *LT2ESWTR Toolbox Guidance Manual* for system design and operation.

8.7.1 Design Guidelines

The following items should be considered in evaluating the applicability of cartridge filtration:

.1 The filter housing and cartridge filter should demonstrate a filter efficiency of at least 3-log reduction in *Cryptosporidium* or surrogate particles size 1 micron and above. Demonstration of higher log removals may be required depending on raw water quality and other treatment steps to be employed. Recommended methods for filtration efficiency demonstration include:

  a. *Cryptosporidium* removal evaluation in accordance with the procedures specified in NSF/ANSI Standard 53 *Drinking Water Treatment Units – Health Effects* or equivalent. These evaluations should be conducted by NSF or by another third-party organization that is accredited to certify equipment to NSF/ANSI Standard 53 in Canada;
  b. The *Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants* procedure specified by the EPA/NSF Environmental Technology Verification Program;
  c. The challenge testing procedure for cartridge filters presented in Chapter 8 of the *Long Term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual*;
  d. "Non-consensus" live *Cryptosporidium* challenge studies that have been designed and carried out by a third-party agent recognized for interim evaluations. At the present time uniform protocol procedures for live *Cryptosporidium* challenge studies have not been established;

.2 The design flow should be determined in consultation with the manufacturer specifications and confirmed with pilot testing;

.3 Pilot testing may be required with a full-scale filter element at the design maximum flux, and should be set up to provide an assurance of practical filter element life;

.4 System components coming into contact with water, such as filter housing, bags, cartridges, membranes, gaskets, and O-rings, should be certified to *NSF Standard 61 Drinking Water System Components – Health Effects* or equivalent;

.5 The flow rate through the treatment process should be monitored with a flow valve and meter. The flow rate through bag/cartridge filters should not exceed the maximum flow rate verified by filtration efficiency testing;

.6 Pressure gauges and sampling taps should be installed before and after the bag or cartridge filter. The pressure differential across the cartridge filter should not exceed the manufacturer's rating;

.7 An automatic air release valve should be installed on top of the filter housing;

.8 Frequent start and stop operation of the bag or cartridge filter should be avoided. To avoid this frequent start and stop cycle the following options are recommended:
   a. A slow opening and closing valve ahead of the filter to reduce flow surges;
   b. Reduce the flow through bag or cartridge filters to as low as possible to lengthen filter run times;
   c. Install a recirculating pump that pumps treated water back to a point ahead of the bag or cartridge filter. Care should be taken to make sure there is no cross connection between finished water and raw water;

.9 A minimum of two bag or cartridge filter housings should be provided for water systems that provide water continuously. Each of the housings should be able to provide the full rated flow of the water treatment plant;

.10 A pressure relief valve should be incorporated into the bag or cartridge filter housing; and

.11 A plan of action should be in place should water quality parameters fail to meet GCDWQ or other applicable treated water standards.

8.7.1.1 Design of Pre-treatment for Cartridge and Bag Filtration Systems

Pre-treatment prior to cartridge or bag filtration is strongly recommended to extend cartridge life. Examples of pre-treatment include media filters, and larger pore cartridge/bag filters. The following should be considered when designing pre-treatment:

.1 The location of the raw water intake should be optimized to provide the best water quality, and may be moved to avoid the need for pre-treatment;

.2 Particle count analysis can be used to determine what level of pre-treatment should be provided. It should be noted that particulate counting is a 'snapshot' in time and that there can be seasonal variations such as algae blooms, lake turnover, spring runoff, and heavy rainfall events;

.3 Chlorine or another disinfectant may be added at the head of the treatment process to reduce/eliminate the growth of algae, bacteria, etc., on the filters. The impact on disinfection by-product formation should be considered;

.4 A filter-to-waste component is strongly recommended for pre-treatment pressure sand filters. At the beginning of each filter cycle and/or after every backwash of the pre-filters a set amount of water should be discharged to waste before water flows into the cartridge filter. Filter to waste should be provided for the final filter(s) and a set amount of water should be discharged to waste after changing the filters;

.5 If pressure media filters are used for pre-treatment, they should be designed according to Section 8.8 – Pressure Filtration;

.6 A sampling tap should be provided ahead of any treatment so a source water sample can be collected; and

.7 The filtration and backwash rates should be monitored so that the pre-filters are being optimally used.

8.7.2 Operations

The following operations criteria should be considered for cartridge and bag filters:

.1 Cartridge and bag filters should be replaced before the differential pressure exceeds the manufacturer’s rating. If unspecified by the manufacturer, 103 kPa (15 psi) should be considered as the maximum differential pressure. It should be noted that bag filters do not load linearly. Additional observation of the filter performance is required near the end of the filter run;

.2 Maintenance (O-ring replacement) should be performed in accordance with the manufacturer's recommendations;

.3 Sterile rubber gloves and a disposable face mask covering the nose and mouth should be worn when replacing or cleaning cartridge or bag filters; and

.4 Every time cartridge or bag filter vessels are opened for maintenance, the filter system should be properly disinfected, and the filter vessel water should be run to waste until disinfectant residual has been purged from the filter vessel.

8.8 Pressure Filtration

Pressure filtration is typically used in situations where an ion-selective media is used (e.g. iron and manganese removal systems) and for systems that do not require coagulation (due to the potential for floc breakup), see Chapter 15 – Parameter Specific Treatment. Pressure filtration is commonly used in small-scale applications for particle removal (as defined in Chapter 21 – Small Systems) and as a pre-treatment for nanofiltration and/or reverse osmosis filtration systems.

Pressure filtration units cannot receive pathogen log reduction credits in British Columbia and several other jurisdictions in Canada. They are generally unsuitable for filtration of surface waters, GARP, or other polluted waters. Noted issues with pressure filters include the potential for floc breakup after coagulation, the inability to observe backwash or media levels, and the loss of media during backwash.

8.8.1 Rate of Filtration

The filtration rate should not exceed 10 m/h except where pilot or full-scale testing has demonstrated satisfactory results at higher rates. Loading rates are specific to media and target contaminants.

8.8.2 Details of Design

Minimum criteria relative to the rate of filtration, structural details and hydraulics, filter media, etc., provided for rapid rate gravity filters (Section 8.2 – Rapid Rate Gravity Filtration) also apply to pressure filters where appropriate. However, detailed design criteria is often specific to media and target contaminants.

The following provides additional design considerations for pressure filtration systems:

.1 Loss of head gauges on the inlet and outlet pipes of each filter;

.2 An easily readable meter or flow indicator on each set of filters. A flow indicator is recommended for each filtering unit;

.3 Filtration and backwashing of each filter individually with an arrangement of piping as simple as possible to accomplish these purposes;

.4 Minimum side wall shell height of 1.5 m. Reduction of the inside wall height is acceptable where proprietary bottoms permit reduction of the gravel depth;

.5 The top of the backwash water collectors should be at least 450 mm above the surface of the media;

.6 The underdrain system should efficiently collect the filtered water and uniformly distribute the backwash water at a rate of not less than 37 m/h;

.7 Backwash flow indicators and controls that are easily readable while operating control valves;

.8 An air release valve on the highest point of each filter;

.9 An accessible manhole of adequate size to facilitate inspection and repairs for filters 900 mm or more in diameter. Sufficient handholds should be provided for filters less than 900 mm in diameter. Manholes should be at least 600 mm in diameter where feasible;

.10 Means to observe the wastewater during backwashing; and

.11 Construction to prevent cross connection.

9 Aeration

9.1 General

This chapter describes design considerations for aeration treatment processes which remove contaminants in water by transferring gas to the water or by vaporizing the contaminants. The selection of a particular aeration treatment technology and/or technology train will depend on an evaluation of the nature and quality of the water to be treated, seasonal variations in raw water quality, and the desired quality of the finished water.

Aeration is typically used in water treatment for two purposes. The first is for the transfer of a gas to water, such as in the pre-oxidation of raw water for iron and/or manganese removal. This process is known as gas absorption or aeration. The second is for vaporization of contaminants in water into an airstream, such as in the removal of hydrogen sulphide, carbon dioxide, as well as volatile organic compounds causing taste and odour in water. This process is typically known as gas desorption or air stripping.

Because aeration and air stripping are gas-liquid contact processes, the Designer should consider contaminant transfer efficiency, off-gas disposal issues, available hydraulic head, ease of operation, and capital and operating/maintenance costs during treatment evaluation.

This chapter provides guidance for the following aeration methods that are typically used in water treatment:

.1 Natural draft aeration;
.2 Forced or induced draft aeration;
.3 Spray aeration;
.4 Pressure aeration; and
.5 Packed tower aeration.

Other methods of aeration may be used if applicable to the treatment needs. Such methods include, but are not restricted to: diffused air, cascades, and mechanical aeration. The treatment processes should be designed to meet the particular needs of the water to be treated. These methods may require pilot testing to validate treatment.

Where practical, aeration should be applied ahead of treatment. When aeration is required at the end of treatment (such as in air stripping of trihalomethanes), filtration of the source air will be required to prevent contamination of treated water. The materials used in the construction of the aerator(s) should meet *NSF/ANSI Standard 61: Drinking Water System Components – Health Effects*.

In air stripping for methane, due to the relatively low solubility of methane in water, even a splash plate type aerator may provide sufficiently effective treatment. Appropriate ventilation should be provided to ensure that methane concentrations do not reach the Lower Explosive Limit (LEL).

Air stripping for hydrogen sulphide removal has specific limitations, as carbon dioxide is also stripped, leading to pH increases and the potential for scaling. Pilot testing should be conducted to ensure sulphide levels can be sufficiently reduced without causing scaling issues. If air stripping cannot be used, alternative chemical processes to reduce sulphide concentrations to inoffensive levels should be considered. The feasibility of aerators or air strippers should be evaluated through piloting.

9.2 Piloting Requirements

All aeration systems should be piloted to evaluate a variety of loading rates and air-to-water ratios at the peak contaminant concentration. Consideration needs to be given to removal efficiencies, oxidation rates or scaling due to incidental carbon dioxide stripping when multiple contaminants are present. Note that aeration effectiveness will depend on dissolved gases (mainly DO and CO_2), pH and temperature. Also, note that care should be applied with respect to the gas saturation levels in water that will be further treated by downstream processes. Super-saturation of gases can result in "air-binding" in downstream filters.

Piloting may not be required where sufficient past performance data demonstrates the feasibility of the process for a specific contaminant and at a similar concentration level.

9.3 Natural Draft Aeration

The design should provide:

- .1 Perforations in the distribution pan 5 mm to 12 mm in diameter, spaced 25 mm to 75 mm on centers to maintain a 150 mm water depth;
- .2 Distribution of water uniformly over the top tray; in some cases, these trays may be designed with a pebble type media to help distribute flow and/or promote precipitation of metals in raw water;
- .3 Discharge through a series of three or more trays with separation of trays not less than 305 mm;
- .4 Loading at a rate of 2.5 - 12.5 m/h depending on the application and as demonstrated by pilot testing;
- .5 Trays with slotted heavy wire (12 mm openings) mesh or perforated bottoms;
- .6 Construction of durable material resistant to the aggressiveness of the water and dissolved gases;
- .7 Protection from loss of spray water by wind carriage by enclosure with louvres sloped to the inside at an angle of approximately 45°;
- .8 Air intake protection with 24-mesh screen and cover, i.e. louvre or shroud, accessible for maintenance and inspection. Frost protection should be considered for cold climate applications; and
- .9 Provisions for continuous disinfection feed should be provided after aeration.

9.4 Forced or Induced Draft Aeration

Devices should be designed to:

- .1 Include a blower with a weatherproof motor in a tight housing and screened enclosure;
- .2 Ensure adequate counter current flow of air through the enclosed aerator column;
- .3 Exhaust air directly to the outside atmosphere;
- .4 Ensure air intake and outlet are protected with 24-mesh screen and cover, i.e. louvre or shroud, and are accessible for maintenance and inspection and should be down turned;
- .5 Introduce air free from noxious fumes, dust, and dirt;

.6 Allow easy access to the aerator for maintenance and inspection of the interior;
.7 Provide loading at a rate of 2.5 - 12.5 m/h depending on the application and as demonstrated by pilot testing;
.8 Ensure that the water outlet is adequately sealed to prevent unwarranted loss of air;
.9 Discharge through a series of five or more trays with separation of trays not less than 150 mm. Alternatively, air-water surface contact may be achieved with plastic media (packing), or spraying system (see Section 9.5 – Spray Aeration);
.10 Provide distribution of water uniformly over the top tray;
.11 Be of durable material resistant to the aggressiveness of the water and dissolved gases; and
.12 Provide for continuous disinfection feed after aeration.

9.5 Spray Aeration

The design should provide:

.1 A hydraulic head between 1.5 to 8 m;
.2 Nozzles, with the size, number, and spacing of the nozzles being dependent on the flow rate, space, and the amount of head available;
.3 Nozzle diameters in the range of 25 to 40 mm to minimize clogging and provide good air-water surface contact;
.4 An enclosed basin to contain the spray. Any openings for ventilation should be protected with 24-mesh screen and cover, i.e. louvre or shroud and be accessible for maintenance and inspection; and
.5 Continuous disinfection feed after aeration.

9.6 Pressure Aeration

Pressure aeration may be used for oxidation purposes only if a pilot plant study indicates the method is applicable. This process is not acceptable for removal of dissolved gases. Filters following pressure aeration should have adequate exhaust devices for release of air. Pressure aeration devices should be designed to:

.1 Give thorough mixing of compressed air with the water being treated; and
.2 Provide screened and filtered air, free of noxious fumes, dust, dirt and other contaminants.

9.7 Packed Tower Aeration

Packed tower aeration (PTA), also known as air stripping, involves passing water through a column of packing material while pumping air counter-currently up through the packing. PTA is used for the removal of volatile organic compounds, trihalomethanes, carbon dioxide, radon, as well as the control of methane and/or hydrogen sulphide in groundwater.

Generally, PTA is feasible for compounds with a Henry's Constant greater than 100 atm mol/mol at 12 °C, and not normally viable for removing compounds with a Henry's Constant less than 10. For values between 10 and 100, PTA may be feasible but should be evaluated using pilot studies. Values for Henry's Constant should be identified early in the design.

9.7.1 General Packed Tower Aeration Considerations

The following items should be considered when designing a PTA system:

.1 A sufficient number of access ports with a minimum diameter of 600 mm to facilitate inspection, media replacement, media cleaning, and maintenance of the interior;
.2 A method of cleaning the packing material when fouling occurs;
.3 Tower effluent collection and pumping wells constructed according to the recommendations for clearwells discussed in Chapter 17 – Water Storage;
.4 Provisions for extending the tower height without major reconstruction;
.5 An acceptable alternative supply of water during periods of maintenance and operation interruptions;
.6 Disinfection application points both ahead of and after the tower to control biological growth;
.7 Adequate contact time for disinfection after the water has passed through the tower and prior to the distribution system. Refer to Chapter 11 – Disinfection;
.8 Adequate packing support to allow free flow of water and to prevent deformation with deep packing heights;
.9 Standby power to allow operation of the blower and disinfectant feeder equipment during power failures;
.10 Adequate foundation to support the tower and lateral support to prevent overturning due to wind loading;
.11 Fencing and a locking gate to prevent vandalism;
.12 An access ladder with safety cage for inspection of the aerator including the exhaust port and de-mister;
.13 Electrical interconnection between blower, disinfectant feeder and well pump;
.14 The following environmental items should be considered:
  a. The applicant should contact local regulatory authorities to determine if permits are required for the air discharge; and
  b. Noise control facilities should be provided on PTA systems located in residential areas.

9.7.2 Process Design

.1 Process design for PTA involves the determination of Henry's Constant for the contaminant, the mass transfer coefficient, air pressure drop and stripping factor. Pilot plant testing may be required. The Designer should provide justification for the design parameters selected, including:
  a. height and diameter of unit;
  b. air to water ratio;
  c. packing depth; and
  d. surface loading rate.
.2 Water loading rates should be in the range from 37 to 73 m/h, however the pilot test should evaluate a variety of loading rates and air to water ratios at the peak contaminant concentration. Special consideration should be given to removal efficiencies when there are multiple contaminants.
.3 The tower should be designed to reduce contaminants below the maximum acceptable concentration (MAC) and to the lowest practical level;
.4 The ratio of the packing height to column diameter should be at least 7:1 for the pilot unit and at least 10:1 for the full-scale tower. The type and size of packing used in the full-scale unit should be the same as that used in the pilot test;
.5 The minimum volumetric air to water ratio at peak water flow should be 25:1 and the maximum should be 80:1;

.6 The design should consider potential fouling problems from calcium carbonate, iron precipitation and bacterial growth. Where fouling is expected or demonstrated by the pilot, it may be necessary to provide pre-treatment. Disinfection capability should be provided prior to and after PTA; and

.7 The effects of temperature should be considered since a drop-in water temperature can result in a drop in contaminant removal efficiency.

9.7.3 Materials of Construction

.1 The tower can be constructed of stainless steel, concrete, aluminum, fiberglass or plastic. Uncoated carbon steel is not recommended due to corrosion. Towers constructed of light-weight materials should be provided with adequate support to prevent damage from wind; and

.2 Packing materials should be resistant to the aggressiveness of the water, dissolved gases and cleaning materials, and should be suitable for contact with potable water.

9.7.4 Water Flow System

.1 Water should be distributed uniformly at the top of the tower using spray nozzles or orifice-type distributor trays that prevent short circuiting. For multi-point injection, one injection point for every 190 cm^2 of tower cross-sectional area is recommended;

.2 A mist eliminator should be provided above the water distributor system;

.3 A side wiper redistribution ring should be provided at least every 3 m in order to prevent water channeling along the tower wall and short circuiting;

.4 Sample taps should be provided in the influent and effluent piping;

.5 The effluent sump, if provided, should have easy access for cleaning purposes and be equipped with a drain valve. The drain should not be connected directly to any storm or sanitary sewer;

.6 A blow-off line should be provided in the effluent piping to allow for the discharge of water/chemicals used to clean the tower;

.7 The design should prevent freezing of the influent riser and effluent piping when the unit is not operating. If piping is buried, it should be maintained under positive pressure;

.8 The water flow to each tower should be metered;

.9 An overflow line should be provided which discharges 300 to 350 mm above a splash pad or drainage inlet. Proper drainage should be provided to prevent flooding of the area;

.10 Butterfly valves may be used in the water effluent line for better flow control, as well as to minimize air entrainment;

.11 Means should be provided to prevent flooding of the air blower; and

.12 The water influent pipe should be supported separately from the tower's main structural support.

9.7.5 Air Flow System

.1 The air intake and outlet vent should be protected with 24-mesh screen and cover, i.e. louvre or shroud, and be accessible for maintenance and inspection;

.2 The air inlet should be in a location protected from airborne contaminants;

.3 An air flow meter should be provided on the influent airline or an alternative method to determine the air flow should be provided;

.4 A positive air flow sensing device and a pressure gauge should be installed on the air influent line;
.5 The positive air flow sensing device should be a part of an automatic control system which will turn off the influent water if positive air flow is not detected. The pressure gauge will serve as an indicator of fouling build-up; and
.6 A backup motor for the blower or standby blower should be readily available.

9.8 Protection of Aerators

All aerators, except those discharging to the influent lines of surface water treatment plants, should be protected from contamination by birds, insects, wind borne debris, rainfall and water draining off the exterior of the aerator.

9.9 Groundwater Disinfection

Groundwater supplies exposed to the atmosphere by aeration should be disinfected. Disinfection should meet the guidelines set out in Chapter 11 – Disinfection and provincial treatment objectives.

9.10 Bypass

A bypass should be provided for all aeration units except those installed to comply with maximum contaminant levels. The use of a bypass should also be reviewed against the ability to operate the process train without the aeration unit.

9.11 Corrosion Control

The aggressiveness of the water after aeration should be determined and corrected by additional treatment, if necessary (see Chapter 12 – Internal Corrosion Control).

9.12 Monitoring

Equipment should be provided to test for DO, pH, and temperature to determine proper functioning of the aeration device. Equipment to test for iron, manganese, and carbon dioxide should also be considered where aeration is used for removal of these parameters.

9.13 Redundancy

Redundant equipment should be provided for units installed as per best practices.

10 Taste and Odour Control

10.1 General

This chapter describes design considerations for taste and odour control treatment processes. The selection of a particular taste and odour control treatment technology and/or technology train will depend on an evaluation of the nature and quality of the water to be treated, seasonal variations in raw water quality, and the desired quality of the finished water.

As taste and odour cannot be measured objectively, a maximum acceptable limit for drinking water has not been specified. However, taste and odour can often be a large source of customer complaints (Health Canada, 2005).

Taste and odour in surface water is often caused by the breakdown of organic material and/or the production of volatile organic compounds (specifically geosmin and 2-methylisoborneol, 2-MIB) by cyanobacteria (blue-green algae) and other microorganisms. Taste and odour in groundwater can often be attributed to hydrogen sulphide (H_2S, which is frequently characterized as a rotten-egg odour), reduced iron and manganese, and high total dissolved solids (TDS).

Taste and odour reduction and control can be accomplished at the source, in the treatment plant, and to a certain extent in the distribution system. Provisions should be made for the control of taste and odour at all treatment plants where needed. Chemicals should be added to ensure adequate contact time for effective and economical use of the chemicals. Where taste and odour problems are encountered, full scale and/or pilot plant studies should be considered to determine the best treatment process(es).

For taste and odour attributed to cyanobacteria, refer to Chapter 15 – Parameter Specific Treatment. Additionally, reference should be made to the *Guidelines for Canadian Drinking Water Quality: Guideline Technical Documents – Odour* (1979), and *Taste* (2005) by Health Canada.

For taste and odour attributed to high TDS, reverse osmosis is the recommended treatment approach. Refer to Chapter 8 – Filtration.

10.2 Common Treatment Options

The following section describes common treatment options that may be considered for treatment of the taste and odour problems.

10.2.1 Powdered Activated Carbon

Use of powdered activated carbon (PAC, activated carbon with mean particle size of 20-50 µm) can be considered for taste and odour control, particularly for organics including geosmin and MIB. PAC is used as a continuously fed additive that must be removed following the required contact time, but before primary disinfection, by processes such as filtration. Reference to *AWWA B600 – Powdered Activated Carbon* should be made for design of PAC systems.

The following should be considered when designing PAC systems:

.1 PAC should be added as early as possible in the treatment process to provide maximum contact time. Flexibility to allow the addition of carbon at several points is preferred;
.2 PAC should not be applied near the point of chlorine or another oxidant application;
.3 PAC can be added as a pre-mixed slurry or by means of a dry-feed machine as long as the carbon is thoroughly wetted before its introduction to the water to be treated;
.4 Continuous agitation or resuspension equipment should be provided to keep the PAC from depositing in the slurry storage tank;
.5 The required rate of feed of carbon in a water treatment plant depends upon the tastes and/or odours involved and the contact time available, but provision should be made for adding from 0.1 mg/L to 40 mg/L;
.6 Pilot scale testing is recommended to determine contact time and the range of dosages required;
.7 PAC should be considered potentially combustible material and should be stored in a separate fire-retardant building or room, equipped with explosion proof outlets, lights and motors; and
.8 Provision should be made for adequate dust control.

10.2.2 Granular Activated Carbon

Granular activated carbon (GAC or activated carbon with mean particle size of 0.5 - 3.0 mm), like PAC, is also a common taste and odour control measure for organics (including geosmin and MIB). However, its application differs from PAC:

.1 GAC can be used in place of anthracite in granular filters (see Chapter 8 – Filtration) or in separate contactors;
.2 When GAC is used as a layer in filters, the GAC cannot be removed from service or by-passed during periods when tastes and odours are not a problem. This potentially shortens the life of the GAC for taste and odour control as other compounds are adsorbed onto the active sites on the carbon. GAC contactors, however, can be bypassed in winter months to extend the effective bed life;
.3 The empty bed contact time (EBCT) required for taste and odour control depends on the nature of the taste and odour compounds and typically varies from 10 to 30 minutes. Pilot testing is recommended to determine EBCT and expected bed operation life. Where the contaminant to be controlled is present only in short term seasonal excursions, pilot work may be useful to indicate effective bed life and the potential need for off-line contactors;
.4 After filter breakthrough of the taste and odour compounds, GAC media must be removed for regeneration and replaced in order to maintain taste and odour treatment; and
.5 GAC filters should meet the requirements of Chapter 8 – Filtration.

10.2.3 Copper Compounds

Copper compounds (including copper sulphate and chelated copper algaecides) have been used for the treatment of water to kill algae or other growth, and therefore minimizing taste and odour in the source water. The use of copper algaecides is not recommended for blue-green algae (cyanobacteria) control due to the risk of cell lysis (breakage and subsequent release of cyanotoxins). However, it could be incorporated into a multi-treatment approach for algae reduction with other appropriate means of removing dissolved cyanotoxins during subsequent water treatment.

Application of algaecides needs to occur when potentially toxic species are at relatively low densities so that large releases of toxin into the water source do not occur. All the aforementioned mitigation methods are most effective in small water bodies.

The following should be considered if using copper compounds:

.1 Continuous or periodic treatment of water with copper compounds should be controlled to prevent copper in excess of 1.0 milligram per litre as copper in the plant effluent or distribution system;
.2 Care should be taken to ensure that there is an even distribution of the chemical within the treatment area;
.3 Necessary approval and/or permits should be obtained prior to application, if required. Consult the responsible regulatory agencies (BC Ministry of Water, Land and Resource Stewardship) before making applications to public waters;
.4 Algaecidal power of copper sulphate depends on pH, alkalinity, and dissolved organic carbon in water; for example, copper sulphate has low effectiveness in hard, alkaline water;
.5 The BC Ministry of Water, Land and Resource Stewardship specifies chronic and acute WQG values (freshwater aquatic life) for copper based on pH, hardness, and dissolved organic carbon; and
.6 Overfeeding of copper compounds can also cause water discolouration (blue).

10.2.4 Microscreens

Microscreens or microstrainers are mechanical screens with very small openings capable of removing suspended matter from the water by straining. Microscreens generally follow immediately after coarse screens. Microscreens are used during periods when raw water contains nuisance organisms such as algae, and when heavy loadings may negatively impact downstream processes (e.g. granular and membrane filtration).

Designers should consider:

.1 Expected loading and duration of algae blooms;
.2 Corrosiveness of the water;
.3 Effect of chlorination when required as pre-treatment and possibility of DBP formation;
.4 Duplication of units for continuous operation during equipment maintenance;
.5 Automated backflushing; and
.6 Alternative technologies such as dissolved air flotation.

The design should provide:

.1 Bypass arrangements;
.2 Protection against backsiphonage when treated water is used for washing; and
.3 Proper disposal of backwash water.

10.2.5 Dissolved Air Flotation (DAF)

Dissolved air flotation (DAF) can be used to reduce taste and odour resulting from presence of algae in the water. Refer to Section 7.5.7 – Dissolved Air Flotation for details on DAF design.

10.2.6 Chemical Oxidation

Various chemical oxidants can be applied to reduce taste and odour issues. Chemical oxidants for taste and odour control should be added sufficiently upstream of other treatment processes to ensure adequate contact time for an effective and economical use of chemicals. Additionally, potential disinfection by-product formation should be investigated by bench-scale testing prior to design. Chemical options are summarized in Table 10-1.

Table 10-1 Chemical Oxidation Methods for Taste and Odour Control

Chemical	Reference for Design Details	Additional Considerations
Chlorine	Chapter 13 – Chemical Application	• Overdosing or high residual can cause taste and odour issues.
Chlorine dioxide	Chapter 13 – Chemical Application	• Generally recognized as a treatment for tastes caused by industrial wastes, such as phenols.
Potassium permanganate	Chapter 13 – Chemical Application	• Frequently used for taste and odour control. • Comparatively expensive and can cause water discolouration when overdosed (pink/purple).
Ozone	Chapter 13 – Chemical Application	• Generally more desirable for treating water with high threshold odours.
Aeration	Chapter 9 – Aeration	• Feasible for volatile compound removal (i.e. hydrogen sulphide). • Not as effective for algal-related taste and odours.

10.2.7 Advanced Oxidation Processes

Advanced oxidation processes (AOPs) are processes that provide powerful oxidizing conditions to mineralize organic water contaminants. AOPs involve the use of any one of several possible combinations of UV, hydrogen peroxide, ozone and titanium dioxide. For detailed design guidance for AOP processes for taste and odour control, refer to AWWA's *Ozone in Drinking Water Treatment: Process Design, Operation and Optimization,* Raknesss 2015.

The following should be considered when applying an advanced oxidation process for taste and odour control:

.1 AOPs depend on extremely unstable radical chemical species that react very rapidly with any organic material present. Any natural organic matter (NOM) which may also be present in the water is mineralized at a similar rate to the target contaminants. As a result, AOPs should only be used on very low to trace amounts of specific contaminants such as N-nitrosodimethylamine (NDMA) or 1-4 dioxane, and only in water with low NOM content;

.2 UV/H_2O_2 (ultraviolet/hydrogen peroxide) has been shown to be effective in the treatment of taste and odour compounds such as 2-methylisoborneol (MIB) and geosmin. Refer to Chapter 13 – Chemical Application for further guidance;

.3 Bench and/or pilot scale evaluation using the specific source water and covering seasonal variations is needed to establish effectiveness and costs; and

.4 AOPs that use hydrogen peroxide may produce water with a peroxide residual that behaves like chlorine in colourimetric tests, reacts with and destroys free chlorine, and can upset downstream biological processes. Thiosulphates, sulphites or GAC can be used to destroy peroxide residuals, however caution should be used as they can also act as chlorine scavengers/adsorbers.

11 Disinfection

11.1 General

This chapter describes design considerations for chemical and ultraviolet (UV) disinfection treatment processes. The selection of a particular disinfection treatment technology and/or technology train will depend on an evaluation of the nature and quality of the water to be treated, seasonal variations in raw water quality, and the desired quality of the finished water.

Section 5 (2) of the DWPR states that drinking water from a water supply system must be disinfected by a water supplier if the water originates from a surface water source or groundwater that, in the opinion of a Drinking Water Officer, is at risk of containing pathogens (GARP). Schedule A of the DWPR specifies water quality standards for potable water in relation to fecal coliform bacteria, total coliform and *E. coli*. These standards may be achieved through disinfection. There are two distinct types of disinfection, which have two unique functions: primary disinfection and secondary disinfection. These processes are described in the following sections.

Table 11-1 provides a summary of the disinfection methods described within this chapter and the typical application (either primary or secondary disinfection) for each method.

Table 11-1 Disinfection Methods

Disinfection Method	Typical Application	Design Considerations
Hypochlorite (12 – 15%)	Primary or secondary	• Provides an effective disinfectant residual. • Solution strength degrades over time. Design to account for appropriate environmental controls and dose verification monitoring. • Off-gassing can occur in storage, dosing systems and piping systems. • Chlorates may be formed through solution decay. • Trihalomethanes (THMs) and haloacetic acids (HAAs) may be formed as disinfection by-products (DBPs).
Ultraviolet (UV) disinfection	Primary	• Highly effective at inactivating protozoa. • Does not provide a disinfectant residual. • Does not lead to the formation of THMs and HAAs. • May be accompanied with strong oxidant to achieve advanced oxidation (see Chapter 10 – Taste and Odour Control).
Chlorine gas	Primary or secondary	• Highly effective disinfectant and easy to operate. • Highly acidic and consumes alkalinity (may reduce pH). • Specialty operator training required for storage and handling to meet OHS guidelines. • Requires specific risk management planning for transport, storage and handling of the toxic gas.

Disinfection Method	Typical Application	Design Considerations
		• Use of gaseous chlorine requires spill mitigation measures, such as containment or scrubbers. • Proponents of new installation should coordinate this with the local fire prevention authority. • Trihalomethanes (THM) and haloacetic acids (HAA) may be formed as DBPs.
Chlorine dioxide	Primary	• Generated on-site using chlorine gas and sodium chlorite. • Chlorite and chlorate form as DBPs. The GCDWQ should be referenced for maximum acceptable concentrations.
On-site sodium hypochlorite generation	Primary or secondary	• See notes for hypochlorite above. As on-site generation typically produces lower concentration hypochlorite solutions (~0.8%), off-gassing is reduced. • NSF/ANSI Standard 60 certified sodium chloride (salt) to be used to generate the hypochlorite solution. • The design should address ventilation for hydrogen gas to minimize the risk of explosion.
Tablet chlorinators (calcium hypochlorite)	Primary or secondary	• See notes for hypochlorite above. • Design should consider potential for variations in chlorine dosage.
Chloramines	Secondary	• Weak disinfectant. • Long lasting residual. • Forms lower concentrations of THMs and HAAs. • Presents risks to kidney dialysis patients and fish aquariums. • Can increase lead solubility.
Ozone	Primary	• Bromate can be formed as a DBP. • Does not provide a disinfectant residual. • Strong disinfectant.

11.1.1 Primary Disinfection

Primary disinfection kills or inactivates bacteria, viruses, protozoa, and other potentially harmful microorganisms that may be present in the source water prior to the water reaching the first customer. To meet the requirements of Section 5 (2) of the DWPR and to achieve the recommended minimum pathogen log reduction for the source water type, primary disinfection should be employed.

The Ministry of Health *Guidelines for Pathogen Log Reduction Credit Assignment* provides details on the recommended design and operational criteria for the different types of treatment processes used for primary disinfection including CT calculations for chemical disinfection.

11.1.2 Secondary Disinfection

Secondary disinfection or 'residual disinfection' is the maintenance of a disinfection residual concentration to help protect against pathogen contamination and reduce pathogen regrowth within the distribution system. Drinking water distribution system integrity is one of the three core elements of the multi-barrier approach to safe drinking water and secondary disinfection can assist with maintaining and monitoring water quality in the distribution system. A risk-based analysis from a source-to-tap perspective on the biostability of the water should be considered when developing a plan for the maintenance of safe drinking water in the distribution system.

The *British Columbia Guidelines (Microbiological) on Maintaining Water Quality in Distribution Systems* recommends secondary disinfection as a best management practice to maintain the microbiological quality of water in the distribution system to protect against contamination and degradation. A risk-based approach should be used to guide the implementation of secondary disinfection.

The introduction or growth of pathogens (e.g. bacteria, protozoa and viruses) within the distribution system can pose health risks to consumers and impact aesthetic quality. Several factors can cause introduction or growth of pathogens in the distribution system including:

.1 Extended residence times due to network configuration, low water demands, oversized watermains, poor mixing in storage facilities and low storage turnover rates;
.2 Limited network circulation including dead-end watermains or poor network looping;
.3 Leaks within piping and storage facilities;
.4 Cross connection with non-potable sources; and
.5 Biological instability of the water.

Secondary disinfection may be achieved by either maintaining a residual of the primary disinfectant in the distribution system or by adding additional disinfectant(s) prior to the water reaching the customers. Distribution systems with longer retention times or with higher disinfectant residual demands may apply chemical disinfectants at various points within the distribution system to maintain secondary disinfection. Consideration should be given to the formation of disinfection by-products (DBPs) when selecting the disinfectant and feed rates. DBPs are discussed in the following section.

Factors such as the source water pH, temperature and organics levels may impact the stability and effectiveness of chemical disinfectants. Designers should assess the disinfectant demand of the water under the range of anticipated operating conditions (i.e. using bench-scale testing) to determine the disinfectant dose required to meet the minimum residual disinfectant levels without causing formation of DBPs in excess of the *Guidelines for Canadian Drinking Water Quality.*

Secondary disinfection also serves as a method to monitor for changes in the water quality in the distribution system: fluctuations in residuals (against an established baseline) can indicate potential incidents of water quality degradation or contamination, and allow the Water Supplier to respond quickly. Designers should include considerations for disinfection residual monitoring in the distribution system, so that the water system can demonstrate maintenance of a detectable residual in all active parts of the distribution system. This includes provision of sampling ports and/or disinfectant residual monitoring equipment at pump stations, inlet and outlet piping to reservoirs, and throughout the distribution pipe network.

In B.C., secondary disinfection is most commonly accomplished using one of the following chemicals:

.1 Chlorine (chlorine gas or hypochlorite); or
.2 Chloramination.

Primary disinfectants such as chlorine dioxide, ozone, and ultraviolet light (UV) do not maintain a residual and cannot achieve secondary disinfection.

11.2 Disinfection By-Products

Disinfection by-products (DBPs) are formed when disinfectants react with naturally occurring organic (NOM) or inorganic substances (other DBP precursors) in the water. Other factors that affect DBP formation include water temperature, pH, disinfection conditions (i.e. disinfectant, dose, contact time, residual) and the presence of reactive species such as bromide, iodide, ammonia and sulphur.

To manage DBP formation, Health Canada recommends the treatment targets for organics as described in Table 11-2. These are suggested as guidance only as some water sources can be extremely reactive (e.g. form more DBPs), more stringent water quality targets may be required. The treatment targets are determined by the specific DBP yield, which is defined as the mass (in micrograms) of DBP produced by disinfection divided by the DOC (in milligrams) in the water prior to disinfection (µg DBP/mg DOC).

Table 11-2 Treated Water Targets for Organics

Parameter	Source with high specific DBP yield or extensive distribution system	Source with low specific DBP yield
Organic colour	5 - 10 TCU	< 15 TCU
UV absorbance (at 254 nm)	0.02 - 0.04 cm^{-1}	0.02 - 0.07 cm^{-1}
UV transmittance	90 - 95%	85 - 95%
Chemical oxygen demand (COD)	< 5 mg/L O_2	< 5 mg/L O_2
Dissolved organic carbon (DOC)—for DBP control	<2 mg/L carbon	<4 mg/L carbon
DOC—for biological stability	<1.8 mg/L carbon	<1.8 mg/L carbon

Disinfectants may be capable of producing DBPs in concentrations that can present long-term health risks to drinking water consumers. Health Canada provides maximum acceptable concentrations for six types of DBPs: trihalomethanes (THMs), haloacetic acids (HAAs), N-nitrosodimethylamine (NDMA), bromate, chlorate, and chlorite. To reduce DBP formation, it is important to characterize the source water and ensure that the treatment process is optimized for precursor removal. Designers should also assess the disinfection by-product formation potential (DBP-FP) using laboratory analysis, or alternatively conduct distribution system sampling to verify the propensity to generate DBPs. The sampling should assess the seasonal variation and be representative of the distribution system. Refer to APHA/AWWA/WEF *Standard Methods for the Evaluation of Water and Wastewater* for best practices on laboratory sampling and analytical procedures.

Treatment approaches that can reduce disinfection by-product formation potential include the following:

- .1 Evaluate alternatives to pre-chlorination;
- .2 Alternative oxidants and disinfectants;
- .3 Granular media filtration;
- .4 Enhanced coagulation;
- .5 Biological filtration;
- .6 Membrane filtration;
- .7 Granular activated carbon;
- .8 Powdered activated carbon; and
- .9 Anion exchange.

Adding or changing a chemical disinfectant will change water chemistry and could generate secondary effects beyond DBP formation. These secondary effects may cause significant water quality changes in the distribution system, such as the release of corrosion by-products due to changes in oxidation-reduction potential. Refer to Chapter 12 – Internal Corrosion Control for information regarding corrosion control measures.

Operational changes can be made to reduce DBP formation including:

- .1 Decreasing stagnation time; and
- .2 Providing in-reservoir aeration.

Health Canada recommends sampling of organic indicators as described in Table 11-3 for continued optimization and protection against DBP formation.

Table 11-3 Disinfection By-Product Sampling Program (sourced from Guidance on Natural Organic Matter in Drinking Water, Health Canada 2020)

Parameter	Location	Frequency		
		Variable Source[d]	Stable Source[d]	Ideal
Organic colour (true colour)	Raw and treated	Daily	Weekly	Online
UV absorbance (at 254 nm, UV254) or UV transmittance	Raw and filtered	Daily	Weekly	Online
Chemical oxygen demand (COD)	Raw, treatment processes[a] and treated	Daily	Weekly	Online
Dissolved or total organic carbon (DOC or TOC)	Raw and treated	Weekly	Monthly	Online
Specific UV absorbance (SUVA)— calculate from UV254 and DOC	Raw and treated[b]	Weekly	Monthly	Daily
Inorganic compounds that can enhance the reactivity of NOM to form DBPs: – **Ammonia** – **Bromide** – **Iodide** – **Sulphur**	Raw and treated	Quarterly	Quarterly	Quarterly
Coagulant demand	Coagulation process [c]	Daily	Daily	Online
Zeta potential or streaming current— when NOM controls or influences coagulant dose	Coagulation process [c]	Online	Online	Online
Disinfection by-products (DBPs)	Distribution system	Quarterly (measure DOC and inorganic compounds on same day to calculate specific DBP yields to assess NOM reactivity)		

[a] COD decreases across each treatment process. Selected monitoring locations will vary depending on the process trains in place (e.g. flocculation, clarification, filtration) and the Water Supplier's monitoring program.

[b] $\text{Treated water SUVA} = \frac{\text{UV254 (measured in filtered water before disinfectant addition}}{\text{DOC after disinfectant addition}} \times 100\%$

[c] Strict pH control is critical for NOM removal during coagulation. As alkalinity affects pH control, pH and alkalinity are other important coagulation process monitoring parameters.

[d] A variable source water is subject to rapidly changing raw water quality conditions such as in a river. A stable source would be one that generally experiences consistent raw water quality that may be subject to seasonal fluctuations in raw water quality due to lake turn-over or similar event.

11.3 Ultraviolet Disinfection

Ultraviolet (UV) disinfection may be used for primary disinfection. UV irradiation is effective at inactivating *Giardia*, *Cryptosporidium* and bacteria. Viruses generally require a significantly higher dose for inactivation, depending on the target virus (e.g. adenovirus versus rotavirus). UV systems do not provide a disinfectant residual and therefore cannot be used for secondary disinfection. Refer to the *Guidelines for Ultraviolet Disinfection of Drinking Water* by the Ministry of Health for dose selection and design considerations, including validation methods.

There are two primary types of UV disinfection system, low pressure (LP) and medium pressure (MP). LP lamps produce monochromatic wavelength (254 nm) whereas the MP lamps produce polychromatic wavelengths (200-300 nm). MP lamps operate under a mercury vapour pressure of approximately 10 kPa, whereas LP lamps operate between 100-1000 Pa; lamps between these pressures tend to be LPHO (low pressure-high output) lamps.

Due to higher operating pressures for MP lamps, they require higher input power (3-7 kW) as compared to LP lamps (0.05-0.5 kW). LP lamps require more lamps and higher surface area than the MP lamps to provide the same amount of effective dose delivery. MP units typically have higher capital and power costs than their LP counterparts.

11.4 Ozone

Ozone is a strong oxidant that is especially effective for disinfection of *Giardia lamblia*, viruses and bacteria at relatively low CTs; *Cryptosporidium* has comparatively higher tolerance to ozone, but can be effectively disinfected at higher CT values. Ozone is also known to be effective at oxidizing organics present in the source water; due to this, it may be used as part of DBP management program and to control taste and odours.

As a minimum, bench scale studies should be conducted to determine minimum and maximum ozone dosages for disinfection compliance and oxidation reactions. Particular attention should be made to confirm and validate measurements of gas flow rate and ozone concentration. Consideration should be given to multiple points of ozone addition.

Use of ozone may result in an increase in biologically available organics in the ozonated water and may be used to facilitate organics removal through biologically active filtration. Designers should include consideration for unintended biological impacts on downstream processes. Ozone use may also lead to increased chlorinated by-product levels if the water is not stabilized and free chlorine is used for secondary disinfection.

When considering ozone, the potential formation of bromate should also be evaluated. Factors which influence bromate formation potential include source water bromide, temperature, pH, alkalinity, organic matter, as well as applied ozone dose. Refer to the GCDWQ *Guideline Technical Document - Bromate* for mitigation strategies.

Ozone is generated on-site using dried ambient air, oxygen-enriched air, or high-purity oxygen. Ozone systems have a higher level of operational complexity than other disinfection approaches, except in the case of small packaged generators that provide only a few grams of ozone per day. The ability to develop operator skills should be evaluated during treatment process selection. Refer to Chapter 13 – Chemical Application for the design of the ozone generation and feed requirements.

11.5 Chlorination

Chlorination is the process of adding chlorine-containing compounds to water for the purpose of disinfection. Chlorination can be performed through the use of chlorine gas, sodium hypochlorite or calcium hypochlorite. The following Table 11-4 describes the considerations of each. Health Canada recommends that the concentration of chlorine be determined on a system by system basis. Refer to Chapter 13 – Chemical Application for the design considerations for chlorination systems.

Systems are available to generate sodium hypochlorite on-site in low (~0.8%) or medium (12% - 15%) strength solutions. These systems use an electrolytic cell and brine solution to generate sodium hypochlorite. Further details of these and the above chlorine disinfectants are discussed in Chapter 13.

Table 11-4 Chlorination Method Comparison

Chlorine Species	Chlorine Gas (Cl_2)	Sodium Hypochlorite (NaOCl)	Calcium Hypochlorite ($Ca(OCl)_2$)
Description	Transported and stored as a liquefied gas under pressure. Water treatment facilities typically use chlorine in 100 and 150-lb cylinders or one-ton containers. Some large systems use railroad tank cars or tanker trucks.	Produced by adding elemental chlorine to sodium hydroxide and sold as a solution. Typically, hypochlorite solutions contain from 5 to 15% chlorine (trade percent) and are shipped by truck in 5,000 to 40,000 L containers.	Used primarily in smaller applications. It is a white, dry solid containing approximately 65% chlorine, and is commercially available in granular and tablet forms. Typical applications include puck style dose delivery systems.
Advantages	Lowest cost of available chlorine disinfectants. Unlimited shelf life. Simple and effective dose control. Highest concentration of elemental chlorine, requiring the smallest footprint.	Less hazardous than chlorine gas.	More stable than sodium hypochlorite. Less onerous to operate.
Disadvantages	Hazardous gas requires special handling and operator training. Risk of chlorine gas exposure to the environment and public during storage, transport, and delivery.	Limited shelf life. Off-gases within storage and dosing systems. Potential to add inorganic by-products (chlorate, chlorite, and bromate) to water, especially after extended storage.	Precipitates may form in chemical feed systems. Fire/explosive hazard (requires specialty fire retardant). Potential to add inorganic by-products (chlorate, chlorite, bromate) to water.

11.5.1 General Chlorination Design Considerations

The following equipment should be used for chlorination systems:

.1 The chlorinator capacity should be such that primary disinfection requirements can be met under the maximum flow conditions at the facility, and the secondary disinfection requirements can be met under all conditions. The equipment should be designed such that it will provide an accurate chlorine feed over the entire dosing range. Where chlorination is provided for the protection of public health, redundant stand-by equipment should be provided such that it can replace the largest unit. Spare parts should be made available to replace parts subject to wear or breakage. Accurate metering of emergency units should also be provided;

.2 Chemical feed systems should meet the recommendations of Chapter 13 – Chemical Application;

.3 Automatic switchover of standby or emergency chlorine, storage and feed systems should be provided to ensure adequately disinfected water enters the distribution system at all times;

.4 Provide automatic proportioning (flow-pacing) in systems where the rate of flow is variable. Discrete, controlled changes in flow may not require flow proportioning, provided the system is designed to automatically adjust the dose in response to changes in flow (i.e. additional pump start-up); and

.5 The chlorine solution injector/diffuser should be compatible with the point of application to provide a rapid and thorough mix with the water being treated. Where chlorine is injected into pipes, injectors should extend to the center of the pipe. CFD modelling or tracer studies may be required to verify the effective mixing of the applied disinfectant.

11.5.2 Secondary Disinfection with Chlorination

Chlorination is the most common type of secondary disinfection. Water suppliers should maintain secondary disinfection at concentrations that will protect against human health risk while minimizing the impact on the aesthetic quality of the drinking water (e.g. taste and odour) and disinfection by-product formation.

Effective secondary disinfection requires an adequate free chlorine residual throughout the distribution system. The free chlorine residual is defined as the chlorine available as hypochlorous acid (HOCl), hypochlorite ion (OCl^-) and dissolved gas (Cl_2, only present at pH < 2) that is not combined with ammonia or other compounds in water.

Generally, 0.2 mg/L of free chlorine is considered the minimum concentration to control the growth of bacteria in the distribution system. Health Canada recommends a range of 0.4 to 2.0 mg/L of free chlorine in treated water leaving the water treatment plant. Chlorination booster stations may be located throughout the distribution system to maintain adequate residual and reduce DBP levels (as compared with a single, higher concentration injection point).

11.6 Chlorine Dioxide

Chlorine dioxide is a powerful disinfectant that does not form chlorinated organic DBPs, however, the formation of chlorite and chlorate by-products should be evaluated against the GCDWQ MAC. As chlorite is added to water to produce chlorine dioxide, incomplete reactions can result in high chlorite concentrations. Furthermore, chlorine dioxide degrades slowly in water to produce chlorite and chlorate.

Chlorine dioxide is not recommended as a secondary disinfectant. WorkSafeBC *Occupational Health and Safety Exposure Limits* should be reviewed to ensure a safe work environment.

Chlorine dioxide gas, even in mixtures of over 10% in air, is highly unstable. As a result, it must be generated on-site through the reaction of sodium chlorite with chlorine gas, hypochlorous acid or hydrochloric acid, or using an electrochemical process. The gas is toxic and can be explosive; therefore, the Designer should make appropriate provisions to protect operations staff from excessive exposure. Furthermore, advanced leak detection, explosion proof measures and special safety precautions should be provided to protect workers. The gas should be handled only in water solution with feed lines arranged to avoid gas pocket formation, be maintainable under moderate pressure and be easily water purged.

Levels of both chlorite and chlorate should be evaluated against the GCDWQ MAC via bench- or pilot-scale testing.

Refer to Chapter 13 – Chemical Application for general design considerations.

11.7 Chloramination

Chlorine combines with ammonia to form chloramine compounds: mono-, di-, and trichloramine. The ammonia may be naturally occurring or may be added to the water (usually after the chlorine injection point). Chloramines are less powerful oxidants than free chlorine: monochloramine is the strongest and most stable disinfectant of the chloramines and is the desired species in chloramination. Chloramination is inadequate in strength for primary disinfection, as the CT required to inactivate key pathogens is unfeasibly high for water treatment applications.

Typically, chloramines are used for secondary disinfection. In the distribution system, chloramines are more persistent and better at controlling biofilms than free chlorine. Monochloramine has fewer taste and odour issues than free chlorine, although complaints may occur at combined chlorine levels above 3 mg/L, especially if di- and tri-chloramine are present.

The required chloramine concentration at each entry point depends on the size of the distribution system and the decay rate. A generally accepted target concentration for chloramines as they enter the distribution system is at least 2 mg/L; however, residuals greater than 1 mg/L may be necessary to control biological regrowth within piping (Health Canada, 2020).

When using chloramination, the *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Chloramines* by Health Canada should be referenced.

11.7.1 Health and Safety Considerations

Chloramines in water present risks to kidney dialysis patients and fish aquariums. Provide public notice prior to changing the type of chlorine residual. Blending water supplies that contain both free chlorine and chloramines should be avoided except in an emergency. Chloramines depress oxygen levels in natural water bodies and are therefore considered highly toxic to fish populations. Special provisions are to be made for monitoring and responding to system leaks and pipeline breaks.

While chloramines produce lower concentrations of THMs and HAAs, they can generate higher concentrations of N-nitrosodimethylamine (NDMA) and other DBPs (including organic chloramines). NDMA production should be considered when designing chloramination systems and may be mitigated through dose control and reduction of NDMA precursors (dimethylamine, trimethylamine, and dichloramine). The MAC and reduction strategies for NDMA can be found in Health Canada's *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document: N-Nitrosodimethylamine* (NDMA).

Switching from free chlorine to chloramines may increase lead solubility in water. Additionally, the type of chlorine and ammonia chemicals used can affect the finished water pH. An evaluation of the corrosion control strategy is required prior to changing chemicals or disinfectant strategies.

11.7.2 Chloramine Formation

Chloramine formation is dependent on temperature, pH, mixing, organics, and chlorine to ammonia-nitrogen weight ratio. The chlorine to ammonia-nitrogen weight ratio is based upon chlorine residual, not chlorine dose. The desired chloramine compound is monochloramine. The chlorine to ammonia-nitrogen weight ratio for monochloramine formation is between 4.5:1 - 5:1 when pH > 8. A higher ratio can lead to formation of dichloramine and trichloramine and the production of undesirable taste and odours. The Designer should refer to AWWA's *Nitrification Prevention and Control in Drinking Water, M56* for further information on preventing nitrification.

Too low of a ratio will result in excess free ammonia and possible nitrification in the distribution system. Water quality problems caused by nitrification include the formation of nitrite and nitrate, loss of disinfectant residual, bacterial regrowth and biofilm formation, DBP formation, and decreases in pH (especially in low alkalinity waters) and alkalinity that can lead to corrosion issues, including the release of lead and copper. If water contains ammonia (either naturally or added), and a free chlorine residual is desired, the ammonia can be removed by oxidation with chlorine to produce primarily nitrogen gas and some nitrate by the breakpoint reaction.

Ammonia reacts rapidly with chlorine to form chloramines. The chlorine initially reacts with NH_3 to form monochloramine (NH_2Cl). The additional free chlorine then reacts with monochloramine to form dichloramine ($NHCl_2$), and then trichloramine (NCl_3). Chlorine dosing passed the breakpoint results in free chlorine residual. Breakpoint chlorination is thus the addition of chlorine to water until the chlorine demand has been satisfied to reach the breakpoint. The procedures for calculating the breakpoint reaction can be found in *Standard Methods for the Examination of Water and Wastewater*, published by the American Public Health Association, the American Waterworks Association and the Water Environment Federation (APHA/AWWA/WEF).

11.7.3 Feed System Design

The following should be considered when designing a chloramine feed system:

.1 Chemical feed systems should meet the recommendations of Chapter 13 – Chemical Application with respect to specific chemical requirements for chlorine gas, sodium hypochlorite, ammonium sulphate, aqua ammonia, and anhydrous ammonia;

.2 Ammonia and ammonia compounds should be stored in a separate room from chlorine because of the potential explosive or violent reactions that could occur;
.3 Both chlorine and ammonia must be mixed thoroughly and rapidly in the main plant stream to prevent formation of dichloramine and trichloramine; and
.4 A method to maintain the desired chlorine to ammonia-nitrogen weight ratio should be provided. An automated, continuous instrument control method is recommended.

11.7.4 Chloramine Booster System

Booster chlorination of chloraminated water in the distribution system can be used to reform monochloramine from the ammonia released during the decay process. Booster chloramination (adding chlorine and ammonia) may be necessary in certain situations.

11.7.5 Monitoring

A distribution sampling program should be established to verify proper chloramine formation and to monitor for nitrification (see Section 11.7.6 – Nitrification). Sampling should be implemented at the following key points in the water system:

.1 Entry point to distribution system (baseline);
.2 Storage facilities;
.3 Upstream and downstream of booster stations;
.4 In areas of low flow or high-water age;
.5 Pressure zone boundaries;
.6 In mixed zones (blended water); and
.7 In areas with various sizes and types of pipe material.

The *British Columbia Guidelines (Microbiological) On Maintaining Water Quality in Distribution Systems* and Health Canada's *Guideline Technical Document on Chloramines* recommends the following parameters be monitored for systems using chloramination:

- Free and total ammonia;
- Monochloramine;
- Dichloramine;
- Nitrite;
- Nitrate;
- Adenosine triphosphate (ATP);
- Heterotrophic plate count (HPC);
- pH;
- Total organic carbon (TOC);
- Temperature; and
- Alkalinity.

Table 11-5 provides an example sampling program; however, selected parameters and sampling frequency should be adjusted based on the Water Supplier's needs and unique trends in water quality.

Table 11-5 Chloramination Sampling Frequency (example)

Frequency	Parameter
Daily	Free and total chlorine, pH, temperature
Weekly	Nitrite, nitrate, free and total ammonia, alkalinity, monochloramine, dichloramine, TOC
Monthly	Heterotrophic plate count (HPC) or adenosine triphosphate (ATP)

11.7.6 Nitrification

Nitrification is a microbially-mediated process through which ammonia is oxidized to form nitrite and nitrate. Free ammonia concentration should be kept below 0.1 mg/L. Nitrification at the WTP can be prevented by maintaining a chlorine to ammonia ratio that is optimal for monochloramine formation. Nitrification has the potential to occur in the distribution system under various conditions and is most commonly associated with elevated temperatures (above 15 ^{o}C), high water age, lower pH, high free ammonia concentrations, high chlorine demand (i.e. high total organic carbon), and low monochloramine residuals.

The following factors may indicate nitrification in a distribution system:

.1 Decrease in total chlorine residual;
.2 Increase in HPC, ATP and potentially an increase in total coliforms;
.3 Decrease in free ammonia;
.4 Increase in nitrite (≥ 0.05 mg/L as N);
.5 Decrease in dissolved oxygen (DO) (associated with moldy and earthy-tasting water); and
.6 Decrease in alkalinity and pH.

Steps can be taken to reduce water age in the distribution system, such as adding loops to the system. The addition of mixing can prevent tank stratification. Once established, nitrification may require steps such as flushing to restore water quality. A nitrification control plan should include flushing and the temporary use of free chlorine. The following strategies can minimize nitrification:

.1 Decreasing the detention time;
.2 Increasing pH;
.3 Decreasing total organic carbon (TOC);
.4 Increasing the Cl_2/NH_3-N ratio and chloramine residual;
.5 Decreasing excess ammonia; and
.6 Performing occasional breakpoint chlorination.

12 Internal Corrosion Control

12.1 General

This chapter describes design considerations for internal corrosion control treatment processes. The selection of a particular internal corrosion control treatment technology and/or technology train will depend on an evaluation of the nature and quality of the water to be treated, seasonal variations in raw water quality, and the desired quality of the finished water.

Corrosion is the oxidation process by which a native metal (i.e. in pipe or fittings) is converted to an oxidized species, either in the form of metal oxide precipitates or released to the solution as metal ions. Internal corrosion in a drinking water distribution system (i.e. occurring on the insides of pipes) can cause contaminants to leach from the metal components in contact with the water. Internal corrosion in drinking water distribution systems is primarily driven by two factors:

.1 The corrosive properties of the water in contact with the pipes; and
.2 The presence of corrodible metal pipes or piping components.
   - Due to its health effects, lead is normally the target metal for corrosion control strategies; however, copper and iron may also leach due to corrosion.

Mitigating at least one of these two main factors prevents metal leaching, and is therefore the goal of a corrosion control strategy. While pipes and plumbing components (especially those containing lead) can be replaced as part of a corrosion control strategy, most lead-containing pipes and fixtures are located in households (not in distribution systems). Therefore, the primary approaches to managing internal corrosion control in drinking water systems include modifying water chemistry to make water less corrosive, and encouraging the formation of passivating films on the contacting surface (insides of pipes and fixtures).

Water corrosivity can be reduced by pH and/or alkalinity adjustment. Increasing the carbonate buffer level is a consistent method for reducing the corrosion rate and is particularly recommended for systems treating soft water. Where adjustments to water quality parameters prove insufficient to control corrosion rates, the use of corrosion inhibitors should be considered. Corrosion inhibitors generate a protective (passivating) oxide film on the surfaces in contact with potable water, which reduces the rate of corrosion. The application of corrosion inhibitors should be carefully monitored to ensure sufficient concentrations are applied to prevent corrosion while not overdosing and causing deposits or scale buildup on the internals of the distribution system.

The application of water treatment chemicals, such as coagulants, can change the characteristics of the water (e.g. pH, alkalinity, the chloride-to-sulphate mass ratio (CSMR), etc.) and potentially create corrosive water. Designers should carefully assess the corrosivity of the water when selecting new or modifying existing treatment processes. Where material changes in water chemistry are anticipated, if new source water is being considered, or if multiple water sources are to be blended, Designers should consider the impacts on corrosion. A corrosion study serves as a first step in a comprehensive corrosion control strategy that may be employed before or in conjunction with making changes to an existing water system. Water may also become corrosive after prolonged contact with water system components such as distribution or storage facilities. Water that is corrosive due to natural and/or subsequent treatment processes should be stabilized to minimize corrosion in the distribution system and prevent the leaching of contaminants into the water.

Other factors that affect corrosion rates are elevated water temperatures, fluctuations in free chlorine residual, chloramines, chloride, sulphate, natural organic matter (NOM), oxidation-reduction potential (ORP), and the chloride-to-sulphate mass ratio (CSMR). Longer stagnation times in pipes can also lead to increased corrosion.

The following processes can be used for corrosion control, and should be considered based on the specific characteristics of the water system:

.1 Alkalinity and/or pH adjustment using chemical addition including:
   a. Sodium bicarbonate, $NaHCO_3$;
   b. Carbon dioxide, CO_2;
   c. Caustic potash, KOH (potassium hydroxide);
   d. Caustic soda, NaOH (sodium hydroxide);
   e. Hydrated lime, $Ca(OH)_2$ (calcium hydroxide);
   f. Potash, K_2CO_3 (potassium carbonate);
   g. Soda ash, Na_2CO_3 (sodium carbonate);
   h. Sodium silicates, e.g. Na_2SiO_3;
   i. Acid addition;
   j. Alkali addition;
.2 Corrosion Inhibitors:
   a. Phosphate based;
   b. Silica based; and
.3 Split treatment.

Reference should be made to the Health Canada *Guidance on Controlling Corrosion in Drinking Water Distribution Systems* (2009) for additional details and recommendations.

For guidance on external corrosion control, refer to Chapter 16 – Transmission and Distribution.

12.2 Corrosion Control Study

12.2.1 General

A corrosion control study is recommended for source and treatment changes that could alter finished water chemistry (refer to Section 12.2.2 – Scenarios Where Corrosion Control Studies Are Recommended for more details). The *Guidelines on Evaluating and Mitigating Lead in Drinking Water Supplies, Schools, Daycares and Other Buildings* by the Ministry of Health should be referenced when developing the study.

The corrosion control study should include the following key steps:

.1 A sample site location plan for water quality parameter monitoring.
   - When developing a sampling program, refer to Health Canada *Guidance on Controlling Corrosion in Drinking Water Distribution Systems* (2009) and the USEPA's *Lead and Copper Rule* and *Optimal Corrosion Control Treatment Evaluation Technical Recommendations for Primacy Agencies and Public Water Systems* (2016).

- Entry point and distribution system samples should be collected; however, the most effective sampling locations are the customers' taps.
- Water quality data and other system information pertinent to achieving optimum corrosion control should be collected from all sample sites.
- The frequency of sampling and number of sites should be determined in consultation with the Issuing Official.
- Water quality parameters which can be considered for a corrosion sampling program include:
  - Lead and copper
  - Aluminum
  - Iron
  - Calcium
  - Manganese
  - Sulphate
  - pH
  - Conductivity
  - Temperature
  - Hardness
  - Alkalinity
  - Ammonia
  - Dissolved oxygen
  - Oxidation reduction potential (ORP)
  - Total dissolved solids (TDS)
  - Total phosphorus
  - Natural organic matter (for example, through total and/or dissolved organic carbon measurements)
  - Chloride
  - Total and free chlorine
  - Corrosion control inhibitors (orthophosphate, silica), if applied prior to distribution

.2 Health Canada recommends against using corrosion indices (like the Langelier index) to assess corrosion control programs. Corrosion indices should only be used in conjunction with a rigorous sampling program which includes the water quality parameters listed in .1 above.
- For example, modelling a corrosion index across a distribution system may help identify areas with higher water corrosivity for further sampling. This can be spatially overlaid with information on house age, known or potential lead service line presence, and historical test results for the above parameters to help water suppliers design a meaningful sampling program that includes higher risk areas in the distribution system.

.3 A summary and evaluation of all water quality parameter monitoring results collected;
.4 A desktop evaluation using corrosion control computer modeling and/or regulatory guidance; and
.5 Identification of possible limitations and secondary impacts for treatment options.

12.2.2 Scenarios Where Corrosion Control Studies Are Recommended

Changes to the water supply system which affect the finished water chemistry may have impacts on internal corrosion. Scenarios that may warrant a corrosion control study include the following:

.1 Change in source water;
.2 Blending of source waters (e.g. combining surface and groundwater);
.3 Blending of finished waters from two distinct treatment systems;
.4 Change in disinfection type (including additional oxidants) or disinfection strategy;
.5 Addition of any process which changes water pH or alkalinity (may include coagulation and GAC);

.6 Change in coagulation type (for example, from iron to aluminum-based, or chloride to sulphate-based);
.7 Addition of ion exchange; and
.8 Change in a treatment process that increases the final amount of natural organic matter (NOM) in the water.

12.3 Corrosion Control Methods

12.3.1 Alkalinity/pH Adjustment

12.3.1.1 General Considerations

The main water quality parameters that can be adjusted to control corrosion are pH and alkalinity. The pH of water is a measure of its acidity, otherwise known as its hydrogen ion concentration (H^+ or H_3O^+). Alkalinity is the capacity of water to neutralize acid. Both a pH that is too low (acidic) or too high (basic) can cause increased corrosion rates.

The Health Canada *Guidance on Controlling Corrosion in Drinking Water Distribution Systems* (2009) provides guidance on adjusting pH and alkalinity for lead and copper corrosion control. The following are the recommended optimal ranges:

- pH: 7.5 – 9.5
- Alkalinity: 30 – 75 mg/L as $CaCO_3$ (> 60 mg/L $CaCO_3$ is preferable for iron corrosion control)

Treated water may need to be chemically adjusted to within the recommended pH and alkalinity ranges to limit corrosion in the distribution system, depending on other water quality parameters and water system pipe materials.

Alkalinity/pH adjustment systems:

.1 Should be capable of providing a stable pH;
.2 Should be injected after all disinfection log inactivation requirements are achieved;
.3 Should produce water with an alkalinity of at least 30 mg/L as calcium carbonate ($CaCO_3$);
.4 Should have chemical feed facilities conform to Chapter 13 – Chemical Application;
.5 Operator safety precautions should be followed as outlined in Chapter 13 – Chemical Application; and
.6 Piping materials should be of a type suitable for the chemical being fed.

12.3.1.2 Secondary Impacts of Alkalinity/pH Adjustment

The following secondary impacts should be evaluated:

.1 Optimal pH for all other processes;
.2 Calcium carbonate precipitation;
.3 Oxidation of iron and manganese;
.4 Disinfection by-product (DBP) formation (trihalomethanes, haloacetic acids); and
.5 Final sodium content in water.

12.3.1.3 Alkalinity/pH Adjustment Options

Table 12-1 provides a summary of commonly used chemicals for pH or alkalinity adjustment.

When choosing a chemical for pH adjustment, the dissolved inorganic carbon (DIC) content of the water should be reviewed to ensure the applicability of the chosen chemical. DIC is an estimate of the amount of total carbonates in the form of carbon dioxide gas (CO_2 or H_2CO_3), bicarbonate ion (HCO^{3-}), and carbonate ion (CO_3^{2-}). Appendix B of the *Optimal Corrosion Control Treatment Evaluation Technical Recommendations for Primacy Agencies and Public Water Systems* can be referenced to calculate DIC.

Table 12-1 pH/Alkalinity Adjustment Chemical Summary (sourced from the Optimal Corrosion Control Treatment Evaluation Technical Recommendations for Primacy Agencies and Public Water Systems)

Chemical	Composition	pH Change	Alkalinity Change	DIC Change [a]	Notes
Sodium bicarbonate, $NaHCO_3$	98% purity. Dry storage with solution feed [b]	Tends to pH 8.3	Increases 0.60 mg/L as $CaCO_3$ alkalinity per mg/L as $NaHCO_3$ [b, c, e]	0.14 mg/L as C per mg/L as $NaHCO_3$	• Good alkalinity adjustment chemical but expensive. [b] • Recommended for systems with limited technical resources. • Recommended for waters with a DIC < 5 mg/L.
Sulfuric acid, H_2SO_4	Available in 62, 78, or 93% strengths	Decreases	Decreases	None	• Must be stored in corrosion-resistant tanks.
Carbon dioxide, CO_2	Pressurized gas storage. Fed either through eduction or direct gas feed [b]	Decreases	None [b]	0.27 mg/L as C per mg/L as CO_2	• Can be used to enhance NaOH or lime feed systems. [b] • Converts hydroxide to bicarbonate and carbonate species. • Adequate mixing needs to be provided for CO_2.
Caustic potash, KOH (potassium hydroxide)	KOH is available as a 45% solution. Has a low freezing point and can be stored at higher concentrations.	Increases	0.89 mg/L as $CaCO_3$ alkalinity per mg/L as KOH. Converts excess carbon dioxide to carbonate alkalinity species.	None	• pH control is difficult when applied to poorly buffered water. • Is a hazardous chemical, requires safe handling and containment areas.

Chemical	Composition	pH Change	Alkalinity Change	DIC Change [a]	Notes
Caustic soda, NaOH (sodium hydroxide)	93% purity liquid bulk, but generally shipped/stored at < 50% purity to prevent freezing.	Increases	1.25 mg/L as $CaCO_3$ alkalinity per mg/L as NaOH[c, d] Converts excess carbon dioxide to carbonate alkalinity species.	None	• pH control is difficult when applied to poorly buffered water. [b] • For low alkalinity waters, caustic soda should be used in conjunction with carbon dioxide. • Is a hazardous chemical, requires safe handling and containment areas. • Caustic soda can cause severe burns and damage the eyes, WorkSafeBC recommendations should be followed when handling caustic soda. • Recommended for water with DIC > 5 mg/L.
Hydrated lime, $Ca(OH)_2$ (calcium hydroxide)	95 to 98% purity as Ca(OH)[b]. 74% active ingredient as CaO. Dry storage with slurry feed. [b]	Increases	Increases 1.35 mg/L as $CaCO_3$ alkalinity per mg/L as $Ca(OH)_2$	None	• pH control is difficult when applied to poorly buffered water. Slurry feed can cause excess turbidity. O&M is intensive. • Can be applied in form of limestone contactors, which are well suited for small systems. • Increases calcium content (hardness).
Potash, K_2CO_3 (potassium carbonate)	Dry storage with solution feed. [e]	Moderate Increase	Increases 0.72 mg/L as $CaCO_3$ alkalinity per mg/L K_2CO_3 [c, d]	0.09 mg/L as C per mg/L as K_2CO_3	• More expensive than soda ash but more soluble and easier to handle.
Soda ash, Na_2CO_3 (sodium carbonate)	95% purity. Dry storage with solution feed. [b]	Moderate Increase	Increases 0.94 mg/L as $CaCO_3$ alkalinity	0.11 mg/L as C per mg/L as Na_2CO_3	• More pH increase compared with $NaHCO_3$, but less costly .[b] • Has increased buffer capacity over hydroxides.

Chemical	Composition	pH Change	Alkalinity Change	DIC Change [a]	Notes
			per mg/L as $Na2CO_3$ [c, d]		• Recommended for waters with a DIC concentration between 2 to 25 mg/L.
Sodium silicates, e.g. Na_2SiO_3	Available in liquid form mainly in 1:3.2 or 1:2 ratios of Na_2O:SiO_2 . [h]	Moderate increases in pH.	Depends on formulation Moderate increases in alkalinity.	None	• More expensive than other options but easier to handle than lime and other solid feed options. Has additional benefits in sequestering or passivating metals. [h]

[a] Calculated by the formula DIC Change = 12 x (moles carbon/mole compound) / molecular weight of compound.
[b] USEPA, 1992a
[c] Wachinski, 2016
[d] Simon, 1991
[e] USEPA, 2003
[f] Caustic potash (KOH), or potassium hydroxide, is an alternative that does not add sodium to water.
[g] Lime is available as hydrated or slaked lime ($Ca(OH)_2$) and quicklime (CaO).
[h] Schock, 1996

Acids such as hydrogen chloride (HCl), sulphuric acid (H_2SO_4) and citric acid ($C_6H_8O_7$) addition can be used to decrease the pH of the water to within the range stipulated by the regulatory requirements. Adequate precautions should be taken for operator safety: for example, never adding water to concentrated acid. Reference should be made to Chapter 13 – Chemical Application for design and safety considerations when using acids.

12.3.2 Corrosion Inhibitors

Corrosion inhibiting chemicals are used to minimize corrosion in the distribution system. Corrosion inhibiting chemicals include phosphate- and silicate-based compounds.

12.3.2.1 Phosphate-Based Inhibitors

Phosphate-based compounds for use in water distribution systems include orthophosphate, polyphosphates, and blended phosphates (a combination of the two). Orthophosphate-based compounds act as a corrosion inhibitor by forming a protective coating on pipe walls. This film protects the pipe by reducing or eliminating the potential for lead and copper to leach into the water. Orthophosphates need to be fed indefinitely, or there is a risk that the passivation film that has built up will break down and release trapped metals into the water system. Orthophosphates are the most effective phosphate-based compounds for controlling lead release in the distribution system and can also control copper release. Orthophosphates can be added in the form of phosphoric acid, alkali metal orthophosphates (e.g. sodium orthophosphate), or zinc orthophosphate. Phosphates containing zinc help to protect cement lined pipes at low alkalinity/hardness/pH conditions.

Polyphosphates sequester hardness, iron, and/or manganese but do not form a protective barrier on pipe interiors, nor do they react with lead; therefore, they should not be considered as corrosion inhibiting chemicals. Blended phosphates contain some proportion of orthophosphate and polyphosphate. The orthophosphate portion is beneficial for corrosion control while polyphosphate sequesters hardness, iron, or manganese. The orthophosphate to polyphosphate ratio is very important to ensure sufficient orthophosphate residual to control the lead or copper release. Blended phosphates may be used in situations where sequestration and corrosion control are simultaneously sought, but the protective films formed on the pipes will be less uniform (i.e. more amorphous). Caution should be taken to ensure minimal hydraulic or mechanical upset in the pipes, which may disturb the amorphous films and cause release of metals into the water.

Phosphates can have secondary impacts that limit their use. Factors that should be evaluated prior to the installation of these corrosion control systems include:

.1 Reactions with aluminum causing amorphous precipitate rather than a smooth passivation layer;
.2 Impacts on wastewater treatment plants;
.3 Increased biological activity in distribution systems (biofilm formation); and
.4 Possibility of reacting and precipitating with other metals, including iron and manganese. Finding an optimum phosphate dose may be challenging with multiple pipe metal types.

The feeding of polyphosphates may be used for sequestering calcium in lime-softened water and in conjunction with pH adjustment following ion exchange softening. Phosphate addition should meet the following criteria:

.1 Feed equipment should conform to Chapter 13 – Chemical Application;
.2 Stock phosphate solution should be kept covered and disinfected by maintaining approximately 10 mg/L chlorine residual (phosphate solutions having a pH of 2 or less may be exempt from this requirement);
.3 Should include provision to monitor the phosphate residual;
.4 Should be designed to operate within the optimum pH range and alkalinity concentration.
.5 Adequate chlorine residuals should be maintained in the distribution system;
.6 Should have a chemical feed system capable of maintaining an orthophosphate residual of at least 1.0 mg/L as P (3.0 mg/L as phosphate, PO_4) throughout the distribution system;
.7 Should consider a six-month higher dose period to establish the desired residual; and
.8 Should not begin operation until the distribution system has been cleaned by flushing, with hydraulic pigs, or swabbing.

12.3.2.2 Silicate-Based Inhibitors

Silicate-based corrosion inhibitors are a mixture of soda ash and silicon dioxide. The mechanisms by which silicate inhibitors control lead and copper release have been debated. Silicates may form an adherent film on the surface of the pipe. Silicates will also increase the pH of the water, which may reduce lead and copper release.

Many systems have not considered silicate inhibitors for lead and copper control due to the lack of research and field information proving its effectiveness, the estimated operating costs and high dosage rates required, and the time it takes to reduce lead concentrations. There has been demonstrated effectiveness against intermittent red water issues due to silicates' ability to sequester iron and manganese, and they can also reduce loss of calcium from asbestos cement or cement-lined pipes.

The effectiveness of silicate inhibitors depends on silicate level, pH, and the DIC of the water. A start-up dose of 24 mg/L is recommended, followed by a gradual reduction after 60 days to a maintenance dose of 8 to 12 mg/L.

12.3.3 Split Treatment

Under some circumstances, a softening water treatment plant can be designed using "split treatment" in which raw water is blended with softened water to partially stabilize the water prior to secondary clarification and filtration. Treatment plants that use "split treatment" should also contain facilities for further stabilization by other means.

12.4 On-Going Testing

Corrosion cannot be measured using one single parameter or method. Instead, corrosion should be measured by establishing a baseline measure of the existing rate of corrosion by documenting water quality complaint location and frequency, or preferably by adopting widespread sampling.

The most common method for measuring corrosion is to monitor lead concentrations at the consumer's tap. Monitoring lead levels at the consumer's tap can help identify sources of lead (i.e. service lines, solder, or fixtures), and can provide information about water corrosivity throughout the distribution system.

Water Suppliers may assess the corrosion control methods by first making limited water quality changes, such as pH shift of +0.5 units or soda ash addition of up to 10 mg/L and then confirming the effectiveness of the change after allowing 6 to 9 months for the corrosion process to adjust. Effective pH adjustment requires proper process control through monitoring, instrumentation, and alarms. Continuous monitoring of pH should be provided upstream of the chemical injection point and downstream after the chemical is completely mixed.

Monitoring/testing equipment should be provided for determining the effectiveness of stabilization treatment and the chemical residuals at the entry point and in the distribution system, including an acceptable pH probe that uses three standards for calibration.

Laboratory testing equipment should be provided for determining the effectiveness of stabilization treatments where specific water quality parameter targets have been established (e.g. pH, alkalinity, etc.). A coupon corrosion testing station should be considered for in-situ measurement of corrosion in distribution systems to establish the current rate of corrosion and evaluate changes over time with the implementation or adjustment of corrosion control treatment strategies (e.g. addition of corrosion inhibitors). Pipe-loops or other pilot scale work can also be used to evaluate actual corrosion or corrosion rates of proposed treatment.

13 Chemical Application

13.1 General

This chapter provides an overview of the general requirements for the storage, handling, dosing, and safety of chemicals used in drinking water treatment applications. The Designer should refer to WorkSafeBC for safe work practices, which should lead the design of chemical handling systems.

All chemicals and water contact materials should meet the current versions of NSF/ANSI/CAN 60: *Drinking Water Treatment Chemicals – Health Effects* and NSF/ANSI/CAN 61: *Drinking Water System Components – Health Effects*, where these materials are available for the application.

When designing chemical storage rooms, Chapter 5 – Facility Recommendations should be referenced.

13.1.1 Plans and Specifications

Plans and specifications should include:

- .1 Descriptions of feed equipment, including maximum and minimum feed ranges;
- .2 Procedures for handling overfeed;
- .3 Location of feeders, piping layout and points of application;
- .4 Storage and handling facility details include duration of storage;
- .5 Operating and control procedures including proposed application rates;
- .6 Descriptions of testing equipment; and
- .7 System description including all tanks with capacities (with drains, overflows, and vents), feeders, transfer pumps, connecting piping, valves, points of application, backflow prevention devices, air gaps, secondary containment, and safety eyewash and showers.

For each chemical, the following documentation should also be available:

- .1 Documentation that the chemical is NSF/ANSI Standard 60 approved;
    - o In addition to confirming the correct certification for the chemical is met (NSF and/or AWWA), suppliers may also elect to conduct quality assurance testing on the product to confirm suitability and compliance with relevant specifications.
- .2 Specifications for the chemical to be used;
- .3 Purpose of the chemical;
- .4 Proposed minimum non-zero, average and maximum dosages; solution strength or purity (as applicable); and specific gravity or bulk density;
- .5 Method for independent calculation of the amount fed daily; and
- .6 Chemical hazards class, if any, and regulatory workplace health/safety and chemical exposure standards listed in safety data sheets (SDS).

13.2 Safety

Designers should carefully consider chemical delivery and storage when designing water treatment plants. Improper delivery, storage, or use may result in a toxic or explosive environment. The Designer should discuss the safe use and storage of treatment chemicals with the local fire marshal, building code officials, and other authorities responsible for implementing regulations as part of the design process. The Emergency Response Plan (ERP) for the facility should include relevant emergency information for each chemical.

General safety design considerations for chemical systems should include:

.1 Chemical safety considerations and labelling should be in accordance with the Workplace Hazardous Materials Information System (WHMIS).
.2 Eyewash and shower stations with tempered water accessible to operators and delivery personnel with alarm and strobe to indicate shower is in use as per WorkSafeBC;
.3 Separate containment around unloading, storage and feed facilities for each chemical;
.4 Double walled piping or shrouding directing any leakage back to containment or a control sump for overhead piping systems;
.5 Seismic bracing, supports, and pipe design to prevent damage to chemical storage and handling facilities during an earthquake;
.6 Separate delivery, storage, and feed facilities for strong oxidants, such as gaseous chlorine or calcium hypochlorite. Where separate delivery and storage facilities are not feasible, means must be provided to prevent storage and mixing of incompatible chemicals;
.7 Clearly labeled chemical fill ports, piping, and storage tanks with the chemical used;
.8 Locks on every chemical fill port to prevent access when the operator is not present;
.9 Covered spill containment around chemical fill ports;
.10 Equipment to contain and scrub chlorine gas, and/or appropriate containment and treatment for other gases used or created on-site (e.g. hydrogen gas formed during on-site generation of sodium hypochlorite);
.11 Egress and ingress requirements for rooms or areas with chemical storage and feed facilities;
.12 Compliance with all applicable WorkSafeBC standards, such as signage, safety gear, training, atmospheric monitoring devices, ventilation, and eyewash and safety shower locations;
.13 The Designer should review the *Safe Work Practices for Chlorine* by WorkSafeBC when designing chlorination systems;
.14 Chemical buildings or storage areas must be provided with adequate warning signs, conspicuously displayed where identifiable hazards exist;
.15 A storage area for filing safety data sheets (SDS) as set out under the *Federal Hazardous Products Act* and associated Controlled Products Regulations should be provided; and
.16 A safety data sheet (SDS) should be available for each chemical.

13.2.1 Ventilation

Special provisions should be made for ventilation and heating of chemical feed and storage rooms, see Chapter 5 – Facility Recommendations for further information.

13.2.2 Chemical Overfeed Prevention

Injecting chemicals into the water supply always poses some potential of overfeed if equipment is not designed, installed, operated, or maintained properly.

Design elements and appropriate standard operating procedures (SOPs) can minimize the potential for overfeed. The following design considerations should be made to reduce the likelihood of overfeeding:

.1 Include day tanks when the system needs to use large bulk volumes of treatment chemicals. Size the day tanks to store no more than 30 hours of supply and have an operator fill the tanks in a controlled manner *(Ten State Standards, 2018).* These tanks promote daily inspection of the feed systems and reduce the magnitude of an overfeed;

.2 Evaluate the failure modes of the equipment and add redundant safeguards if needed.
.3 Designers should consider the feasibility of installing flow-based chemical feed control or physical limitations to chemical feed flow (e.g. maximum pump rates);
.4 Chemical feeders should be interlocked with plant system controls to shutdown automatically when raw water flows stop;
.5 Select chemical injection points to minimize the potential for siphoning or hydraulically draining chemical storage tanks, even if their design includes antisiphon features;
.6 Include continuous monitoring equipment with integrated alarms (pH, chlorine, fluoride). In some cases, redundant monitoring equipment should be provided. It is appropriate for these alarms to shut down the equipment;
.7 Provide appropriate cross connection control;
.8 Where chemical feed equipment is automatically controlled, the design must allow for override by manual controls;
.9 Where SCADA allows remote access, conduct a cybersecurity risk assessment (for example, using AWWA's Cybersecurity Risk Management Tool) and address any vulnerabilities; and
.10 Refer to design criteria in Section 13.3.6.1 – Control of Feed Systems for more information.

13.2.3 Other Protective Equipment

The following protective equipment should also be considered:

.1 At least one pair of rubber gloves, a dust respirator of a type certified by NIOSH for toxic dust, an apron or other protective clothing, and goggles or face mask should be provided for each operator;
.2 An appropriate deluge shower and eye washing device should be installed where strong acids and alkalis are used or stored as per *American National Standards Institute (ANSI) Standard Z358.1-2014 Emergency Eyewash and Shower Equipment*; and
.3 Other protective equipment should be provided as necessary.

13.3 Chemical System Design

The following should be considered when designing any chemical system:

.1 Any material in contact with a treatment chemical should be resistant to the aggressiveness of the chemical solution;
.2 Corrosive chemicals should be introduced in such a manner as to minimize the potential for corrosion, i.e. the application should not be near sample taps, screens or pumping equipment; and
.3 Incompatible chemicals should not be stored or handled together (i.e. sodium hypochlorite is incompatible with acids or aluminum sulphate). Such incompatible chemicals should not be allowed to mix, including in a common drain.

13.3.1 Chemical Storage

The following should be considered for the storage of all chemicals:

.1 Sufficient chemical supply should be provided for a 30-day period at the maximum monthly consumption rate, but storage should also consider:
   a. A suitable safety factor based on reserve volume requirements and typical chemical delivery lag times;

b. The rate of decay of the chemical;
c. Emergency scenarios, where a delay in delivery may affect the availability of the chemical;

.2 A minimum storage volume of 1.5 times the delivery volume where the purchase is by truckload or railcar;
.3 Space for convenient and efficient handling of chemicals;
.4 Storage tanks and pipelines should not be used for different chemicals;
.5 Chemicals should be delivered in unopened or covered containers until transferred into an approved storage unit;
.6 Safety data sheets (SDS) for all chemicals used should be kept on-site;
.7 Storage location and associated controls should be selected with considerations for chemical and climate conditions to maintain stable product and should consider chemical decay rate and product reliability;
.8 Dry storage conditions;
.9 Floor surfaces should be smooth, impervious, non-slip, and well-drained; and
.10 Floor drains should be directed to separate containment areas, such that incompatible chemicals cannot mix. Containment areas should include provisions for discharge to an appropriate waste receiving/disposal system.

13.3.2 Application Points

The following should be considered when designing chemical application points:

.1 Ensure maximum efficiency of treatment;
.2 Ensure maximum safety to consumer;
.3 Provide maximum safety to operators;
.4 Minimize the potential for siphoning or hydraulically draining chemical storage tanks, even if their design includes antisiphon features;
.5 Ensure satisfactory mixing of the chemicals with the water (i.e. through a suitably designed diffuser which should be designed for removal and cleaning);
.6 Should not be located where the flow splits;
.7 Provide maximum flexibility of operation through various points of application, when appropriate;
.8 Prevent backflow or backsiphonage between multiple points of feed; and
.9 The sequence of addition of chemicals should be evaluated for potential interactions (reactions) that may decrease or eliminate the intended process effect.

13.3.3 Makeup Water Supply

Makeup water supply should be:

.1 Ample in quantity and adequate in pressure;
.2 Provided with a means for measurement when preparing specific solution concentrations by dilution;
.3 Properly treated for hardness, when necessary;
.4 Properly protected against backflow; and
.5 Obtained from the finished water supply, or from a location sufficiently downstream of any chemical feed point to ensure adequate mixing.

13.3.4 Cross Connection Control

Designers should refer to Chapter 5 – Facility Requirements for general cross connection considerations. Cross connection control should be provided to ensure that:

.1 The service water lines discharging to liquid storage tanks are properly protected from backflow as required;
.2 Chemical solutions or slurries cannot be siphoned through liquid chemical feeders into the water supply;
.3 No direct connection exists between any sewer and a drain or overflow from the liquid chemical feeder, liquid storage chamber or tank by providing that all drains terminate at least 150 mm or two pipe diameters, whichever is greater, above the overflow rim of a receiving sump, a conduit or waste receptacle; and
.4 In the absence of other cross connection control measures, separate day tanks and feeders should be provided for chemical feed systems that have feed points at both unfiltered and filtered water locations such that all unfiltered water feed points are fed from one day tank and feeder, and that all filtered water feed points are fed from another day tank and feeder.

13.3.5 Chemical Handling

When designing the handling methods of chemicals, safe work practices should be followed, including the following:

.1 The offloading area is to be designed to adequately contain spills and account for failure of delivery equipment;
.2 Carts, elevators, dollies and other appropriate means should be provided for lifting chemical containers to minimize any excessive lifting by operators;
.3 Provisions should be made for disposing of empty bags, drums, carboys, or barrels by an approved procedure which will minimize exposure to dust and prevent environmental damage; and
.4 Provision should be made for measuring quantities of chemicals used to prepare feed solutions.

13.3.6 Chemical Feed Equipment

When feeding chemicals into the system, the following should be considered:

.1 Each chemical should be conducted from the feeder to the point of application in separate conduits;
.2 A separate feeder should be used for each chemical applied;
.3 Where a chemical feed pump is necessary for the protection of the supply, such as chlorination, coagulation or other essential processes, a standby unit or a combination of units of sufficient size to meet capacity should be provided to replace the largest unit when out of service;
.4 Spare parts should be available on-site for all feeders and chemical booster pumps to replace parts which are subject to wear and damage;
.5 Feeders should be able to supply, at all times, the necessary amounts of chemicals at an accurate rate, throughout the range of feed;
.6 Chemical feeders and pumps should operate at no lower than 20% of the maximum feed rate (unless the pump is equipped with two independent adjustment mechanisms such as

pump pulse rate and stroke length, in which case the pump should operate at no lower than 10% of the rated maximum unless approved); and

.7 Gravity feed may be used where practical; design must include adequate control (refer to Section 13.3.6.1 – Control of Feed Systems) and safety considerations.

13.3.6.1 Control of Feed Systems

The following should be considered for the control of the feed system:

.1 Feeders may be manually or automatically controlled. Automatic controls must be designed to allow override by manual controls;

.2 Systems should have automatic valve closure to isolate dosing lines in the event of a high-level chemical alarm, where the dosing chemical can have an adverse effect on the process or human health;

.3 Chemical feed rates should be proportional to the flow streams being dosed;

.4 A means to measure the water flow should be provided in order to determine chemical feed rates;

.5 Coagulant and coagulant aid addition may be controlled, where water quality conditions warrant, by turbidity, streaming current detectors, pH, or some other sensed parameter, in addition to plant flow;

.6 Chemical disinfectants should be automatically controlled by monitoring residual disinfectant concentrations in addition to plant flow with appropriate alarms and other procedures to prevent inadequately disinfected water from entering the distribution system; and

.7 Provisions should be made for measuring the quantities of chemicals used.

13.3.6.2 Locations of Feed Systems

The following should be considered for the location of the feed system:

.1 Should be readily accessible for servicing, repair, and observation of operation;

.2 Should be located in a separate room wherever hazards and dust problems may exist;

.3 Chemical feeders should be as near as practical to the feed point, to minimize feed line lengths; and

.4 Chemical feed pumps should be located within secondary spill containment.

13.3.7 Feed Lines

Feed lines should be:

.1 As short as possible;

.2 Avoid overhead installations and provide double wall or shielding where required (refer to Section 13.2 – Safety);

.3 Of durable, corrosion-resistant material;

.4 Easily accessible throughout the entire length;

.5 Readily cleanable;

.6 Neatly installed to avoid excessive changes in elevations and looping, and properly secured;

.7 Provide flushing ports at suitable locations to allow draining and cleaning of pipelines;

.8 Protected from freezing;

.9 Underground chemical lines should have double containment and leak detection;

.10 Slope upward from the chemical source to the feeder when conveying gases;
.11 Designed consistent with the scale-forming or solids depositing properties of the water, chemical, solution or mixtures being conveyed;
.12 Have an isolating valve when chemicals are dosed into a pressurized line; and
.13 Colour-coded and labelled as per Chapter 5 – Facility Recommendations.

13.4 Liquid Chemicals

13.4.1 Liquid Chemical Storage

The following should be considered when storing liquid chemicals:

.1 All tanks should have a liquid level indicator;
.2 All tanks should have an overflow and a receiving basin capable of receiving accidental spills or overflows without uncontrolled discharge. A common receiving basin may be provided for each group of compatible chemicals, which provides sufficient containment volume to prevent accidental discharge in the event of failure of the largest tank;
.3 The minimum containment should be equal to or greater than 110% of the volume of the largest storage unit, or combination of units if interconnected, less the volume remaining in the container(s) where storage vessels are located within the containment area;
.4 Storage tanks and pipelines for liquid chemicals should be specified for use with individual chemicals and not used for different chemicals;
.5 The minimum containment for chemical unloading and delivery areas should be equal to or greater than 110% of the volume of the largest vessel within the vehicle;
.6 Offloading areas should be clearly labelled to prevent accidental cross-contamination; and
.7 Chemicals should be stored in covered or unopened shipping containers, unless the chemical is transferred into an approved storage unit.

13.4.1.1 Bulk Tanks

Bulk liquid storage tanks should:

.1 Have a means, which is consistent with the nature of the chemical stored, to maintain a uniform chemical strength;
.2 Have continuous agitation to maintain slurries in suspension;
.3 Have a means to ensure continuity of chemical supply while servicing a tank;
.4 Have a method to measure the liquid level in the liquid storage tank, and where an external level gauge is provided, a shut-off valve at the tank connection is recommended;
.5 Have fill lines, which should be:
  a. A minimum of 50 mm in diameter;
  b. Properly identified at the end remote from the tank, and have provisions to drain the fill line;
  c. Sloped to drain into the tank;
.6 Low level and high-level alarms, enunciated where an operator is present, should be provided where applicable, and should be alarmed in the SCADA system where appropriate;
.7 Be kept covered. Large tanks with access openings should have such openings curbed and fitted with overhanging covers;
.8 Subsurface locations should:
  a. Be free from sources of possible contamination;

b. Have positive drainage away from the area for groundwaters, accumulated water, chemical spills, and overflows;

.9 Have overflow pipes, which should be:
a. Sized appropriately for the rate of fill;
b. Turned downward, with the end screened;
c. Not connected directly to the sewer;
d. Have proper cross connection control;
e. Sloped down from the tank;
f. Have a free fall discharge into the containment area;
g. Located where noticeable;

.10 Have vents, which should be:
a. Not in common with other chemicals or day tanks;
b. Minimum size 50 mm;
c. With a down-turned end;
d. Provided with an insect screen, where venting outside is required;
e. Secured, if externally accessible;
f. The potential for moisture build-up resulting in vent freezing should also be considered;

.11 Acid storage tanks should be vented to the outside atmosphere;
.12 Be provided with a valved drain, which should not discharge directly to a sewer;
.13 Be protected against cross connections;
.14 If lined, weep holes in the outer shell should be provided to give an indication of liner leakage;
.15 Have secondary containment, which should be located so that the chemicals from equipment failure, spillage or accidental drainage do not enter the water system or environment;
.16 Piping should be designed to minimize or contain chemical spills in the event of pipe ruptures.

13.4.1.2 Day Tanks

Chemicals that are delivered to the facility in liquid form and are not likely to precipitate, or chemical solutions that have been mechanically mixed in batch tanks, may be transferred to a day tank which is the supply for liquid metering pumps. Chemicals may be fed directly from the shipping containers if they are less than 200 L in volume, but protection against overfeeding should be considered. Day tanks help to reduce the impact of chemical overfeeding. The following should be considered when designing day tanks:

.1 Day tanks should meet all the requirements of the bulk liquid storage tanks in Section 13.3.1 – Chemical Storage, except that day tanks do not require overflow lines and drains;
.2 Day tanks should hold no more than a 30-hour supply based on average day demand;
.3 Day tank sizing should consider the following:
a. The rate of use of the chemical;
b. The decay of the chemical;
c. The dilution ratio of the chemical;
d. The frequency of operator attendance to the WTP;

.4 Day tanks should be covered;

.5 Acid storage tanks should be vented to an exterior building vent through separate vent pipes that are located far enough from the air intakes (air condition, ventilation, etc.) to prevent contamination of indoor air;
.6 Subsurface day tanks should not be used; if necessary, they should meet the requirements in Section 13.3.1 – Chemical Storage;
.7 Day tanks should be scale-mounted, or have a calibrated gauge painted or mounted on the side if liquid level can be observed in a gauge tube or through translucent sidewalls of the tank. In opaque tanks, a gauge rod may be used;
.8 Piping arrangement for refilling the day tanks should be such that it will prevent over-filling of the tanks;
.9 Except for fluosilicic acid, hand pumps should be provided for transfer from a shipping container. A tip rack may be used to permit withdrawal into a bucket from a spigot. Where motor-driven transfer pumps are provided, a liquid level limit switch should be provided;
.10 A means which is consistent with the nature of the chemical solution should be provided to maintain uniform chemical strength in a day tank;
.11 Low level and high-level alarms, enunciated where an operator is present, should be provided where applicable, and should be alarmed in the SCADA system where appropriate;
.12 Continuous agitation should be provided to maintain chemical slurries in suspension;
.13 Tanks and tank refilling line entry points should be clearly labelled with the name of the chemical contained; and
.14 Filling of day tanks should not be automated, unless otherwise authorized.

13.4.2 Liquid Chemical Feed Systems

Positive displacement solution feed pumps should be:

.1 Capable of operating at the required maximum rate against the maximum head conditions found at the point of injection;
.2 Provided with calibration tubes or mass flow monitors which allow for direct physical measurement of actual feed rates and to calibrate pumps;
.3 Provided with a pressure relief valve (PRV) on the pump discharge line:
   a. The PRV should be adequately sized for the pump and set to be not greater than 20% of the pump discharge pressure in normal operation;
   b. If the pumped fluid is relieved through the PRV, it should pass to a safe location, preferably back to the storage tank;
   c. Where liquid-filled diaphragm pumps are in use, the over-pressure should be relieved by discharge of the motive fluid to a safe location; and
   d. Where oil-filled diaphragm pumps are used, the oil must be of a grade suitable for use in drinking water supplies (food grade).

Special considerations should be made for slurry feed applications based on solids content, homogeneousness, operating pressure, and discharge feed piping configuration.

Eductors can be used to feed liquid chemicals. They should be selected for the point of application with consideration given to the quantity of chemical to be added, the maximum injector flow rate, the injector location pressure, the injector operating pressure, and the size of chlorine solution piping. Gauges for measuring water pressure and vacuum at the inlet and outlet of each eductor should be provided.

Liquid chemical feeders should be designed such that chemical solutions cannot be siphoned or overfed into the water supply, by:

.1 Ensuring discharge at a point of positive pressure;
.2 Providing vacuum relief;
.3 Providing emergency shutoff valves;
.4 Providing a suitable air gap or anti-siphon device; or
.5 Providing other suitable means or combinations as necessary.

13.5 Dry Chemicals

13.5.1 Dust Control

The following dust control measures should be designed to control dust from dry chemicals:

.1 Granular materials are preferred to powders;
.2 Particular care should be taken to protect mechanical and electrical equipment from fine dust;
.3 Provisions should be made for disposing of empty bags, drums or barrels by an approved procedure which minimizes exposure to dust;
.4 The transfer should be in such a way as to minimize the quantity of dust which may enter the room in which the equipment is installed;
.5 Dust control should be provided by use of vacuum pneumatic equipment or closed conveyor systems, facilities for emptying shipping containers in special enclosures and/or exhaust fans and dust filters that put the hoppers or bins under negative pressure;
.6 Where exhaust fans, filters, and conveying systems are used, grounding should be provided to prevent the build-up of static electricity;
.7 Floor drains should be provided for the wash down of floors in the transfer/storage area; and
.8 Silo vent and exhaust systems should be provided with dust filters and/or cyclone type separators to prevent the release of dust into the atmosphere.

13.5.2 Bulk Storage Silos & Feeders

For the design of bulk storage silos and feeders, the following should be considered:

.1 Bulk storage silos should be provided with adequately sized fill openings;
.2 Fill lines, where necessary, should be smooth internally with long radius elbows;
.3 Silos should be provided with suitable level indicating devices, such as load cells;
.4 A pressure relief valve should be provided when pneumatic fill systems are used;
.5 Air exhausted from the handling areas should be directed away from air intakes;
.6 The Designer should take into account material characteristics such as flowability, tendency to pack tightly, the angle of repose in the design of the silo bottom, and method of removal of material to a feeder; and
.7 Provision should be made to relieve bridging or rat-holing of the stored material, either by manual, mechanical or other means of rapping or agitating the hopper bottom or improving the flowability of the material, for example, by air fluidization.

13.5.3 Dry Chemical Feed Systems

When feeding dry chemicals, the following should be considered:

.1 Provide a means of measuring chemicals volumetrically or gravimetrically;
.2 Provide adequate solution water and agitation of the chemical at the point of placing in solution/slurry;
.3 Provide gravity feed from solution containers; and
.4 Completely enclose chemicals to prevent the emission of dust.

13.6 Gaseous Chemicals

13.6.1 Measuring Contents

Means of measuring the contents of gas containers should be provided, and where necessary for the proper operation of the feed system, means of adjusting and indicating gas pressure/vacuum and flow rates should be provided.

13.6.2 Moving Cylinders

The Designer should allow sufficient space in the storage area for convenient moving of cylinders from full storage to on-line to empty storage. For chlorine, sulphur dioxide, ammonia and carbon dioxide gas systems, the Designer should refer to documentation from the Chlorine Institute and gas equipment suppliers.

13.6.3 Storage Areas

Storage areas should:

.1 Be separated from other areas;
.2 Have separate outside access; and
.3 Be arranged to prevent the uncontrolled release of spilled gas to other areas of the plant and surrounding environment.

13.6.4 Feed Rates

Where high feed rates are required by evaporation from liquefied gas, it may not be possible to withdraw the required gas quantity from a single-cylinder due to evaporative cooling and the consequent reduction in gas vapour pressure.

The Designer should consider either using multiple cylinders online or the use of an evaporator to meet higher withdrawal rates. Where multiple cylinders are being used, provision for automatic switching between duty and standby cylinders should be provided for gaseous chemicals that are being relied upon for pathogen log reduction credit (e.g. disinfectants).

13.7 Chemical Specific Design

This section details design considerations that are unique to some of the commonly used water treatment chemicals.

13.7.1 Acids and Caustics

The following should be considered when designing chemical systems for acids and caustics:

- .1 Acids and caustics should be kept in closed corrosion-resistant shipping containers or bulk liquid storage tanks;
- .2 Acids and caustics should not be handled in open vessels but should be pumped in undiluted form to and from bulk liquid storage tanks and covered day tanks or from shipping containers through suitable hoses, to the point of treatment;
- .3 Adequate precautions should be taken for operator safety, such as not adding water to concentrated acid; and
- .4 Strong acids and bases require careful selection, storage, and handling to protect worker safety. For example, a 50% caustic solution starts to solidify at approximately 12 °C, which can plug piping and even cause injury if valves or piping fail as a result. For this reason, the use of a more dilute solution (25% or less) is recommended. When feeding concentrated acids and bases, include design features to lower the risk of chemical overfeed. Refer to Section 13.2 – Safety for more information.

13.7.2 Chlorine Gas

The Designer should refer to the *Safe Work Practices for Chlorine* by WorkSafeBC when designing a chlorine gas system. General design considerations for chlorine gas are below.

13.7.2.1 Chlorine Gas Storage

The following should be considered when designing chlorine gas storage:

- .1 Chlorinators should be housed in a room separate from, but adjacent to, the chlorine storage room;
- .2 Only equipment essential to the chlorine gas system should be stored in the chlorine gas room, including no other chemicals stored in the room;
- .3 Regulator should be located as close as possible to the cylinder or tonner head. Regulator pressure relief valve vent should be directed outdoors, alarmed and remote from air intakes and occupied areas;
- .4 All piping carrying chlorine gas or liquid should be identified according to WHMIS requirements;
- .5 Both the chlorine gas feed and storage rooms should be located in the corner of the building, on the prevailing downwind side of the building and be away from entrances, windows, louvres, walkways, etc.;
- .6 Premanufactured chlorine cabinets maybe used for retrofitting cylinder installations only. These cabinets should have an observation window, fan, air intake, ventilation, and light. These cabinets should not be placed on the sunny side of the building;
- .7 A valve stem wrench should be kept in place on each cylinder or tonner in use, to allow quick closure during an emergency;
- .8 Cylinders or tonners should be equipped with auto shutoff valves to limit release of chlorine gas in the event a chlorine gas leak;
- .9 Cylinders should be stored in an upright position, tagged if empty and securely chained to the wall or weigh scale post

.10 Tonners should be stored on trunnions and tagged if empty. Online tonners should be loaded on weigh scales to monitor chemical storage levels;

.11 Ability to shut off chlorine gas at cylinder remotely, either manually or automatically due to alarm, with notice to operator;

.12 Protective hood in place when cylinder is not connected to chlorinator;

.13 Suitable weigh scale in use for active connected cylinder;

.14 Chlorinator rooms should be heated to 15.5 °C and protected from excessive heat. Cylinders and gas lines should be protected from temperatures above that of the feed equipment, with consideration for providing a heat detector alarm;

.15 Both the feed and storage rooms should be constructed to meet the following requirements:

a. A shatter-resistant inspection window should be installed in an interior wall to allow for visual inspection of the room and gas monitor to assess whether the room is safe to enter;
b. Include chlorine gas detection equipment located at floor level to continuously monitor for the presence of chlorine gas. Locate gas monitor display unit in a location that is visible from the monitoring window.
c. Signs should be posted identifying hazards and precautions for safe entry and designated as a restricted work area and limited to entry by authorized staff. The signs also need to be worded to ensure that the interior of the chlorine room is viewed for signs of a gas leak before the exhaust fan is turned on, and that the fan is turned on before routine entry. The specific alarm levels must be noted on the warning signs;
d. Room should be located above ground and enclosed from other rooms with a fire resistant floor and wall and be designed to prevent chlorine gas leaks from entering areas occupied by the public or by staff;
e. All openings between the rooms and the remainder of the plant should be sealed; The chlorine room needs to be smoke or pressure tested to confirm a complete seal upon completion of construction;
f. Doors should be equipped with panic hardware, ensuring ready means of exit, and opening outward only to the building exterior. Doors should also have a locking mechanism but not be self locking;
g. All room exits are external;
h. A signal light showing ventilating fan operation should be provided at each entrance when the fan can be controlled from more than one point;
i. Floor drains are discouraged. Where provided, the floor drains must discharge to the outside of the building and not be connected to other internal or external drainage systems; and
j. Provisions must be made to chemically neutralize or contain chlorine gas (or other acceptable measures) where feed and/or storage is located near residential or developed areas in the event of any measured chlorine release. The chemical neutralizing equipment must be sized to treat the entire contents of the largest storage container on site.

.16 Heating and ventilation in the feed and storage rooms should include the following considerations:

a. The ventilating exhaust fan should take suction near the floor and as great a distance as is practical from the door and air inlet. The point of discharge should be located outside of the building away from air inlets to any rooms or structures and designated walkway areas. The exhaust duct should not pass through other rooms. It also needs to be equipped with a gas-rated back-draft damper, as a major leak from a full cylinder of chlorine could displace several times the volume of air in a normal chlorine room;

b. A ventilating exhaust fan with a capacity to complete one air change per minute when the room is occupied; where this is not appropriate due to the size of the room, a lesser rate could be considered. The fan should be able to be operated in emergency situations and well as routinely;
c. Air inlets with corrosion-resistant louvres should be installed near the ceiling on the exterior wall;
d. Air intake and exhaust louvres should provide airtight closure;
e. Discharge ducts should be separate from other ducts and should be vapour proof and corrosion resistant. Discharge duct should extend vertically up to at least 2.5 m above the roof (if near the edge) or 6 m (if in the middle of the roof); and
f. Separate switches for the ventilating exhaust fan and for the lights should be located outside and at the inspection window and easily identified. Outside switches must be protected from vandalism.

13.7.2.2 Chlorine Gas Feeders

The following should be considered when designing chlorine gas feeders:

.1 Chlorine gas feed systems should be of the vacuum type and include a vacuum regulator on all individual cylinders in service;
.2 Service water to injectors/eductors should be of adequate supply and pressure to operate feed equipment within the needed chlorine dosage range for the proposed system;
.3 Pressurized chlorine feed lines should not carry chlorine gas beyond the chlorinator room. The chlorine gas ejector should be located within the chlorine room, and the ejector water supply line brought to it, so that all chlorine gas facilities are contained within the chlorine room;
.4 Full and empty cylinders of chlorine gas should meet the following requirements:
  a. Housed only in the chlorine storage room;
  b. Isolated from operating areas; and
  c. Restrained in position.

13.7.2.3 Chlorine Gas Leak Detection

Chlorine gas leaks are a public health and safety issue when using chlorine gas as a disinfectant. Leak prevention is the primary objective. The following should be considered when designing a chlorine gas leak detection system:

.1 A bottle of concentrated ammonium hydroxide (56% ammonia solution) should be available for chlorine leak detection;
.2 Where ton containers are used, a leak repair kit approved by the Chlorine Institute should be provided;
.3 Where pressurized chlorine gas is present, continuous chlorine leak detection equipment is required and should be equipped with both an audible alarm and a warning light;
.4 The alarm equipment, except the sensor, should be located inside the building and outside the chlorine room near the viewing window, to protect the equipment from corrosion and to ensure that a major leak does not destroy it before it alarms; and

.5 The gas sensor should be located near floor level within the chlorine room and remote from the door, ventilation inlet, and vacuum regulator vent outlet. The alarm unit should preferably not be hard wired to allow for maintenance, but the connection needs to be protected to prevent accidental unplugging.

13.7.2.4 Respiratory Protection Equipment

Respiratory protection equipment, meeting the requirements of the *CAN/CSA-Z94.4-18 Selection, Use and Care of Respirators* should be available where chlorine gas is handled and should be stored at a convenient heated location, but not inside any room where chlorine is used or stored. The units should use compressed air, have at least a 30-minute capacity, and be compatible with or be the same as the units used by the fire department responsible for the plant.

13.7.3 Chlorine Dioxide

Refer to Chapter 11 – Disinfection for guidance on the use of chlorine dioxide for disinfection.

13.7.3.1 Chlorine Dioxide Generators

Chlorine dioxide generation equipment should be factory assembled pre-engineered units with a minimum efficiency of 95%. Health Canada recommends a maximum feed dose of 1.2 mg/L of chlorine dioxide should not be exceeded to control the formation of chlorite and chlorate.

Common continuous generators require a stream of sodium chlorite solution and a carefully proportioned stream of chlorine. Where chlorine is not available, hypochlorite solution and an acid may be used in a three-feed reactor. When feed streams are correctly proportioned, these generators can show an efficiency in generating chlorine dioxide of over 95%. A variant generator that uses only hydrochloric acid and chlorite solution is simpler to feed but operates at a lower conversion efficiency. It produces chlorine dioxide that does not contain any elemental chlorine contamination; as a result, it does not form any THMs or HAAs when used as a disinfectant.

13.7.3.2 Feed and Storage Facilities

Chlorine gas and sodium chlorite feed and storage facilities should comply with Section 13.7.2 – Chlorine Gas and Section 13.7.4 – Sodium Chlorite, respectively. Sodium hypochlorite feed and storage facilities should comply with Section 13.7.5 – Sodium Hypochlorite.

13.7.3.3 Public Notification

Notification of a change in disinfection practices and the schedule for the change should be made known to the public; particularly to hospitals, kidney dialysis facilities, and fish breeders, as chlorine dioxide in water and its by-products may have health and safety considerations similar to those for chloramines.

13.7.4 Sodium Chlorite

Provisions should be made for the proper storage and handling of sodium chlorite to eliminate any danger of fire or explosion associated with its strong oxidizing nature.

13.7.4.1 Storage

The following should be considered when designing the storage of sodium chlorite:

.1 Sodium chlorite should be stored by itself in a separate room and preferably should be stored in an outside building detached from the water treatment facility. It should be stored away from organic materials because many materials will catch fire and burn violently when in contact with sodium chlorite;
.2 Storage structures should be constructed of non-combustible materials; and
.3 If a storage structure must be located in an area where a fire may occur, water must be available to keep the sodium chlorite area cool enough to prevent heat-induced explosive decomposition.

13.7.4.2 Handling

The following should be considered when designing the handling of sodium chlorite:

.1 Care should be taken to prevent spillage;
.2 An emergency plan of operation should be available for the cleanup of any spillage; and
.3 Storage drums must be thoroughly flushed to an acceptable drain prior to recycling or disposal.

13.7.4.3 Feeders

The following should be considered when designing the feeders for sodium chlorite:

.1 Positive displacement feeders should be provided;
.2 Tubing for conveying sodium chlorite or chlorine dioxide solutions should be Type 1 PVC, polyethylene or materials recommended by the manufacturer;
.3 Chemical feeders could be installed in chlorine rooms if sufficient space is provided, or in separate rooms;
.4 Feed lines should be installed in a manner to prevent formation of gas pockets and should terminate at a point of positive pressure; and
.5 Check valves should be provided to prevent the backflow of chlorine into the sodium chlorite line.

13.7.5 Sodium Hypochlorite

Sodium hypochlorite storage and handling procedures should be arranged to minimize the slow natural decomposition process of sodium hypochlorite either by contamination or by exposure to more extreme storage conditions. Additionally, feed rates should be regularly adjusted to compensate for this progressive loss in chlorine content.

Sodium hypochlorite is highly corrosive; the design should incorporate appropriate precautions such as avoiding contact with metals, including stainless steel.

13.7.5.1 Storage

When designing the storage of sodium hypochlorite systems, the following should be considered:

.1 Sodium hypochlorite should be stored in the original shipping containers or in sodium hypochlorite compatible bulk liquid storage tanks;

.2 Storage containers or tanks should be located out of the sunlight in a cool area and should be vented to the outside of the building;
.3 Wherever reasonably feasible, stored sodium hypochlorite should be pumped undiluted to the point of application. Where dilution is unavoidable, deionized or softened water should be used;
.4 Storage areas, tanks, and pipe work should be designed to avoid the possibility of uncontrolled discharges and a sufficient amount of appropriately selected spill absorbent should be stored on-site; and
.5 Reusable sodium hypochlorite storage containers should be reserved for use with sodium hypochlorite only and should not be rinsed out or otherwise exposed to internal contamination.

13.7.5.2 Feeders

When designing the feeders for sodium hypochlorite systems, the following should be considered:

.1 Avoid the use of threaded connections as much as possible with PVC systems. Flanged or solvent welded joints are preferable;
.2 Positive displacement pumps with sodium hypochlorite compatible materials for wetted surfaces should be used;
.3 To avoid air locking in smaller installations, small diameter suction lines should be used with foot valves and degassing pump heads;
.4 In larger installations, flooded suction should be used with pipework arranged to ease the escape of gas bubbles;
.5 Calibration tubes or mass flow monitors which allow for direct physical checking of actual feed rates should be provided; and
.6 Injectors should be made removable for regular cleaning, where hard water is to be treated.

13.7.6 Calcium Hypochlorite

Calcium hypochlorite, which is sold as a white powder and as tablets, is typically used to boost chlorine concentration in service reservoirs or for chlorination of small systems. Granular calcium hypochlorite comes in the form of chlorinated lime (a mixture of $Ca(OH)_2$, $CaCl_2$ and $Ca(OCl)_2$) or high test hypochlorite (HTH). All forms of calcium hypochlorite are made with added inert materials (i.e. 30-35% w/w in the case of HTH tablets and 65-80% w/w in the case of chlorinated lime in powder form).

Calcium hypochlorite feeders are manufactured for a range of flow rates. For larger flows, volumetric or gravimetric feeders drop a measured amount of HTH powder (in volume or weight) into a dissolution tank (always accompanied by mixing). After dissolution, the solution is dosed similarly to sodium hypochlorite. Solutions should be prepared on a batch basis for use. The use of feeder devices for calcium hypochlorite is uncommon for larger flows which are usually treated by liquid sodium hypochlorite or chlorine gas.

For smaller flows, HTH in solid tablet form is used (65% w/w Cl_2). These tablets lose less than 1 to 2% w/w Cl_2 per year if stored properly under appropriate conditions. Application in tablet form tends to be limited to small chlorine usage (water flow rates < 0.5 ML/d) due to cost and the practical difficulties of making up aqueous solutions of hypochlorite from the solid product. Tablets are typically used in conjunction with tablet erosion feeders.

Both granular calcium hypochlorite and tablets include additives to prevent powdering of the active material and to stop the adsorption of moisture. This inert material must be separated from the dissolved active hypochlorite to prevent clogging and blockages of pumps and equipment. Separation of diluted calcium hypochlorite from inert materials can be achieved as follows:

.1 From granular product, by the provision of a separate mixing tank upstream of the dosing tank and mechanically mixing. Following proper mixing the inert insoluble material can settle prior to decantation of the dissolved liquid only to the dosing tank;
.2 From granular product, by allowing mixed batched solution to stand for a period of 24 hours prior to dosing so that inert residues settle out prior to use; and
.3 By the use of tablet erosion feeders.

A typical calcium hypochlorite tablet chlorinator consists of a cylindrical PVC tank with a diameter ranging from 230 to 610 mm and a height ranging from 0.6 to 1.2 m. A sieve plate with holes supports the 80 mm diameter calcium hypochlorite tablets.

Tablet chlorinator systems can typically provide between 1 and 295 kg of chlorine per day. A side stream from the main flow is piped into the chlorinator at the bottom of the tank. The flow rises through the holes in the sieve plate, contacting and eroding the bottom layer of tablets. The tablets erode at a predictable rate based on the amount of water that enters the chlorinator. A correct chlorine dosage can be achieved by controlling the water flow rate through the chlorinator. The chlorinator effluent is mixed with the main water flow, providing the desired level of available chlorine to meet operational requirements. Due to the simplicity of the dosing method, tablet chlorinators can be useful for applications in small water systems with reduced maintenance requirements; however, for the same reason, it can be difficult to maintain chlorine doses if the influent water flow rate or quality is variable.

13.7.7 On-Site Hypochlorite Generation Systems

For the design of on-site hypochlorite generation systems, the Designer should consult equipment manufacturers and *AWWA M65 Onsite Generation of Hypochlorite*. Proprietary equipment is available to produce dilute hypochlorite solution by electrolysis of sodium chloride brine. The low concentration sodium hypochlorite solution produced (typically around 0.8%) has a number of advantages compared to bulk sodium hypochlorite (typically around 12%): greatly reduced off-gassing, minimal scaling at feed points, lowered impact on finished water pH and reduced health hazards (i.e. skin irritation).

It should be noted that these systems are typically only cost effective for larger WTPs. Additionally, this process may be more advantageous in remote locations where chemical transportation/delivery is an issue.

The following variables determine the overall efficiency of a given system:

.1 The feed rates of brine and dilution water;
.2 The temperature of the dilute brine entering the cell; and
.3 Electrode (particularly anode) condition.

Water is used in the electrolysis process, both to prepare saturated brine and to dilute the brine prior to the electrolytic cell(s). The high pH within the cell during electrolysis will rapidly precipitate the dissolved calcium and magnesium salts naturally present in some waters, forming scale on the electrode surfaces and reducing electrolysis efficiency. To avoid this, an ion exchange (cationic) softener should be used to treat the water supply to reduce the total hardness of the feed water to typically less than 15 mg $CaCO_3$/L to reduce the need for frequent cell cleaning. Even where the natural hardness of the feed water is low, softening may be installed because of the additional purification provided in terms of the removal of manganese and iron, which could otherwise precipitate in the electrolysis cells and on electrodes. Refer to Section 15.2.3 – Ion Exchange for design considerations.

Cell designs vary from one manufacturer to another. Within the electrolysis cell is a matrix of plate type electrodes manufactured from metals which are resistant to the chemically aggressive environment present during electrolysis. The anode typically comprises a titanium base with a precious metal oxide coating; the cathode is made of either Hastelloy C (a nickel-based alloy) or titanium.

A greater electrolysis voltage is required at low temperatures (lower electrical conductivity) and this can lead to stripping of the metal oxide coating on the anode. This may require that the dilute brine entering the cell is heated indirectly via heat exchange with the warmer cell product. Additional thermostatically-controlled electrical heating should be provided in situations where feedstock temperature can fall below 6 °C. A benefit of heating is the enhanced electrolysis efficiency at higher temperatures, although too great an electrolyte temperature leads to accelerated formation of chlorate by-product, and deterioration in overall efficiency.

The electrolyser system is designed to produce hypochlorite with a chlorine concentration usually in the range of 7 to 9 g Cl_2/L (or 0.7 to 0.9% w/v). Salt consumption rates of proprietary systems are typically 3 kg of salt per kg of equivalent chlorine.

The product from the electrolytic cell, a mixture of aqueous sodium hypochlorite and hydrogen gas, passes to a storage tank. A blower is used to force air into the tank headspace during hypochlorite generation, which reduces the hydrogen concentration to < 1% v/v (25% of lower explosive limit of 4% v/v) and assists ventilation. The diluted hydrogen gas is vented to the atmosphere via a vent above the storage tank. An atmospheric gas monitor should be installed to monitor hydrogen concentration in the electrolyser room.

The following should be considered during the design of on-site hypochlorite generating (OSHG) systems:

.1 The design should provide for a supply of brine makeup water of adequate temperature and quality. Water softening should be considered for brine makeup water to remove excess calcium and magnesium in order to protect electrode life and efficiency by preventing scaling;

.2 Hydrogen gas is a by-product: the design should include a means to safely discharge an off-gas stream of hydrogen. The explosion hazard should be addressed by forced venting of storage tanks to maintain low hydrogen concentrations (<1% v/v).
   - Vents must terminate at a safe exterior location (away from walkways/entrances/air intake and adequately above building high points to allow proper discharge into the atmosphere;

.3 A gas monitor should be installed at the highest point within the generation room and provide an alarm and/or shutdown of the equipment if hydrogen concentration exceeds 1% v/v; and

.4 A day tank for storage of the hypochlorite solution should be provided.

13.7.8 Potassium Permanganate

When designing potassium permanganate systems, the following should be considered:

.1 Potassium permanganate solution decomposes slowly and can be purchased as a granular solid;
.2 Potassium permanganate may be supplied in dry form in buckets, drums and bulk;
.3 A concentrated potassium permanganate solution (1 to 4%) can be generated on-site for water treatment applications;
.4 A source of heated water should be available for dissolving potassium permanganate and mechanical mixers should be provided;
.5 Depending on the amount of permanganate required, solutions should be made up in batch modes, using storage tanks with mixers and a metering pump for small feed systems;
.6 Larger systems should include a dry chemical feeder, storage hopper and dust collector configured to automatically supply permanganate to the solution storage tank;
.7 In conventional treatment plants, potassium permanganate solution is added to the raw water intake, or as far upstream of coagulant addition as possible;
.8 Adequate mixing should be provided;
.9 In all cases, potassium permanganate should be added prior to filtration;
.10 Potassium permanganate solution should be pumped from the solution tank to the injection point. If the injection point is a pipe, a standard injection nozzle protruding midway into the pipe section should be used;
.11 Injection nozzles can also be used to supply the solution to mixing chambers and clarifiers; and
.12 Powered activated carbon (PAC) and potassium permanganate should not be added concurrently.

13.7.9 Activated Carbon

When designing an activated carbon system, the following should be considered:

.1 Activated carbon is a potentially combustible material requiring isolated storage;
.2 Storage facilities should be fireproof and equipped with explosion-proof electrical outlets, lights and motors in areas of dry handling;
.3 Bags of powdered carbon should be stacked in rows with aisles between in such a manner that each bag is accessible for removal and stored in locked and secure rooms separate from ammonia storage;
.4 Protection should be provided from direct sunlight or exposure to excessive heat; and
.5 The Designer should avoid feeding chlorinated water to any form of carbon.

13.7.9.1 Powdered Activated Carbon (PAC)

The following should be considered for PAC design:

.1 The Designer should consider the possibility of powered activated carbon (PAC) addition at several points within the treatment process;
.2 PAC addition should take place as far upstream of coagulant addition as possible, preferably with mechanically aided mixing;

.3 PAC can be added as a premixed slurry or by means of dry feed;
.4 Continuous agitation should be provided to ensure that the PAC does not deposit in the slurry storage tank;
.5 PAC should be considered as a potentially combustible material and should be stored in a separate fire-retardant building or room equipped with explosion proof lighting and electrical systems. Spark-free lighting and electrical systems should be provided;
.6 Wet activated carbon may create an oxygen-deficient environment in enclosed spaces; therefore, appropriate safety precautions should be provided;
.7 Manufacturer recommendations regarding storage and handling should be followed;
.8 Provision should be made for adequate dust control;
.9 Provision should be made to scrub or filter carrier air, when dry PAC is off-loaded into silos; and
.10 PAC should be added downstream of potassium permanganate because it may adsorb permanganate, rendering it unavailable for the oxidation of target organics.

13.7.10 Ammonia

Ammonia for chloramine formation may be added to water either as an aqueous solution of ammonium sulphate, as aqua ammonia, or as anhydrous ammonia (purified 100% ammonia in liquid or gaseous form). The special provisions required for each form of ammonia are listed below.

13.7.10.1 Ammonium Sulphate

An aqueous solution is made by the addition of ammonium sulphate solid to water, with agitation. The tank and dosing equipment contact surfaces should be made of corrosion-resistant non-metallic materials. Provision should be made for removal of the agitator after dissolving the solid. The tank should be fitted with an air-tight lid and vented outdoors. The application point should be at the center of treated water flow, at a location where there is high-velocity movement.

13.7.10.2 Aqua Ammonia (Ammonium Hydroxide)

Aqua ammonia feed pumps and storage should be enclosed and separated from other operating areas. The aqua ammonia room should be equipped as in Section 13.6.3 – Storage Areas with the following changes:

.1 Corrosion-resistant, closed, and unpressurized tanks should be used for bulk liquid storage and day tanks, vented through inert liquid traps to a high point outside;
.2 An incompatible connector or lockout provisions should be provided to prevent accidental addition of other chemicals to bulk liquid storage tank(s);
.3 Bulk liquid storage tank(s) should be designed to avoid conditions where temperature increases cause the ammonia vapour pressure over the aqua ammonia to exceed atmospheric pressure. Such provisions should include either:
   a. Refrigeration or other means of external cooling, and/or;
   b. Dilution and mixing of the contents with water without opening the bulk liquid storage tank;
.4 An exhaust fan should be installed to withdraw air from high points in the room and makeup air should be allowed to enter at a low point;

.5 The aqua ammonia feed pump, regulators and lines should be fitted with pressure relief vents discharging outside the building away from any air intake and with water purge lines leading back to the headspace of the bulk storage tank;
.6 Aqua ammonia should be conveyed directly from a day tank to the treated water stream injector without the use of a carrier water stream, unless the carrier stream is softened;
.7 The application point should be placed in a region of rapid, preferably turbulent, water flow;
.8 Provisions should be made for easy access for the removal of calcium scale deposits from the injector; and
.9 Provision of a modestly sized scrubber capable of handling occasional minor emissions should be considered.

13.7.10.3 Anhydrous Ammonia

Anhydrous ammonia is readily available as a pure liquefied gas under moderate pressure in cylinders or as a cryogenic liquid boiling at -15 °C at atmospheric pressure. The liquid causes severe burns on skin contact.

The following should be considered when designing an anhydrous ammonia system:

.1 Anhydrous ammonia and storage feed systems (including heaters where required) should be enclosed and separated from other work areas and constructed of corrosion resistant materials;
.2 Pressurized ammonia feed lines should be restricted to the ammonia room and any feed lines located outside the room should be installed in airtight conduit pipe;
.3 An emergency air exhaust system, as in Chapter 5 – Facility Recommendations but with an elevated intake, should be provided in the ammonia storage room;
.4 Leak detection systems should be provided in all areas through which ammonia is piped;
.5 Special vacuum breaker/regulator provisions must be made to avoid potentially violent results of the backflow of water into cylinders or storage tanks;
.6 Carrier water systems of soft or pre-softened water may be used to transport ammonia to the application point and to assist in mixing;
.7 The ammonia injector should use a vacuum eductor or should consist of a perforated tube fitted with a closely fitting flexible rubber tubing seal punctured with a number of small slits to delay fouling by lime or other scale deposits;
.8 Provision should be made for the periodic removal of lime or other scale deposits from injectors and carrier piping; and
.9 Consideration should be given to the provision of an emergency gas scrubber capable of absorbing the entire contents of the largest anhydrous ammonia storage unit whenever there is a risk to the public as a result of potential ammonia leaks.

13.7.11 Hydrogen Peroxide

Advanced oxidation processes (AOPs) may use a combination of peroxide and ozone or peroxide and UV. For AOPs using ozone, hydrogen peroxide can be added upstream or downstream of ozone, or simultaneously with ozone dosing. Where UV is used, peroxide is added either upstream or simultaneously with UV irradiation. Peroxide residual should be removed before the application of chlorine. Alternatively the peroxide residual can be quenched with chlorine itself through the application of a higher chlorine dose to accommodate for demand from the peroxide residual. In either case, bench-scale testing of the quenching should be conducted, and chlorine residual should be closely monitored after quenching.

Peroxide is a strong oxidant and contact with personnel should be avoided. Secondary containment should be provided for storage tanks. Dual containment piping should be considered to minimize the risk of exposure to plant personnel.

Peroxide can be stored on-site but decomposes gradually over time, releasing oxygen in the process. Peroxide decomposes rapidly if contaminated and with heat or exposure to certain materials. Excessive heat may cause a tank rupture due to gas generation if the tank is not vented properly. Tanks and storage rooms should be vented according to manufacturer/supplier specifications.

Peroxide can be stored in high density polyethylene, 304L or 316L grade stainless steel drums or tanks. Pipes, gaskets and metering pumps should be constructed of peroxide-resistant materials. The Designer should ensure that all wetted stainless-steel components are passivated using industry accepted passivation procedures. Peroxide has a lower freezing point than water, however, housing or heat tracing should be provided for storage tanks and exterior piping if extended periods with temperatures below freezing are anticipated.

Pumps should be designed to prevent potential air binding of off-gas. Adequate mixing should be provided. It is recommended that all peroxide chemical dosing systems be provided with safety relief valves in areas where hydrogen peroxide can become trapped.

13.7.12 Ozone

Ozonation systems are generally used for the purpose of disinfection, oxidation, micro-flocculation and algal control. Typically, only one of these purposes is the primary goal of ozonation, although the other outcomes are achieved as secondary benefits. Ozone may also be used in an AOP (advanced oxidation) installation. For detailed design guidance refer to *Ozone in Drinking Water Treatment: Process, Design and Optimization* (Rakness 2005).

Ozone is an effective disinfectant for pathogens: ozone CT values for the inactivation of viruses, *Cryptosporidium* and *Giardia* cysts are considerably lower than the CT values for other disinfectants. Refer to the *Guidelines for Pathogen Log Reduction Credit Assignment* for the required ozone CT.

Micro-flocculation and enhanced filterability have been demonstrated in many ozone installations, but depend on source water characteristics. Oxidation of organic compounds that contribute to colour, taste and odour, and inorganic compounds such as iron, manganese, heavy metals and hydrogen sulphide has been documented. The effectiveness of oxidation varies, depending on the pH and alkalinity of the water.

These parameters affect the formation of highly reactive hydroxyl radicals, or, the scavenging of this oxidant. High levels of hydroxyl radicals cause lower levels of residual ozone. Depending on the desired oxidation reaction, it may be necessary to maximize ozone residual or maximize hydroxyl radical formation.

As a minimum, bench scale studies should be conducted to determine minimum and maximum ozone dosages for disinfection CT compliance and oxidation reactions. Pilot-scale studies should be conducted when necessary to document benefits and DBP precursor removal effectiveness. Consideration should be given to multiple points of ozone addition. Pilot studies should be conducted for all surface waters. Extreme care should be taken during bench and pilot scale studies to ensure accurate results. Parameters which require particularly accurate and precise measurement include gas flow rate, water flow rate, and ozone concentration.

Ozone does not provide a stable residual. For secondary disinfection, the application of a disinfectant which maintains a measurable residual (i.e. chlorine or chloramine) is needed after ozonation.

Due to the operational complexity of ozone processes, a higher degree of operator maintenance skills and training is required than for most other chemical treatment processes. The ability to obtain qualified operators should be considered in the selection of the treatment process. The necessary operator training for the equipment should be provided prior to plant start-up.

The production of ozone is an energy intensive process: substantial efficiencies in electrical usage, reduction in equipment size, and waste heat removal requirements can be obtained by using oxygen enriched air or 100% oxygen as feed, and by operating at increased electrical frequency.

The use of ozone may increase the biologically available organics content of the treated water. Biologically active filtration may be required to stabilize some treated waters. Ozone use may also lead to increased chlorinated by-product levels if the water is not stabilized and free chlorine is used for distribution system protection.

13.7.12.1 Feed Gas Preparation

Feed gas can be air, oxygen-enriched air, or high purity oxygen. Sources of high purity oxygen include purchased liquid oxygen; on-site generation using cryogenic air separation; or temperature, pressure or vacuum swing (adsorptive separation) technology. For high purity oxygen feed systems, dryers typically are not required.

Air handling equipment on conventional low-pressure air feed systems should consist of an air compressor, water/air separator, refrigerant dryer, heat reactivated desiccant dryer, and particulate filters. Some "package" ozonation systems for small plants may work effectively operating at high pressure without the refrigerant dryer and with a "heatless" desiccant dryer. In all cases the Designer must ensure that the maximum dew point of -60 °C will not be exceeded at any time.

The following should be considered in the design of air compression systems:

.1 Air compressors should be of the liquid-ring or rotary lobe, oil-less, positive displacement type for smaller systems or dry rotary screw compressors for larger systems;
.2 The air compressors should have the capacity to simultaneously provide for maximum ozone demand, provide the air flow required for purging the desiccant dryers (where required) and allow for standby capacity;
.3 Air feed for the compressor should be drawn from a point protected from rain, condensation, mist, fog and contaminated air sources to minimize moisture and hydrocarbon content of the air supply;
.4 A compressed air after-cooler and/or entrainment separator with automatic drain should be provided prior to the dryers to reduce water vapor; and

.5 A back-up air compressor must be provided so that ozone generation is not interrupted in the event of a break-down.

The following should be considered in the design of air drying systems:

.1 Dry, dust-free and oil-free feed gas must be provided to the ozone generator. Dry gas is essential to prevent formation of nitric acid, to increase the efficiency of ozone generation and to prevent damage to the generator dielectrics. Sufficient drying to a maximum dew point of -60 °C must be provided at the end of the drying cycle;
.2 Drying for high pressure systems may be accomplished using heatless desiccant dryers only. For low pressure systems, a refrigeration air dryer in series with heat-reactivated desiccant dryers should be used;
.3 A refrigeration dryer capable of reducing inlet air temperature to 4 °C should be provided for low pressure air preparation systems. The dryer can be of the compressed refrigerant type or chilled water type;
.4 For heat-reactivated desiccant dryers, the unit should contain two desiccant filled towers complete with pressure relief valves, two four-way valves and a heater. In addition, external type dryers should have a cooler unit and blowers. The size of the unit should be such that the specified dew point will be achieved during a minimum adsorption cycle time of 16 hours while operating at the maximum expected moisture loading conditions;
.5 Multiple air dryers should be provided so that ozone generation is not interrupted in the event of a dryer breakdown; and
.6 Each dryer should be capable of venting dry gas to the atmosphere, prior to the ozone generator, to allow start-up when other dryers are online.

The following should be considered for air filters:

.1 Air filters should be provided on the suction side of the air compressors, between the air compressors and the dryers and between the dryers and the ozone generators; and
.2 The filter before the desiccant dryers should be of the coalescing type and be capable of removing aerosol and particulates larger than 0.3 microns in diameter. The filter after the desiccant dryer should be of the particulate type and be capable of removing all particulates greater than 0.1 microns in diameter, or smaller if specified by the generator manufacturer.

Preparation piping design should consider:

.1 Piping in the air preparation system can be common grade steel, seamless copper, stainless steel or galvanized steel; and
.2 Piping must be designed to withstand the maximum pressures in the air preparation system.

13.7.12.2 Ozone Generator

The following should be considered for capacity design:

.1 The production rating of the ozone generators should be stated in pounds per day and kWh per pound at a maximum cooling water temperature and maximum ozone concentration;
.2 The design should ensure that the minimum concentration of ozone in the generator exit gas will not be less than 1% (by weight);

.3 Generators should be sized to have sufficient reserve capacity so that the system does not operate at peak capacity for extended periods of time. This can result in premature breakdown of the dielectrics;

.4 The production rate of ozone generators will decrease as the temperature of the coolant increases. If the supply temperature of the coolant will vary throughout the year, then relevant data should be used to determine associated production changes. The design should ensure that the generators can produce the required ozone at maximum coolant temperature; and

.5 Appropriate ozone generator backup equipment must be provided.

The generators can be low, medium or high frequency type. Specifications should require that the transformers, electronic circuitry and other electrical hardware be proven, high quality components designed for ozone service.

Adequate cooling should be provided. The required water flow to an ozone generator varies with the ozone production. Normally unit design provides a maximum cooling water temperature rise of 8 °C. The cooling water must be properly treated to minimize corrosion, scaling and microbiological fouling of the water side of the tubes. A closed loop cooling water system is often used to ensure proper water conditions are maintained. Where cooling water is treated, cross connection control should be provided to prevent contamination of the potable water supply.

To prevent corrosion, the ozone generator shell and tubes should be constructed of Type 316L stainless steel.

13.7.12.3 Ozone Contactors

The selection or design of the contactor and method of ozone application depends on the purpose for which the ozone is being used.

For bubble diffusers:

.1 Where disinfection is the primary treatment goal, a minimum of two contact chambers each equipped with baffles to prevent short circuiting. Ozone should be applied using porous-tube or dome diffusers;

.2 The minimum contact time should be 10 minutes. A shorter contact time may be considered if justified by appropriate design and CT calculations;

.3 For ozone applications in which precipitates are formed, such as with iron and manganese removal, porous diffusers should be used with caution;

.4 Where taste and odour control are of concern, multiple application points and contactors should be considered;

.5 Contactors should be separate closed vessels that have no common walls with adjacent rooms. The contactor must be kept under negative pressure and sufficient ozone monitors should be provided to protect worker safety. Placement of the contactor where the entire roof is exposed to the open atmosphere is recommended;

.6 Large contact vessels should be made of reinforced concrete. All reinforcement bars should be covered with a minimum of 38 mm of concrete. Smaller contact vessels can be made of stainless steel, fiberglass or other material which will be stable in the presence of residual ozone and ozone in the gas phase above the water level;

.7 Where necessary a system should be provided between the contactor and the off-gas destruct unit to remove froth from the air and return the froth to the contactor or another location. If foaming is expected to be excessive, then a potable water spray system (with appropriate cross connection controls) should be placed in the contactor head space;
.8 All openings into the contactor for pipe connections, hatchways, etc. should be properly sealed using welds or ozone-resistant gaskets such as Teflon or Hypalon;
.9 Multiple sampling ports should be provided to enable sampling of the effluent from each compartment and to confirm CT calculations;
.10 A pressure/vacuum relief valve should be provided in the contactor and piped to a location where there will be no damage to the destruction unit;
.11 The diffusion system should work on a countercurrent basis such that the ozone is fed at the bottom of the vessel and water is fed at the top of the vessel;
.12 The depth of water in bubble diffuser contactors should be a minimum of 5.5 m. The contactor should also have a minimum of 1 m of freeboard to allow for foaming; and
.13 All contactors should have provisions for cleaning, maintenance and drainage of the contactor. Each contactor compartment should also be equipped with an access hatchway.

Other contactor styles, such as the venturi or aspirating turbine mixer contactor types, may be considered provided adequate ozone transfer is achieved and the required contact times and residuals can be met and verified.

13.7.12.4 Ozone Destruction Unit

.1 A system for treating the final off-gas from each contactor must be provided in order to meet safety and air quality standards. Acceptable systems include thermal destruction and thermal/catalytic destruction units;
.2 In order to reduce the risk of fires, the use of units that operate at lower temperatures is encouraged, especially where high purity oxygen is the feed gas;
.3 The maximum allowable ozone concentration in the discharge is 0.1 ppm (by volume);
.4 At least two units should be provided which are each capable of handling the entire gas flow;
.5 Exhaust blowers should be provided in order to draw off-gas from the contactor into the destruct unit;
.6 Catalysts must be protected from froth, moisture and other impurities which may harm the catalyst; and
.7 The catalyst and heating elements should be located where they can easily be reached for maintenance.

13.7.12.5 Piping Materials

Only low carbon 304L and 316L stainless steels should be used for ozone service; 316L is preferred due to its superior corrosion resistance.

13.7.12.6 Joints and Connections

.1 Connections on piping used for ozone service are to be welded where possible;
.2 Connections with meters, valves or other equipment are to be made with flanged joints with ozone resistant gaskets, such as Teflon of Hypalon. Screwed fittings should not be used because of their tendency to leak; and

.3 A positive closing plug or butterfly valve plus a leak-proof check valve should be provided in the piping between the generator and the contactor to prevent moisture from reaching the generator.

13.7.12.7 Instrumentation

.1 Pressure gauges should be provided at the discharge from the air compressor, at the inlet to the refrigeration dryers, at the inlet and outlet of the desiccant dryers, at the inlet to the ozone generators and contactors and at the inlet to the ozone destruction unit;

.2 Electric power meters should be provided for measuring the electric power supplied to the ozone generators. Each generator should have a trip which shuts down the generator when the wattage exceeds a certain pre-set level;

.3 Dew point monitors should be provided for measuring the moisture of the feed gas from the desiccant dryers. Because it is critical to maintain the specified dew point, it is recommended that continuous recording charts be used for dew point monitoring which will allow for proper adjustment of the dryer cycle. Where there is potential for moisture to enter the ozone generator from downstream of the unit or where moisture accumulation can occur in the generator during shutdown, post-generator dew point monitors should be used;

.4 Air flow meters should be provided for measuring air flow from the desiccant dryers to each of the other ozone generators, air flow to each contactor and purge air flow to the desiccant dryers;

.5 Temperature gauges should be provided for the inlet and outlet of the ozone cooling water and the inlet and outlet of the ozone generator feed gas, and, if necessary, for the inlet and outlet of the ozone power supply cooling water;

.6 Water flow meters should be installed to monitor the flow of cooling water to the ozone generators and, if necessary, to the ozone power supply;

.7 Ozone monitors should be installed to measure ozone concentration in both the feed-gas and off-gas from the contactor and in the off-gas from the destruct unit. For disinfection systems, monitors should also be provided to measure ozone residuals in the water. The number and location of ozone residual monitors should be such that the amount of time that the water is in contact with the ozone residual can be determined; and

.8 A minimum of one ambient ozone monitor should be installed in the vicinity of the contactor and a minimum of one ambient ozone monitor should be installed in the vicinity of the generator. Ozone monitors should also be installed in any areas where ozone gas may accumulate.

13.7.12.8 Alarms

The following alarm/shutdown systems should be considered at each installation:

.1 Dew point shutdown/alarm - This system should shut down the generator in the event the system dew point exceeds -60 °C;

.2 Ozone generator cooling water flow shutdown/alarm - This system should shut down the generator in the event that cooling water flows decrease to the point that generator damage could occur;

.3 Ozone power supply cooling water flow shutdown/alarm - This system should shut down the power supply in the event that cooling water flow decreases to the point that damage could occur to the power supply;

.4 Ozone generator cooling water temperature shutdown/alarm - This system should shut down the generator if either the inlet or outlet cooling water exceeds a certain preset temperature;
.5 Ozone power supply cooling water temperature shutdown/alarm - This system should shut down the power supply if either the inlet or outlet cooling water exceeds a certain preset temperature;
.6 Ozone generator inlet feed-gas temperature shutdown/alarm - This system should shut down the generator if the feed-gas temperature is above a preset value;
.7 Ambient ozone concentration shutdown/alarm - The alarm should sound when the ozone level in the ambient air exceeds 0.1 ppm or a lower value chosen by the Water Supplier.
.8 Ozone generator shutdown should occur when ambient ozone levels exceed 0.3 ppm (or a lower value) in either the vicinity of the ozone generator or the contactor; and
.9 Ozone destruct temperature alarm - The alarm should sound when temperature exceeds a pre-set value.

13.7.12.9 Safety

The following should be considered in ozone safety design:

.1 The maximum allowable ozone concentration in the air to which workers may be exposed must not exceed 0.1 ppm (by volume);
.2 Noise levels resulting from the operating equipment of the ozonation system should be controlled to within acceptable limits by special room construction and equipment isolation;
.3 High voltage and high frequency electrical equipment must meet current electrical and fire codes;
.4 Emergency exhaust fans must be provided in the rooms containing the ozone generators to remove ozone gas if leakage occurs;
.5 A portable purge air blower should be provided to remove residual ozone in the contactor prior to entry for repair or maintenance; and
.6 A sign should be posted indicating “No smoking, oxygen in use” at all entrances to the treatment plant. In addition, no flammable or combustible materials should be stored within the oxygen generator areas.
.7 Refer to the WorkSafeBC *Ozone Safe Work Practices* manual for additional considerations.

13.7.12.10 Construction Considerations

.1 Prior to connecting the piping from the desiccant dryers to the ozone generators, the air compressors should be used to blow the dust out of the desiccant;
.2 The contactor should be tested for leakage after sealing the exterior. This can be done by pressurizing the contactor and checking for pressure losses; and
.3 Connections on the ozone service line should be tested for leakage using the soap-test method.

13.7.13 Carbon Dioxide

.1 Re-carbonation basins should provide:
   a. A total minimum detention time of 20 minutes;
   b. Two (2) compartments, with a depth that will provide a diffuser submergence greater than 2.3 m but not greater that the submergence recommended by the manufacturer. The two compartments should serve the following purposes:

i. A mixing compartment, having a minimum detention time of 3 minutes; and
ii. A reaction compartment;

.2 To ensure worker safety, re-carbonation tanks should be housed outside, or tanks should be sealed and vented to the outside with adequate seals and adequate purge flow of air;
.3 Where liquid carbon dioxide is used, adequate precautions should be taken to prevent carbon dioxide from entering the plant during the re-carbonation process;
.4 Provisions should be made for draining the re-carbonation basin and sludge removal; and
.5 On-site generation of carbon dioxide is discouraged.

13.7.14 Limestone Contactors

Limestone contactors may be required prior to treatment of the raw water (primary limestone contactor) to provide sufficient alkalinity for coagulation, or after the chlorine contact tank (secondary limestone contactor) for corrosion control. The following general design guidelines are provided for both limestone contactor types, followed by special provisions for the primary limestone contactors.

13.7.14.1 General Limestone Contactor Design Guidelines

.1 Contact time - the required contact time is dependent on the quality of limestone used, and the pH and alkalinity of the raw water or filtered water. In most cases, a minimum 60-minute contact time is recommended;
   - Bench- or pilot-scale testing should be used to confirm the contact time required to increase raw water alkalinity to the amount needed for downstream process optimization, e.g. for adequate coagulation to occur or to meet corrosion control needs;
   - To provide a safety factor, the contact time determined by the test should be increased by 10%. An actual contact time of less than 60 minutes may be considered based on test results. The testing should use the same limestone as proposed for the full-scale limestone contactor;

.2 Tank design - the tank geometry should minimize the wall area to tank volume ratio and minimize short circuiting. The inlet, outlet, and flow through the contactor should be designed to provide uniform flow through all of the limestone and to prevent short-circuiting;
.3 Access - the limestone contactor should be open at the top, or provided with sufficient access points to allow observation of the top of the limestone, and easy installation and removal of limestone and internal components such as piping and valves;
.4 Bypass - provisions for bypassing the limestone contactor should be included; and
.5 Drainage - contactor tanks should be provided with a means for dewatering. The contactor's floor should slope toward the drain at not less than 50 mm in 5 meters (1% slope).

13.7.14.2 Special Considerations for Primary Limestone Contactor

.1 Pre-screening - a basket strainer should be provided capable of preventing an accumulation of debris that cannot be removed by backwashing. The ability to modify the size of screen openings after plant start-up should be provided if required;
.2 Limestone backwash - a water flushing system should be provided to dislodge sediment that may accumulate in the limestone and to remove and dispose of it;
.3 The limestone contactor bypass should include a throttling valve and required piping and fittings to allow the operator to blend limestone treated water with raw water; and

.4 The limestone should be thoroughly washed at the treatment plant site prior to being placed into the contactor tanks.

13.7.14.3 Limestone

The following specifies requirements for the supply, installation and testing of limestone for the limestone contactor(s):

.1 The limestone should yield results similar to the test results used to determine the contact time. The consultant's specifications should require certification of dissolution performance;
.2 The limestone should comply with the latest issue of *NSF/ANSI Standard 60: Drinking Water Treatment Chemicals - Health Effects*;
.3 The material provided and installed should be high calcium content limestone with greater than 95% calcium carbonate ($CaCO_3$) and have a high rate of dissolution. Impurities such as aluminum (Al) and iron (Fe) should be kept to a minimum. Testing should demonstrate that the limestone will not increase aluminum, iron, and heavy metal concentrations in the treated water to concentrations above the GCDWQ MACs/AOs; and
.4 The limestone should have an effective size, D10, between 6 mm and 8 mm. The uniformity coefficient should be 2 to 3. The maximum diameter of the limestone should be 32 mm. The limestone gradation should be determined by using the latest issue of *ASTM C-110, Standard Test*.

14 Waste Residuals Handling and Treatment

14.1 General

This chapter provides design guidance for waste residuals management. Waste residuals represent the liquid, semi-solid and solid waste streams generated by the various water treatment processes used to remove contaminants from the source water in drinking water systems. The process of handling and treating the residuals is referred to as waste residuals management.

When determining the waste residuals management approach for a water treatment facility, the following should be considered, as a minimum:

.1 Cost of handling and treatment of the solid and liquid waste residuals streams;
.2 Characteristics of the waste residuals;
.3 Impacts to the primary treatment process(es)[6];
.4 Impacts to the environment pertaining to the discharge, application or disposal of the waste residuals; and
.5 Environmental regulations and guidelines pertaining to the discharge, application or disposal of the waste residuals.

Water treatment waste residual discharges are not specifically regulated by ENV, however, the Designer and Water Supplier should follow industry best practice and apply professional judgement to adequately treat, manage, and monitor waste residuals streams to limit impacts to the environment.

The Designer should make provisions for the proper handling and disposal of all water treatment plant wastes such as sanitary and laboratory wastes, clarification sludge, softening sludge, filter backwash water, backwash sludge, and brines (including softener/ion exchange regeneration wastes and membrane and reverse osmosis concentrate), spent filtration media or cartridges, hazardous wastes (including radioactive and arsenic waste), and all other potential process waste streams that may impact the environment and drinking water supply.

Where waste residual streams are discharged to ground, the Designer should adequately assess the potential impact on the receiving soils, water supply source and/or aquifer. The Designer should follow the minimum setback distances specified for underground stormwater infiltration facilities with respect to water supply wells, as set out in the *Ground Water Protection Regulation Handbook.*

The Designer should review the B.C. Hazardous Waste Regulation for definitions of "hazardous wastes" and requirements for handling facilities, and the Federal *Transportation of Dangerous Goods Act* for shipping implications. Most WTP residuals will not be considered as hazardous waste, but some (particularly media for removal of specific contaminants) may require further assessment. Refer to Section 14.5 – Hazardous Waste for more details.

Cross connection controls must be provided as needed to protect the public water supply when designing residuals management facilities.

[6] The cost or feasibility of a proposed water treatment approach or technology can be significantly affected by the properties of the residuals produced and should be considered when evaluating treatment alternatives.

14.2 Domestic and Ancillary Waste Streams

14.2.1 Sanitary

The sanitary waste from water treatment plants, pumping stations, and other waterworks installations must be treated or disposed of as required by the authority having jurisdiction. Waste from these facilities should discharge directly to a sanitary sewer system when available and feasible, or to an appropriate onsite sewage treatment system.

For maximum daily flows less than 22.7 m^3/d, the system is regulated under the *Public Health Act* 'Sewerage System Regulation' (SSR). These onsite sewage systems must be constructed and maintained by an authorized person (a *Registered Onsite Wastewater Practitioner* or a professional, as defined in the SSR) and filing documents must be received by the Health Authority. If maximum daily flows are greater than 22.7 m^3/d, the Municipal Wastewater Regulation applies. The MWR stipulates that a person must not discharge non-domestic waste to a municipal wastewater facility unless the person ensures that the pre-discharge quality of the non-domestic waste meets the standards or is within the ranges specified in the Standard for Discharges Directed to Municipal or Industrial Effluent Treatment Works under Column 3 of Schedule 1.2 of the Hazardous Waste Regulation, B.C. Reg. 63/88.

14.2.2 Laboratory Wastes

Laboratory wastes should be appropriately disposed, based on the types of chemicals used in analysis and discarded in laboratory drains. Toxic laboratory wastes should be drained to a separate holding tank and disposed of at a toxic waste facility or the local wastewater treatment plant as appropriate.

14.2.3 Online Analyzer Wastewater

If the waste stream from an online analyzer does not can contain any additional reagents, due to the small volumes and low toxicity, these waste streams may be permitted to be recycled to the head of the water treatment facility, blended with the treated water, or discharged to ground. The Designer should implement appropriate best management practices, and all known, available, and reasonable methods of prevention, control and mitigation to prevent negative impacts to the environment or quality of drinking water supply.

A waste stream containing online analyzer reagents must not be discharged to a surface water without prior treatment and consultation with ENV. The toxicity and content of the waste stream should be reviewed, and the waste stream should be treated and/or discharged appropriately. Typically, these types of waste streams are directed to a sanitary sewer or disposal field.

14.2.4 Coarse Screening and Pre-Sedimentation

Course screening and pre-sedimentation processes are designed to remove larger debris and particulates from the source water, to protect and improve the efficiency of the downstream treatment processes. The waste from these processes consist of larger inorganic solids such as rocks and sediment, as well as organic material such as wood debris, rags, or other stringy materials.

The solids residuals from these processes may be disposed through an appropriate manner depending on the nature of the waste, including landfill or land application.

14.3 Sludges

Sludges produced from the water treatment processes are the semi-solid and solid waste streams captured from the clarification and treated filtration waste processes. Treatments for sludges should be designed to properly condition and reduce the volume for disposal, to limit the impact on downstream sewage treatment processes, reduce disposal costs and reduce environmental impacts. These processes may involve any combination of thickening, pre-conditioning, and/or dewatering processes.

Methods for sludge thickening may include gravity thickeners, dissolved air flotation, lagoons, and drying beds. These processes can increase the solids content of the sludge from less than 1% to as high as 6%, depending on the characteristics of the sludge and the thickening process employed.

Mechanical dewatering methods such as centrifuges, rotary drum thickeners or filter presses may be appropriate to further dewater the sludge for disposal or land application of the dewatered sludge. Where land availability and climatic conditions permit, natural lagoon dewatering, drying beds or freeze-thaw methods may be considered.

The liquid stream from the dewatering process should be discharged to the sewer or further treated to satisfy ground discharge, surface water disposal or reuse alternatives. With the agreement of the Owner, sludge may be directed to a sanitary sewer provided that the sewer and the wastewater treatment plant have enough hydraulic and treatment capacity. Some water treatment sludges contain high concentrations of grit and can increase the wearing of sewer collection and headworks equipment. Use of pre-sedimentation tanks or a settling process is recommended when discharging sludges with high grit contents to a sanitary sewer.

> Residuals can sometimes be reused by other industries in their manufacturing processes (e.g. the manufacture of cement and compost). Designers are encouraged to explore options for alternative uses of residuals.

14.3.1 Metal Hydroxide Sludge

Metal hydroxide sludge can be generated from sedimentation/clarification processes or treated filter waste backwash waters when metal salts (e.g. alum, ferric chloride) are used as coagulants. The sludge can be discharged to a sanitary sewer if the owner of the wastewater system and the authority having jurisdiction give approval before final designs are made.

Thickening lagoons/basins, drying beds, or other mechanical thickening may be used as a method of handling metal hydroxide sludge. The thickening process should be sized based on the solids and hydraulic loading determined by calculating the solids produced by the total chemical, turbidity, and suspended solids concentrations in the primary process while accounting for the total process removal efficiency. Mechanical concentration should be considered to condition and reduce the volume of the waste stream prior to disposal. It is recommended that a pilot plant study be conducted prior to the design of a mechanical dewatering installation.

14.3.1.1 Land Application

Metal hydroxide sludge or dewatered cake may be disposed by land application alone or in combination with other wastes, in cases where an agronomic value has been determined and disposal has been approved by the authority having jurisdiction. Refer to Section 14.3.2.1 – Land Application for more information on land application of sludges.

14.3.2 Precipitative Softening Sludge

Sludge from treatment plants using precipitative softening, often called lime sludge, varies in quantity and in chemical characteristics depending on the softening process and the chemical characteristics of the water being softened. The quantity of sludge produced may be much larger than indicated by stoichiometric calculations, so additional sludge capacity should be considered. The high pH of this material can make it difficult to provide adequate treatment and disposal. Methods of treatment and disposal are as follows: lagoons, land application, mechanical dewatering and landfilling.

14.3.2.1 Land Application

The application of precipitative softening sludge to farmland (for soil pH adjustment) can be considered as a method of disposal. Prior to land application the BC *Environmental Management Act* and the Code of Practice for Soil Amendments (B.C. Reg. 210/2007) should be reviewed; additionally, a chemical analysis of the sludge including calcium and heavy metals content should be conducted. Approval from the authority having jurisdiction should be obtained. When this method is selected, the following provisions should be considered:

- .1 Transport of sludge by vehicle or pipeline should incorporate a plan or design which prevents spillage or leakage during transport;
- .2 Interim storage areas at the application site should be kept to a minimum and facilities should be provided to prevent runoff of sludge or flooding of the facilities;
- .3 Sludge should not be applied at times when runoff from the land could be expected;
- .4 Sludge should not be applied to sloping land where runoff could be expected unless provisions are made. For suitable land, the sludge can immediately be incorporated into the soil;
- .5 Trace metals loading should be limited to prevent significant increases in trace metals in the food chain, phytotoxicity or water pollution; and
- .6 Each area of land to receive lime sludge should be considered individually and a determination made as to the amount of sludge needed to raise soil pH to the optimum for crop growth.

14.3.2.2 Additional Considerations and Alternative Uses

Additional considerations for the disposal of lime sludge include:

- .1 Discharge of lime sludge to sanitary sewers should be avoided since it may cause both liquid and solids volume problems at the sewage treatment plant. This method should be used only when the sewage system has the capability to adequately handle the lime sludge;
- .2 Appropriate and sufficient storage should be allowed for between applications or pickup;
- .3 Mixing of lime sludge with activated sludge waste (from a wastewater treatment plant) may be considered as a means of co-disposal; however, the Organic Matter Recycling Regulation should be reviewed if land application is considered in this scenario;
- .4 Disposal at a landfill can be done as either a solid or liquid if the landfill can accept such waste;

.5 Mechanical dewatering of sludge may be considered. It is recommended that a pilot study on the particular plant waste be conducted. Mechanical dewatering should be preceded by sludge concentration and chemical pre-treatment; and

.6 Calcination, of sludge as a resource recovery process for use in concrete mixtures may be considered. Pilot studies on a particular plant waste are required. Calcination is the process of heating of residuals to a high temperature but below the melting or fusing point, causing loss of moisture, reduction or oxidation, and dissociation into simpler substances.

14.3.3 Treatment of Sludges

14.3.3.1 Gravity and Flotation Thickening of Sludges

Gravity and flotation thickening processes may be used to increase the solids content of the waste residuals by removing a portion of the water. Gravity thickening may be designed similar to a solids contact clarifier, where the sludge is fed into the centre and a rotating circular collector mechanism promotes compaction of the sludge matrix. Flotation thickening is most commonly implemented with a DAF process and relies of saturated air-water mixture to float solids to the surface for removal of the concentrated sludge float. For both processes, the clarified liquid stream may be returned to the headworks of the process, depending on the quality and capabilities of the treatment processes. The thickened sludge can be discharged to sanitary sewer, directed to mechanical dewatering for further solids concentration or disposed through other appropriate manner.

The following Table 14-1 provides a summary of typical design data used to size gravity and flotation process for thickening waste residual sludges.

Table 14-1 Typical Design Data for Mechanical and Flotation Sludge Thickening Processes (MWH, 2015)

Parameter	Unit	Gravity Thickener	DAF	Notes
Solids Content Feed Flow Thickened Sludge	%	0.1 – 1 2 - 3	0.5 – 1 3 - 5	Feed solids concentrations will vary based on the primary treatment process and preceding sludge conditioning.
Hydraulic Loading	m/h	0.2 - 0.5	4.5 - 6.3	DAF hydraulic loading rates may be increased to conventional rates between 10 – 12 m/h when feed flow solids content is less than 0.1%.
Solids Loading	$kg/m^2/day$	20 - 80	48 - 120	

14.3.3.2 Passive Dewatering and Thickening of Sludges

When passively dewatering and thickening sludges, decanting and drainage systems should be provided and required solids concentration, climate, drainage discharge location, and regulatory requirements should be considered. The following provides brief design considerations for air/gravity drying processes:

.1 Sand drying beds: Sludge is placed on a sand medium, and dewatering occurs primarily by gravity drainage.
   a. More effective for lime sludges than for metal hydroxyl sludges;
   b. Loading rates are typically between 1.0 and 2.4 kg/m^2;
   c. Draining time is typically 3 to 4 days;
   d. Applied sludge depth should be 20 - 75 cm for coagulant sludges and 30 - 120 cm for lime sludges;

.2 Freeze-assisted drying beds: Freeze-thaw cycling is used to break the molecular bonds between the water and the sludge, which enhances the dewatering rate;
   a. More suitable for dewatering alum sludges in cold climates;
   a. Should be designed using two drying beds, each sized to accommodate one year of sludge storage;

.3 Solar drying beds: Asphalt is used as a sub-base for dewatering of sludge, where the absorbed heat effects promote faster drying;

.4 Vacuum-assisted drying beds: Vacuum provides a suction to the underside of rigid, porous media plates upon which the residuals are placed, which draws the water from the sludge;
   a. Frequent plate cleaning and chemical sludge conditioning is typically required for this type of process; and
   b. Sludge layers should be kept thin to maximize drying rates.

.5 Dewatering bags: The waste residual stream or sludge is pumped into a manufactured woven geotextile bag or tube that separates the solids from the liquid stream;
   a. Chemical addition may be added to increase the solids separation efficiency;
   b. Bags may be filled multiple times;
   c. Filtrate and sludge should be sampled to confirm suitability for disposal; and
   d. Filtrate should be collected and discharged in an appropriate manner.

14.3.3.3 Lagoon Design

Thickening lagoons/basins should be designed to produce an effluent satisfactory to the authority having jurisdiction and should provide:

.1 Two and half years of sludge storage;
.2 A location free from flooding;
.3 Adjustable decanting device;
.4 Effluent sampling point;
.5 Low permeability liner;
.6 Retention time of between 15 and 30 days;
.7 Adequate safety provisions;
.8 Where necessary, dikes, deflecting gutters, or other means of diverting surface water runoff so that it does not flow into the lagoon;
.9 Outlet at the end opposite the inlet;

.10 A weir overflow device at the outlet end with weir length equal to or greater than the depth;
.11 Velocity dissipation at the inlet end;
.12 A minimum usable depth of 1.5 to 1.75 m;
.13 Adequate freeboard of at least 0.6 to 1.0 m;
.14 A minimum of two cells, each with appropriate inlet/outlet structures to facilitate independent filling/dewatering operations;
.15 Length four times width, and the width at least three times the depth, as measured at the operating water level;
.16 An acceptable means of final sludge disposal; and
.17 Provisions for convenient cleaning of the lagoons.

The Designer should refer to the Dam Safety Regulation to determine if the lagoon would be required to meet the stipulations set out in regulation. As of 2016, dams with a live storage capacity of more than 10,000 m^3 or greater than 7.5 m in height are regulated under the Dam Safety Regulation.

Subsurface infiltration lagoons may be acceptable, however consideration should be given to the downstream watercourse.

14.3.3.4 Mechanical Dewatering of Sludges

Mechanical dewatering may be implemented to produce a dried cake for improved handling of the residual solids. It is recommended that a pilot study for the mechanical process(es) be conducted on the waste produced at the water treatment plant. Mechanical dewatering should be preceded by sludge concentration and chemical pre-treatment. The following are general design recommendations for filter presses and centrifuges:

.1 Belt and diaphragm filter presses: Dewater residuals by sandwiching sludge between two porous belts;
   a. Suitable for dewatering lime sludges to 50% - 60%, and coagulant sludges to 15% - 20%;
   b. Applied pressure is typically in the 600 to 1,500 kPa (87 to 218 psi) range;
   c. Roller bearings should be designed to have an L10 service life of approximately 300,000 hours;
   d. A polymer conditioning system should be provided for all belt filter presses;
   e. Consideration should also be given to desired cake solids content, conditioning requirements, pressure requirements, belt speed, belt tension, belt type, and belt mesh size;

.2 Centrifuges: Dewater residuals by forcing water from solids under high centrifugal forces;
   a. Both concurrent and counter-current designs are acceptable;
   b. Design criteria will be proprietary in nature and the manufacturer should be consulted in each case a centrifuge is being considered; and
   c. A polymer conditioning system should be provided for all centrifuge systems.

Similar to passive dewatering systems, decanting and drainage systems should be provided for the water produced from the dewatering of the sludge, including leachate, centrate or filtrate. Additionally, the required solids concentration, drainage discharge location and regulatory requirements should be considered for disposal of the liquid waste streams.

14.4 Wastewater

14.4.1 Filter Backwash Water and Filter-to-Waste

14.4.1.1 Rapid Rate Media Filter or Membrane Backwash Water

Filter backwash water (FBWW) produces high volume, short duration wastewater flows with relatively low concentrations of solids (i.e. typically less than 0.1% solids content) and requires handling in a suitably sized surge/equalization tank. These waste streams are generated from rapid rate media filters and membrane backpulse or wash cycles.

Surge tank discharges may be directed to a sanitary sewer where the sewer and the wastewater treatment plant have sufficient hydraulic and treatment capacity, and with the agreement of the wastewater treatment plant owner.

Where limited wastewater treatment capacity exists, the waste flow may be directed to a holding tank and allowed to settle before the supernatant is discharged to a sanitary sewer and the sludge removed for further treatment.

Where sewer discharge is not possible, appropriate effluent quality control measures are provided (i.e. treatment processes) and applicable environmental regulatory requirements are met, discharge to ground, a receiving water body or recycle to the head of the water treatment facility may be acceptable. Refer to Section 14.4.1.3 – Recycling Filter Backwash Water for more information about recycling requirements.

Discharges to ground may be achieved using infiltration basins or other subsurface ground disposal methods, where the soil and ground water conditions are determined to be suitable through hydrogeological investigation. The Designer should refer to principles set out in the *Groundwater Protection Regulation Handbook*, Municipal Sewage Regulation, and industry best practices to prevent detrimental impacts to source waters and the environment.

14.4.1.2 Filter-to-Waste

Filter-to-waste is the water produced by filters immediately after backwashing. This water has higher particulate and turbidity levels, above the criteria required for pathogen log reduction credit assignment.

Filter-to-waste water may be discharged directly to a sanitary sewer system, if the sewers and the wastewater treatment plant can withstand the hydraulic surges.

Filter-to-waste water may also be recycled back into the headworks without further treatment or recycled back immediately upstream of the filters if the recycled flow does not exceed 10% of the total inflow into the filters.

Recycling of the filter-to-waste stream can be used to accelerate the filter ripening process. This process is known as filter maturation, where the filter-to-waste stream is returned to the headworks or immediately upstream of the filters. This process may be particularly effective for direct filtration processes, where the incoming raw water may have very low turbidity (i.e. <1 NTU) to promote filter stabilization and reduce the filter ripening times.

Refer to Section 14.4.1.3 – Recycling Filter Backwash Water for more information about recycling requirements.

14.4.1.3 Recycling Filter Backwash Water

Recycling filter backwash water (FBWW) or filter-to-waste to the head of the water treatment facility may be an effective method to reduce waste volumes and increase the climate change resiliency of the WTP. Recycling of backwash water involves consideration of special hazards due to the potential for increased concentration of pathogens in the water. Reference should be made to the USEPA's Technical Guidance Manual, the *Filter Backwash Recycling Rule* (2002).

Recommendations for recycling filter backwash water or filter-to-waste include:

.1 FBWW or filter-to-waste should not be recycled when:
   a. The raw and/or reclaimed water contains excessive:
      a. pathogen concentrations;
      b. algae; or
      c. turbidity;
   b. The raw and/or reclaimed water contains algal toxins;
   c. Disinfection by-product levels in the distribution system may exceed allowable levels; or
   d. Finished water taste and odour are problematic;

.2 The recycling of filter backwash wastewater, thickener supernatant, and other liquids to the head of the plant may be acceptable under the following conditions:
   a. The recycle stream should be monitored for flow rate, turbidity, and any other relevant parameters;
   b. The recycle stream should be returned at a rate of less than 10% of the instantaneous raw water flow rate entering the plant, as per *Filter Backwash Recycle Rule* (USEPA, 2001);
   c. A recommended operational goal for recycle stream turbidity is less than 2 NTU;
   d. The primary treatment process train is designed (and where possible, demonstrated through a pilot study) to effectively treat the anticipated recycled stream hydraulic and solids loading;
   e. Suspended solids in the backwash water from surface water treatment and lime softening plants should be reduced prior to recycling to the head of the plant through additional settling or chemical treatment (e.g. coagulation);
   f. Reclaimed filter backwash water does not add increased risk to the treated water quality;
   g. Consideration should be given to the presence of protozoa such as *Giardia* and *Cryptosporidium* concentrating in the wastewater stream;
   h. Pre-treatment of filter backwash wastewater prior to recycling may be required; and
   i. The use of a disinfecting agent effective for the inactivation of protozoa, typically UV disinfection, is recommended in the recycling line.

.3 A backwash reclaim tank should be included in the design and contain:
   a. The anticipated volume of wastewater produced by the WTP when operating at design capacity;
   b. A volume that takes into account the number of filters and the anticipated backwash frequency and volume, using the greater of the design backwash duration and rate or 15 minutes of backwashing at a rate of 50 m/h. As a minimum the tank should be sized to

hold the total flow from two consecutive backwash cycles plus a 20% safety factor without concurrent recycling;

.4 Consideration should be made for emergency discharge or backup storage of the FBWW, should the WTP not be able to accept the recycled FBWW due to diminished water quality.

14.4.2 Membrane Filtration Wastewater

Membrane filtration produces many types of wastewater including backwash water, chemical cleaning residuals, and membrane reject water.

14.4.2.1 Membrane Backwash Residuals

Refer to Section 14.4.1.1 – Rapid Rate Media Filter or Membrane Backwash Water.

14.4.2.2 Membrane Clean-in-Place Residuals

All membrane filters require periodic chemical cleaning (recovery clean or clean-in-place), which generates waste residuals with high oxidant concentrations, high pH or low pH, depending on the cleaning type or phase. Chemical cleaning wastes should be reviewed on a case-by-case basis: depending on community infrastructure, there may be alternative uses for such waste residuals (i.e. for pH adjustment or reduction of organic loading at wastewater treatment plants). Such alternative uses must be assessed to ensure all applicable regulations are adhered to and that safety and transportation/handling are considered in design.

For disposal, chemical cleaning residuals should be treated on-site where possible and discharged to either a sanitary sewer or holding tank for further disposal. Oxidants such as chlorine used in the chemical cleaning process should be quenched prior to discharge, and acids and bases should be neutralized. The use of other chemicals, such as surfactants or proprietary cleaning agents, may require additional treatment. The rinse water applied to the membranes after the cleaning process may also represent a chemical waste and thus may require treatment prior to discharge.

14.4.2.3 Membrane Reject Water

Reject or concentrate water produced by NF or RO membrane filtration processes typically contain high levels of TDS and inorganic solutes. If appropriate effluent quality control measures are provided (i.e. treatment) and applicable environmental regulatory requirements are met, discharge of chemically unaltered membrane reject water to a ground or a receiving water body may be acceptable. Dilution may be required to reduce the concentration of regulated parameters prior to discharge to the environment or sanitary sewer. Dilution can be a legitimate treatment strategy given that the concentrated inorganic solutes originate from a natural water source.

Where this option is not available, the concentrate or reject should be discharged to a sanitary sewer.

14.4.3 Iron and Manganese Wastewater

Iron and manganese waste or “red water” wastes can be treated using sedimentation basins, thickening processes, lagoons, or discharge to a sanitary sewer. For thickening process design criteria, refer to Section 14.3.3 – Treatment of Sludges. For lagoon design criteria, refer to Section 14.3.3.3 – Lagoon Design.

14.4.3.1 Discharge to Sanitary Sewer

"Red water" can be discharged to a sewer if the owner of the wastewater system and the authority having jurisdiction give approval before final designs are made. An equalization basin or tank is recommended to prevent overloading of the sewers. Consideration should be given to the hydraulic, TSS and organic loading on sewage conveyance and treatment systems. The design should prevent cross connections and there should be no common walls between potable and non-potable water compartments.

14.4.3.2 Recycling Red Water Wastes

Recycling of supernatant or filtrate from "red water" waste treatment facilities to the head of the WTP is not recommended.

14.4.4 Brine Waste

Waste from ion exchange, demineralization, and reverse osmosis or nanofiltration membrane plants, or other plants which produce brine, must be treated or discharged in accordance with all federal, provincial, and local regulations. Dependent on approval by the authority having jurisdiction, brine wastes may be disposed by discharge to a soak-away pit, deep well injection into the ground, or discharge to a wastewater treatment system provided it is approved by the wastewater treatment plant owner.

When discharging to a sanitary sewer, an equalization basin or tank may be required to prevent the overloading of the sewer and/or interference with the waste treatment processes. The quality of the brine waste should be confirmed to ensure that the high salinity will not negatively affect the performance of the wastewater treatment plant prior to design. The effect of brine discharge to sewage lagoons may depend on the rate of evaporation from the lagoons. Brine waste may be toxic to microbial processes in a wastewater treatment plant. If practical, it may be preferable to blend the brine waste stream with the wastewater treatment plant effluent. If brine wastes are deemed to be acceptable to discharge to the sanitary sewer, the Designer should coordinate with the wastewater treatment owner/operator and include provision for controlling the discharge rate to allow for optimizing the wastewater treatment plant unit process operation and avoid slug loading of brine waste to the system.

Other higher cost technologies (e.g. mechanical, thermal, etc.) are available for treatment of brine waste and can be considered if regulatory or environmental constraints warrant.

14.5 Hazardous Waste

14.5.1 Regulatory Information

Under the *Environmental Management Act*, the Hazardous Waste Regulation (HWR) provides a definition of hazardous wastes. Solid residuals from WTPs which treat specific contaminants may be considered as hazardous wastes if they meet the criteria for leachable toxic wastes: "wastes [which] when subject to the extraction procedure described in the US EPA Method 1311 produce an extract with a contaminant concentration greater than those prescribed in Table 1 of Schedule 4 [of the HWR]". These wastes should be managed through off-site treatment at a hazardous waste facility.

Furthermore, as stated in Schedule 3 of the HWR: "Wastes which when subjected to the Modified Leachate Extraction Procedure referenced in Part 2 of Schedule 4 produce an extract which contains one or more contaminants in Column 1 of Table 1 of Schedule 4 in concentrations equal to or greater than the concentration specified for each contaminant in Column II of the Table" may not be disposed in a secure landfill. Therefore, WTPs may need to conduct both the US EPA Method 1311 (also referred to as the Toxicity Characteristics Leaching Procedure, or TCLP) and the HWR Modified Leachate Extraction Procedure tests on the solid residuals to determine the proper disposal method or facility for the waste.

If the production in a 30-day period or storage amount of residuals exceeds the limits listed in Schedule 6 of the HWR, the hazardous waste must be registered with the Ministry of Environment and Climate Change Strategy. Refer to the Ministry's website (https://www2.gov.bc.ca/gov/content/environment/waste-management/hazardous-waste/registration-of-hazardous-waste-generators-and-facilities) for more details.

14.5.2 Arsenic Waste Residuals

Arsenic-bearing wastes may be found in the following waste streams and may be considered hazardous, including but not limited to:

.1 Filter backwash wastewater and sludge;
.2 Lime softening sludge;
.3 Reverse osmosis reject water, and
.4 Adsorptive filter media.

Under the *Environmental Management Act* and the Hazardous Waste Regulation, residual wastes from an arsenic water treatment facility may be defined as being hazardous waste. Solid residuals should be tested as described in Section 14.5.1 – Regulatory Information to determine if they would be considered as leachable toxic wastes and how they can be properly disposed.

14.5.3 Radioactive Waste

Radioactive materials may be found in the following waste streams, including, but not limited to:

.1 Granulated activated carbon (GAC) used for radon removal;
.2 Radium adsorptive filter media;
.3 Ion-exchange regeneration wastewater;
.4 Manganese greensand backwash solids from manganese removal systems;
.5 Precipitative softening sludge; and
.6 Reverse osmosis concentrates.

The build-up of radioactive decay products should be considered, and adequate shielding, ventilation, and other safeguards should be provided in the plant design to protect water operators and visitors, particularly when raw water radiological parameters are in excess of the GCDWQ MACs.

Radioactive materials and waste facilities are regulated by the Canadian Nuclear Safety Commission (CNSC). Reference should be made to the *Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials (NORM)*. Approval should be obtained from the authority having jurisdiction prior to disposal of all wastes.

Additional guidance on the handling of radioactive residuals is in the U.S. EPA's *A Regulators' Guide to the Management of Radioactive Residuals from Drinking Water Treatment Technologies*.

14.6 Filtration Media and Cartridges

Landfill is the most common disposal approach for spent filtration media, cartridge filters and membranes. Depending on source water and treatment targets, spent treatment components may need to be disposed as hazardous waste – refer to Section 14.5 – Hazardous Waste for more information.

Granular activated carbon can be regenerated after exhaustion (i.e. when contaminant breakthrough occurs). For drinking water facilities, off-site regeneration is normally conducted as on-site regeneration is not practical nor cost effective. Provisions for storage and shipment of spent media should be considered during design.

Some manufacturers may offer recycling or disposal of proprietary media, cartridge filters or other spent treatment components. Options for recycling and disposal should be discussed early during the design process.

15 Parameter Specific Treatment

15.1 General

This chapter provides a high-level overview of the treatment processes for specific water contaminants. The selection of a particular treatment technology and/or technology train will depend on an evaluation of the nature and quality of the water to be treated, seasonal variations in raw water quality, and the desired quality of the finished water.

15.2 Iron and Manganese

Iron (either Fe (II) or Fe (III)) and manganese are commonly occurring metals that can impact aesthetic water quality and, for manganese, can have health implications when the GCDWQ is exceeded. Presence of these parameters may lead to visible water colour, increased turbidity, staining on plumbing fixtures, and growth of iron bacteria in watermains.

The GCDWQ identifies a maximum acceptable concentration (MAC) limit for manganese of 0.12 mg/L, based on the neurological health risks to infants and other sensitive populations. Elevated iron and manganese concentrations are more frequently found in groundwater sources from rock and soil weathering than surface waters. Under reducing conditions, which may exist in some groundwaters, lakes or reservoirs, and in the absence of sulphide and carbonate, high concentrations of soluble Fe(II) may be found. At neutral and oxic conditions, iron (Fe(III)) and manganese are generally insoluble and settle out or adsorb onto surfaces.

Testing equipment should be provided for water treatment plants where iron and manganese pose potential issues, with the capacity to measure iron and manganese to minimum concentrations of 0.1 mg/L and 0.05 mg/L, respectively. Some manganese sampling protocols utilize reagents containing cyanide, requiring disposal and handling of hazardous chemistry. For this reason, offsite analysis at commercial laboratories may be advisable when appropriate analytical equipment (such as inductively coupled plasma (ICP) mass spectrometry/atomic emission spectroscopy, or atomic absorption spectroscopy (AAS)) is not available on-site. Where polyphosphate sequestration is practiced, phosphate testing equipment should also be provided.

This section describes treatment processes designed specifically for iron and manganese control. For further guidance, refer to the *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Iron*, and *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Manganese* by Health Canada, and *Guidance on Manganese in Drinking Water* by the B.C. Ministry of Health.

15.2.1 Oxidation, Detention and Filtration

Oxidation of soluble iron and manganese results in the formation of solid, oxidized precipitate that can then be filtered. Oxidation can be performed by aeration, and/or through chemical oxidation with chlorine, potassium permanganate ($KMnO_4$), ozone, or chlorine dioxide. The most effective oxidation and filtration of iron and manganese occurs at pH 7.5 and above, and the minimum effective pH level should be above 7. This process is highly pH dependant as iron and manganese solubility varies with pH. Elevated pH levels may be required for adequate removal, particularly for manganese.

Aeration or chemical feed points should be provided prior to filtration. Aeration and chlorine do not effectively oxidize manganese unless it is present at very low levels relative to iron. See Chapter 9 – Aeration for specific aeration design considerations. Water systems that use chlorine should consider and monitor for disinfection by-products.

The minimum detention time following the addition of oxidants differs depending on the oxidant used. For example, aeration typically requires a minimum detention time of 30 minutes for iron and 60 minutes for manganese (depending on the raw water pH) to ensure that the oxidation reactions are as complete as possible. The minimum detention time should be determined based on the oxidant used and may be optimized based on the findings from pilot testing. The Designer should also account for seasonal variations in temperature, pH, and the presence of natural organics as these will impact the detention time required.

The detention basin may be designed as a free surface holding tank (i.e. water surface open to atmosphere) or pressure vessel. The basin should have sufficient baffling and be designed to prevent short circuiting. The basin should be provided with an overflow, vent and access hatch in accordance with Chapter 17 – Water Storage.

Sedimentation basins may be required when treating water with high iron and/or high manganese content, or where chemical coagulation is used to aid in filtration of iron and manganese. Coagulants should be added after oxidation reactions have reached sufficient completion. Sedimentation basin design should meet the design requirements specified in Chapter 7 – Pre-sedimentation, Coagulation, Flocculation and Clarification. Provisions for sludge removal should be made where sedimentation basins are required.

Filters should be provided and should conform to design requirements specified in Chapter 8 – Filtration.

15.2.2 Manganese Oxide Media

Manganese oxide filter media (coated or solid) selectively removes iron and manganese through contact adsorption. This process is the option of choice for treating waters with moderate amounts of iron and manganese (< 5 mg/L of iron and < 1 mg/L of manganese), however piloting is recommended to confirm the feasible level of iron and manganese removal. The equipment for this process is typically more compact than ion-exchange or chemically assisted filtration processes. Silica levels in the raw water should be tested as they can impact the feasibility of manganese oxide for removal of iron and manganese.

15.2.2.1 Oxidation

An oxidant is typically added to the raw water to oxidize soluble iron and manganese. The dosage and selection of oxidant should take into consideration the oxidant demands of all contaminants to be removed (DOC, H_2S, ammonia etc.). Designers are encouraged to sample for contaminants affecting oxidant demand to confirm dosing requirements. For example, benchtop testing of chlorine demand can inform dose selection to achieve breakpoint chlorination and maximize oxidation of soluble iron and manganese. Multiple oxidizing agents may be used; for example, aeration may be used prior to the oxidant feed to reduce the amount of chemical needed. Provisions should be made to supply the oxidant as far in advance of the filters as possible to maximize contact time before the oxidized water reaches the filters, and to a point immediately before the filter for media regeneration.

15.2.2.2 Filtration

The filter media that could be used are:

- .1 Manganese greensand or other manganese dioxide coated media;
- .2 Pyrolusite or other form of solid pure manganese dioxide media; and
- .3 Other proprietary media.

Filter media should conform to *NSF/ANSI Standard 61: Drinking Water System Components - Health Effects* and the applicable *AWWA Standard B101: Precoat Filter Media* or *AWWA Standard B102: Manganese Greensand for Filters*.

The key to the success of the contact adsorption process is the re-generation of the manganese dioxide (MnO_2) coating on the media. Regeneration can be done on a continuous basis or on an intermittent basis.

Typically, this media is used in a pressure filtration setup. Per the *Guidelines for Pathogen Log Reduction Credit Assignment*, pressure filters are not assigned pathogen log reduction credits. Refer to Chapter 8 – Filtration for further guidance on filter design.

15.2.2.3 Design Considerations for Manganese Dioxide Media Filtration

Dual media filtration incorporating a layer of anthracite with a layer of MnO_2 is recommended if iron removal is the main objective. Continuous regeneration of the manganese dioxide (MnO_2) is also recommended where iron removal is the main objective, regardless of the presence of manganese. Continuous regeneration operation involves the feeding of a pre-determined amount of oxidant (typically $KMnO_4$ or chlorine) directly to the raw water prior to the filters. If chlorine is used for waters containing ammonia, sufficient chlorine should be added to go beyond the breakpoint to produce free chlorine for media regeneration.

Intermittent regeneration is recommended for waters where only manganese or manganese with small amounts of iron is to be removed. This involves adding a pre-determined amount of oxidant after a specified quantity of water has been treated. Intermittent regeneration is often conducted during the filter backwash cycle.

Filter backwash rates should be determined in accordance with pilot studies, manufacturer information, or sufficient reference materials. Backwash rates should be controlled to prevent complete stripping of the base catalytic surface from the media, as this can result in process failure and may require media replacement. Air scour should also be provided.

A summary of the design considerations for manganese coated media filtration systems is shown in Table 15-1. The Designer should refer to the media manufacturer’s specifications for design details and consider piloting bench-scale testing.

Table 15-1 Design Considerations for Manganese Coated Filtration Systems

Design Parameter	Metal to be Removed	
	Iron	Manganese
Regeneration of media	Continuous	Intermittent
Bed type	Dual media	Single media
Depth of bed	Anthracite - 375 to 450 mm MnO_2 media - 450 to 600 mm	MnO_2 media > 750 mm
pH	6.2 to 8.5	7.0 to 8.5
Typical media loading rate [1]	4 to 12 m/h	4 to 12 m/h
Head loss	1.5 m (maximum)	1.5 m (maximum)
Backwash [2]	Sufficient for 40% bed expansion	Sufficient for 40% bed expansion

.1 Filter loading rates should be established based on media manufacturer requirements. As concentrations of iron and manganese increase, loading rates for equivalent run lengths will decrease. Pilot testing should be undertaken to determine optimum design parameters.

.2 Typical backwash rates for manganese dioxide-coated media and solid manganese dioxide media are 20 - 24 m/h and 37 - 49 m/h respectively.

15.2.3 Ion Exchange

15.2.3.1 General Ion Exchange Design Considerations

Ion exchange (IEX) is a process in which ions of given species are displaced (exchanged) from insoluble exchange material by ions of different species in solution (MWH, 2015). Treatment systems which use ion exchange may also be referred to as ‘softeners’. Ion exchange units can be used to treat many raw water quality issues including hardness, and high levels of nitrate, natural organic material, arsenic, iron, manganese, and fluoride, among others.

Pilot studies should be conducted to confirm the suitability of the ion exchange media, assess ion exchange performance, hydraulic considerations (flow rate, head loss, backwashing rate), and regeneration requirements (i.e. salt requirements, backwash cycle time, rinse requirements, and column requirements).

15.2.3.1.1 Types of Resin

Based on the functional groups bonded to the resin backbone, the four general types of exchange resins are strong-acid cation (SAC), weak acid cation (WAC), strong-base anion (SBA), and weak-base anion (WBA). Anion exchange resin should have a generally high selectivity for the contaminant of concern. Table 15-2 below provides recommendations for the resin type and the ion to be removed.

Table 15-2: Ion Exchange Resins (MWH, 2015)

Resin Type	Ions Removed	Regenerant	pH Operating Range
Strong-acid cationic (SAC)	Cations: e.g. Ca^{2+}, Mg^{2+}, Ra^{2+}, Ba^{2+}, Pb^{2+}	HCl or NaCl	1 to 14
Weak-acid cationic (WAC)	Cations: e.g. Ca^{2+}, Mg^{2+}, Ra^{2+}, Ba^{2+}, Pb^{2+}	HCl or NaCl	~ 6 to 11
Strong-base anionic (SBA)	Anions: e.g. NO_3^-, SO_4^{2-}, ClO_4^-, $HAsO_3^{2-}$, SeO_3^{2-}	NaOH or NaCl*	1 to 13
Weak-base anionic (WBA)	Anions: e.g. NO_3^-, SO_4^{2-}, ClO_4^-, $HAsO_3^{2-}$, SeO_3^{2-}	NaOH, NH_4OH, Na_2CO_3 or $Ca(OH)_2$	< 6

*KCl may also be used in place of NaCl; consult with the equipment supplier for compatibility.

Prior to start-up of the equipment, the resin should be regenerated with no less than two bed volumes of water containing an appropriate regenerant followed by an adequate rinse.

15.2.3.1.2 Pre-treatment

Pre-treatment may be required for contaminant-specific resins. Iron, manganese or a combination of the two, should not exceed 0.3 mg/L in the water as applied to the ion exchange resin. Pre-treatment is required when a combination of iron and manganese exceeds 0.5 mg/L. Pre-treatment may also be required for water with high concentrations of natural organic matter (measured as total organic carbon, TOC).

15.2.3.1.3 Design

The following should be considered when designing an ion exchange resin:

.1 Ion exchange units are gravity or pressure type, upflow or downflow design. Automatic regeneration based on volume of water treated should be used unless manual regeneration is justified. A manual override should be provided on all automatic controls;

.2 If a portion of the water is bypassed around the units and blended with treated water, the maximum blend ratio allowable must be determined based on the highest anticipated raw water level of the contaminant of concern. If bypassing is provided, a totalizing meter and a proportioning device or flow regulating valves must be provided on the bypass line;

.3 Design capacity - The design capacity of the regeneration process should be in accordance with the specifications of the resin manufacturer.

.4 Number of units - For water systems treating health-related contaminants, at least two units should be provided. The treatment capacity must be capable of meeting the maximum day water demand at a level below the treatment objective for the contaminant of concern with one exchange unit out of service;

.5 Flow rates - For the contaminant of concern, the treatment flow rate should not exceed the manufacturer's recommendation for the selected resin;

.6 Adequate distance between the resin media surface and backwash collection units must be provided to accommodate the backwash flow rate of the unit. This distance will depend on the size and specific gravity of the resin. Generally, the backwash water collector should be 600 mm above the top of the resin on downflow units;

.7 Sampling taps - Smooth-nose sampling taps should be provided for the collection of representative samples. The taps should be located to provide for sampling of the influent, effluent and blended water. The sampling taps for the blended water should be at least 6 m downstream from the point of blending. Petcocks are not acceptable as sampling taps. Sampling taps should also be provided on the brine tank discharge piping;

.8 Pipes and contact materials must be resistant to the aggressiveness of the regenerant. Steel and concrete must be coated with a non-leaching protective coating which is compatible with salt and brine, or other regenerants;

.9 The treatment equipment should include an adequate underdrain, resin support system and brine distribution system; and

.10 Brine disposal - Suitable disposal must be provided for brine waste. Refer to Chapter 14 – Waste Residuals Handling and Treatment for further details.

15.2.3.1.4 Brine and Salt Storage Tanks

The following should be considered in the design of brine and salt storage tanks:

.1 Brine tank - Salt dissolving or brine tanks and wet salt storage tanks must be covered and corrosion resistant;

.2 Make-up water - The make-up water inlet must be protected from back-siphonage by an approved backflow prevention device or an air gap. Water for filling the tank should be distributed over the entire surface by pipes above the maximum brine level in the tank.

.3 Tanks should be equipped with manholes or hatchways for access and filling. Openings should be provided with raised curbs and watertight covers having overlapping edges similar to those required for finished water reservoirs. Each cover should be hinged on one side and should have a locking device;

.4 Overflows, where provided, must be protected with corrosion resistant screens and terminate with either a turned downed bend having a proper free fall discharge or a self-closing flap valve;

.5 Two wet salt storage tanks or compartments designed to operate independently should be provided;

.6 Salt should be supported on graduated layers of gravel placed over a brine collection system;

.7 Alternative designs which are conducive to frequent cleaning of the wet salt storage tank may be considered;

.8 Total salt storage should have sufficient capacity to store in excess of 150% of the delivery volume of salt and provide for at least 30 days of operation. Brine storage should be adequate to regenerate the softeners for 24 hours of operation without being replenished;

.9 Bagged salt and dry bulk salt storage should be enclosed and separated from other operating areas to prevent damage to equipment;

.10 Eductor - An eductor may be used to transfer brine from the brine tank to the ion exchange unit. If a pump is used, a brine measuring tank or means of metering should be provided to obtain proper dilution; and

.11 Cross connection control - Regeneration, rinse, and air relief discharge pipes should be installed with an air gap between the discharge and the disposal point to prevent back-siphonage.

15.2.3.2 Considerations for Iron and Manganese IEX Design

Dissolved iron and manganese can be removed via cationic exchange systems (i.e. ion exchange resins). The resin regeneration process should be as directed by the manufacturer. Often a salt brine displaces the iron and manganese ions. Alternatively, some resins use either an acid or sodium hydroxide (NaOH), to remove metals off the resin, in a process referred to as high pH regeneration. The salt brine, laden with iron and manganese, should then be safely disposed; refer to Chapter 14 – Waste Residuals Handling and Treatment for further guidance.

The form of iron and manganese (dissolved vs total), the need for pre-treatment, and competing ions that may reduce ion exchange efficacy should be considered. Ion exchange should not be used where:

.1 The water to be treated contains more than 0.3 mg/L of either iron, manganese, or combination thereof;
.2 The raw water or backwash water contains oxidants (such as chlorine) as they can damage the resins; and
.3 Iron and manganese are organically bound or are not in divalent state.
   a. It is frequently observed that as groundwater wells age, bacterial activity and oxidized iron and manganese become more common. The presence of oxidized iron and/or manganese may result in fouling of the ion exchange resin. Divalent iron and manganese can be measured on-site using colourimetric tests, or proportions of divalent iron and manganese can be roughly estimated by determining the dissolved concentrations of the metals and comparing them with the total concentrations. Dissolved concentrations can be determined by filtering water samples (ideally with a 0.45 µm filter) promptly after collection. Prompt filtration is important to prevent metal oxidation in the water sample when exposed to air.

15.2.4 Lime and Lime-Soda Softening Process

Lime and lime-soda softening may be used to soften water or removal metal ions. Lime softening involves adding lime (calcium hydroxide, CaOH) and optimizing the precipitation of $Mg(OH)_2$ and metal carbonates to either reduce the hardness or remove target dissolved ions, such as arsenic. Lime-soda softening involves adding lime (calcium hydroxide, CaOH) and soda ash (Na_2CO_3) to remove iron and manganese ions through precipitation. Addition of lime increases the pH of the raw water and shifts the carbonate species from carbon dioxide (CO_2) to bicarbonate (HCO^{3-}) to carbonate (CO_3^{2-}). The dissolved iron and manganese ions react with carbonate to form the insoluble precipitates of iron (II) carbonate ($FeCO_3$) and manganese (II) carbonate ($MnCO_3$), respectively. The precipitates can then be removed (see Chapter 7 – Pre-sedimentation, Coagulation, Flocculation and Clarification and Chapter 8 – Filtration).

Lime-soda softening operates at a high pH (between 10.3 and 10.6), which reduces magnesium (Mg), and with the use of ferrous chloride ($FeCl_2$) can co-precipitate manganese and silicates (SiO_2).

15.2.5 Biological Removal

Aerobic biofiltration can be used to remove iron and manganese from groundwater. This method involves establishing a biomass on the filter media and providing sufficient oxygen to allow the biomass to oxidize the target contaminants. Porous media such as granular activated carbon (GAC) or pumice stone are commonly used; the micropores of the media provide surface area to support biofilm growth.

The dissolved oxygen content is critical to biotreatment, as sufficient oxygen should be supplied to maintain biological activity. Nutrient addition or pH adjustment may also be required to maintain the biomass.

15.2.5.1 Design Considerations

Pilot testing of biological treatment is recommended as there are limited full-scale aerobic biofilters for iron/manganese removal in operation. The following should be considered:

- .1 Type of filtration/contactor (gravity or pressure);
- .2 Depth of filter/contactor media;
- .3 Type, size, and gradation of filter/contactor media;
- .4 Filtration and backwash rates, backwash system design;
- .5 Filter-to-waste;
- .6 Type of backwash water (raw vs. treated, unchlorinated vs. chlorinated, etc.);
- .7 Empty bed contact time (EBCT);
- .8 Dissolved oxygen concentration and method of/need for oxygen addition;
- .9 Number and types of filters piloted;
- .10 Need for chemical addition and dose;
- .11 Maximum acceptable filter/contactor head loss before backwash; and
- .12 Approximate hydraulic trends (run time, "clean-bed" head loss, total head loss).

For additional design considerations for biological iron and manganese removal, refer to AWWA: *Iron and Manganese Removal Handbook Second Edition*.

15.2.6 Sequestration

Sequestration is the process of adding a chemical sequestrant to keep iron and manganese in a colourless suspension and delay the formation of visible yellow/brown colour in the finished water. Sequestration does not remove iron and manganese. The effects of sequestering last a maximum of a few days. Since sequestration is temporary, iron and manganese may precipitate downstream, especially in hot water heaters.

Sequestration is only appropriate for addressing aesthetic concerns (for example, precipitation in distribution systems), and is not acceptable where manganese levels exceed the GCDWQ MAC.

15.2.6.1 Design Considerations

Sequestering may be performed using polyphosphate or sodium silicate. Both sequestrants are generally more effective for iron than for manganese. On-site colourimetric testing should be conducted to confirm that iron is mostly present in divalent form. Regular total metals analytical scans should be performed to confirm that manganese levels are low relative to iron levels. Seasonal variations in iron and manganese speciation and concentration for GARP and surface water sources should be considered. Designers should also note that groundwater sources tend to show increasing iron levels as they age. In this case, Designers should consider providing space for future iron removal equipment if evidence from other local wells indicate that this may eventually become necessary.

A summary of the design considerations for sequestering systems is shown in Table 15-3. Designers should note that presence of calcium and magnesium hardness will reduce the effectiveness of sequestration and raise the required dosage of sequestrant. Additionally, there is no predictable pattern of the impact of pH on sequestration effectiveness, thus pilot or bench testing is needed to optimize pH based on raw water quality. The success of the sequestration process is highly variable and is largely dependent on the ability to maintain a sequestrant residual throughout the distribution system. Water Suppliers should monitor for the sequestrant residual, contaminants of concern (e.g. lead, copper, etc.), pH and alkalinity to assess the effectiveness of the corrosion inhibitor throughout the distribution system.

Table 15-3 Design Considerations for Sequestering Systems

Consideration	Sequestrant	
	Polyphosphate	**Sodium Silicate**
Applicable water type	Surface or groundwater	Groundwater prior to air contact
Maximum concentration of either iron, manganese, or combination thereof	• 0.5 mg/L (recommended limit) • 1.0 mg/L (firm limit)	• 2 mg/L
Maximum total concentration of parameter in finished water	• 10 mg/L (total applied phosphate as PO_4)	• 20 mg/L (applied SiO_2) • 60 mg/L (combined applied and naturally occurring SiO_2)
Sequestrant point of application	• Polyphosphates should not be applied ahead of iron and manganese removal systems. • Point of application should be prior to any aeration, oxidation or disinfection if no iron or manganese removal is provided. • Should be as far ahead of oxidant feed point as possible.	• Sodium silicates should not be applied ahead of iron and manganese removal. • Rapid oxidation of metal ions (ex. by chlorine) should accompany or closely precede sodium silicate addition. Addition of sodium silicate more than 15 seconds after oxidation may cause noticeable loss of efficiency.
Sequestrant feed solution	• Stock phosphate solutions should be kept covered and disinfected by carrying ~10 mg/L free chlorine residual (unless phosphate cannot support bacterial growth or has a pH less than 2.0).	• Minimum 5% silica as SiO_2 should be maintained in feed solutions. • Silicate should be diluted to no more than 1:2, preferably with softened water. Greater dilution ratios should be avoided as this reduces sequestering effectiveness, particularly in warm seasons.
Distribution system considerations	• Watermain and service line materials.	• Watermain and service line materials.

Consideration	Sequestrant	
	Polyphosphate	**Sodium Silicate**
	• Chlorine residuals should be maintained in distribution system.	• Chlorine residuals should be maintained throughout distribution system.
Cost	• Considerably more expensive than sodium silicate.	• Less expensive than polyphosphate.

Initially, higher concentrations of sequestrant may be required to form a corrosion inhibiting film on the distribution pipe wall, after which the concentration can be significantly reduced to only what is required to maintain the presence of the film.

15.2.6.2 Sequestration Equipment

Sequestration equipment is similar to hypochlorite dosing equipment. Specific to sodium silicate sequestering, the following should be provided:

.1 A locally-placed day tank with lid for hypochlorite;
.2 A locally-placed day tank with lid for silicate, sized for up to two weeks of water treatment that allows for 1:2 dilution of silicate (for viscosity reduction), preferably with softened water;
.3 Peristaltic feed pumps, or other pumping arrangements adapted to provide continuous, pulse free addition of hypochlorite and silicate to the flowing water stream;
.4 Injectors of the "duck bill" or other scale blockage resistant variety that allow for injection of the silicate and hypochlorite to the center of a rapidly flowing stream to aid in the necessary rapid dispersion of the two chemicals. Several tappings should be made to allow for easy injector relocation and spacing changes; and
.5 A nearby downstream wide bore sample tap that allows for easy collection of 20 L samples for observation and dosage optimization.

15.3 Arsenic

Arsenic (As) often exists in source waters as arsenite (AsO_3^{3-} and other negatively-charged ions containing As(III)), arsenate (AsO_4^{3-}, containing As(V)), or a combination thereof. Speciation should be performed by a laboratory to determine the form of arsenic present as the oxidation state is critical in the selection of treatment technology. Due to the health effects associated with arsenic, every effort should be made to maintain arsenic levels in drinking water as low as reasonably achievable (or ALARA). The maximum acceptable concentration (MAC) for arsenic in drinking water is based on municipal- and residential-scale treatment achievability. Pilot testing is particularly important to confirm treatment effectiveness.

For information on the arsenic MAC, refer to the *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Arsenic*. For additional arsenic removal design information, refer to *USEPA: Arsenic Treatment Technology Demonstrations*.

15.3.1 General Design Considerations

The following points should be considered when selecting and designing an arsenic reduction technology:

.1 Oxidation state of arsenic.
- Most technologies are more effective at treating arsenate (anions containing As(V)) due to its insolubility and increased tendency to sorb;

.2 Raw water parameters including pH;

.3 Presence of competing ions including fluoride, sulphate, ammonia, silica.
- Ammonia can prevent effective oxidation of As(III) to As(V). Silica can reduce the effectiveness of arsenic removal, particularly when pH is greater than 8.0. Pre-treatment may be needed to remove these ions in addition to reducing total dissolved solids;

.4 Waste stream/solid waste disposal; and

.5 Cost.

15.3.2 Oxidation and Filtration

Oxidation and filtration can be used to effectively co-remove arsenic in the presence of iron. When iron, manganese, and arsenic are oxidized in the raw water through aeration, the As(V) is adsorbed on the $Fe(OH)_2$ precipitate, which can then be removed by filtration. Filtration rates are typically between 5 - 10 m/h. Higher filtration rates may be achievable using manganese dioxide-coated media or other proprietary media.

Oxidation/filtration systems work well for raw water where the Fe:As ratio is 20:1 or greater; the ratio may need to be greater than 100:1 in some cases. Raw water with a lower Fe:As ratio may require the addition of iron in the form of an iron-based coagulant such as ferric chloride ($FeCl_3$) or ferric sulphate ($Fe_2(SO_4)_3$) to increase arsenic removal. It is recommended that this approach be piloted before detailed design; refer to Chapter 3 – General Design Guidance for further guidance on piloting.

15.3.3 Adsorption

Arsenic can be removed from water through adsorption onto an adsorptive media, typically a proprietary media. The media consists of a porous solid coated with a metal oxide, typically iron (ferric oxide), titanium, or aluminum (including activated alumina). Filtration rates can range from 6 - 20 m/h and EBCT from 3 - 10 minutes.

Chemical pre-oxidation is typically required to ensure that arsenic is present in As(V) form. The pH should be maintained around 8; adjustment of pH may be required to enhance removal effectiveness and reduce corrosion. Silica, phosphates, iron and manganese should also be removed prior to arsenic adsorption to prevent fouling of the adsorptive media.

The replacement period for adsorbents can vary widely and can be significantly reduced due to interference by silica, phosphate and other compounds. Designers should evaluate adsorbents for the specific source water quality before selecting an adsorbent or proceeding with detailed design.

15.3.4 Electrodialysis/Electrodialysis Reversal

Electrodialysis/electrodialysis reversal uses an electrical charge across a reverse osmosis (RO) membrane to remove arsenic. Pre- and post-adjustment of pH may be needed to prevent scaling, to enhance filtration, and to reduce corrosivity. Other contaminants that may be removed using this technology include hardness, dissolved solids, nitrates, and sulphates.

If iron and manganese are too high, this may cause interference with the arsenic removal process. Oxidation and filtration of iron and manganese is normally used upstream to prevent fouling of the RO membrane.

15.3.5 Membrane Processes

Reverse osmosis or nanofiltration membranes can be used as stand-alone arsenic treatment under most water quality conditions. If micro or ultra-membranes are used, they usually require a coagulation step to create arsenic-bound floc prior to filtration. Membrane processes are usually not sensitive to pH, but pre-filtration may be needed if the feed water contains NOM, iron and inorganic ions such as chlorides, silica, calcium and magnesium. To increase the arsenic removal efficiency and reduce the volume of reject water, multiple units should be installed in series. See Chapter 8 – Filtration for membrane filtration process design considerations.

15.3.6 Lime Softening

Lime softening involves adding lime (calcium hydroxide, CaOH) and optimizing the precipitation of $Mg(OH)_2$ and metal carbonates. High iron concentrations are desired for optimal arsenic removal through lime softening. Waters with low dissolved iron may require the addition of ferric chloride or ferric sulphate. Hardness may also be removed in this process.

Other considerations include the disposal of lime sludge (refer to Chapter 14 – Waste Residuals Handling and Treatment), the large quantity of chemicals required and the high labour intensity of handling lime.

15.3.7 Coagulation and Filtration

This method typically consists of chemical oxidation and the addition of a coagulant or polymer to remove arsenic by sedimentation and filtration. Other contaminants may be removed in this process, and pre- and post-adjustment of pH may be needed. Sulphate may cause interference or reduce treatment efficiency.

15.3.8 Anion Exchange

Anion exchange uses a resin to remove arsenic by exchanging the anions for As(V) ions in the raw water. Refer to Section 15.2.3 – Ion Exchange for further ion exchange design guidance. Salt brines are periodically used to regenerate the exchange resin. Chloride-form resins are the most common, however sulphate or nitrate selective resins may also be used. The pH should be maintained between 6.5 to 9.0. Anion exchange should only be used for waters with low concentrations of total dissolved solids and other anions (sulphate, nitrates etc.) which can compete with binding sites on the resin. Typical loading rates are 10 - 30 m/h with EBCT from 2 - 5 minutes.

Corrosion control should also be considered as anion exchange initially decreases the pH and alkalinity. This may make the water more corrosive to lead, copper, and other metals. Additionally, resins require regeneration, which results in the production of a waste stream that needs to be safely disposed. Refer to Chapter 14 – Waste Residuals Handling and Treatment for further direction on proper disposal of the waste stream.

15.4 Cyanobacteria

Cyanobacteria, also known as blue-green algae, are photosynthetic bacteria that share some properties with algae. Primarily in the warmer seasons, cyanobacteria can multiply rapidly in surface water and cause harmful algal blooms. Decay of the bloom consumes oxygen, creating hypoxic conditions which can result in plant and animal die-off. Cyanobacteria also contain toxic by-products known as cyanotoxins, which are excreted when the cell splits during death or through mechanical means (lysis), and may be spontaneously released from intact cells. The most widespread cyanotoxins are in the class called microcystins. There are at least 80 known microcystins, the most toxic of which is microcystin-LR (MLR). Other cyanotoxins include anatoxin-a (ANA), cylindrospermopsin (CYN) and saxitoxins. If persistent cyanobacterial blooms are occurring in the source water, the feasibility of an alternate source should be considered. If an alternative source is not available, steps should be attempted to prevent the blooms from occurring.

Harmful algal blooms can also cause taste and odour concerns. For further information addressing these concerns, refer to Chapter 10 – Taste and Odour Control.

For information on the maximum acceptable concentration (MAC) for total microcystins, as well as design and management strategies, refer to the following:

.1 *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Cyanobacterial Toxins*, by Health Canada;
.2 *Decision Protocols for Cyanobacterial Toxins in B.C. Drinking Water and Recreational Water*, by the Ministry of Health;
.3 *Managing Cyanotoxins in Drinking Water: A Technical Guidance Manual for Drinking Water Professionals*, by the AWWA; and
.4 *Cyanobacteria and Cyanotoxins: Information for Drinking Water Systems*, by the USEPA.

The following sections discuss treatment approaches for removing cyanobacteria. Cyanobacteria should be monitored post treatment to confirm adequate removal, and that the cells have not been lysed.

15.4.1 Dissolved Air Flotation (DAF)

Dissolved air flotation (DAF) is a clarification process that effectively removes light particles such as blue-green algae. The DAF process involves using microbubbles to bind to particles, and floating them to the surface, where they can be removed with a sludge scraper. DAF is particularly effective as it typically does not damage the algae during the removal process and therefore avoids the release of the cyanotoxins. The waste sludge is then disposed. See Chapter 7 – Pre-sedimentation, Coagulation, Flocculation and Clarification for further information on DAF. Flotation processes, including DAF, are effective for removal of intracellular cyanotoxins since many of the toxin-forming cyanobacteria are buoyant. However, DAF will not remove extracellular cyanotoxins (i.e. toxins that have already been released to the water).

15.4.2 Ozone

Ozone (O_3) can be effective in oxidizing extracellular dissolved microcystins. However, its efficacy is impacted by the presence of organic matter and the pH at which it is applied. Another concern is the formation of disinfection by-products as a result of ozone application. Refer to Chapter 11 – Disinfection for use of ozone for disinfection purposes.

Note that application of oxidants upstream of cyanobacteria cell removal treatment should be discouraged as they can cause cell lysis, prompting cyanobacteria release. However, ozone can be an exception because it may simultaneously oxidize cyanotoxins.

15.4.3 Advanced Oxidation Process

Advanced oxidation processes (AOP) involve the generation of highly reactive hydroxyl radicals which can oxidize cyanobacteria and their toxins. This can be done in various combinations: the most common combinations are ozone with H_2O_2 ("peroxone"), ozone with UV light, and H_2O_2 with UV light. AOPs have been effective in treating microcystins (MLR), anatoxin (ANA), and cylindrospermopsin (CYN), in addition to some taste and odour compounds such as 2-methylisoborneol (MIB) and geosmin. The efficacy of AOP is strongly impacted by water quality parameters including natural organic matter (NOM), alkalinity, and pH. Formation of disinfection by-products (DBPs) should be considered when applying advanced oxidation processes.

Bench scale studies have indicated the reactivity of cyanotoxins with ozone to be MLR>CYN>ANA, though oxidation of all cyanotoxins increases with increased ozone dosage (Jasim et al., 2020). The required ozone and H_2O_2 dosage will differ depending on the characteristics of the raw water, cyanotoxin(s) present, and target cyanotoxin(s) to be removed (Schneider and Blaha, 2020). Pilot studies should be performed to determine the optimum dosages and operating method, particularly as AOP efficacy has been studied mostly at the bench scale and few studies have been performed at full scale.

For further information, refer to Section 10.2.7 – Advanced Oxidation Processes in the *Design Guidelines*, the *Cyanobacterial Toxins in Drinking Water Document for Public Consultation* by Health Canada, *Ozone in Drinking Water Treatment: Process Design, Operation, and Optimization* by Rakness (AWWA), the *Advanced Oxidation Handbook* by Collins (AWWA), and *Water Treatment for Purification from Cyanobacteria and Cyanotoxins*.

15.4.4 Powder Activated Carbon

Powdered activated carbon (PAC) can be added to the raw water at the inlet of the treatment plant to mitigate taste and odour issues and toxins associated with cyanobacteria. Refer to Section 13.7.9 – Activated Carbon for more details about PAC application and design.

15.5 Ammonia

The *Guidelines for Canadian Drinking Water Quality* do not specify a MAC for ammonia. However, the GCDWQ recommends that ammonia entering the distribution system is below 0.1 mg/L and preferably below 0.05 mg/L. Excess free ammonia in finished water can lead to nitrification, decreased free chlorine levels due to the formation of chloramines, and corrosion or biofilm problems in the water distribution system. If monochloramine is used as the secondary disinfectant, it is recommended that free ammonia in the finished water be less than or equal to 0.05 mg/L to prevent nitrification in the distribution system. As nitrate is an intermediate compound in the oxidation of ammonia to nitrate in biological filters, utilities should ensure that their systems are optimized such that the biological process is complete, and nitrate is not present in the treated water. The *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Ammonia* by Health Canada should be referred to when designing ammonia removal systems.

15.5.1 Biological Removal

Aerobic biotreatment of groundwater can effectively degrade/oxidize ammonia, similar to the biofilter treatment methods for iron and manganese removal described in Section 15.2 – Iron and Manganese. Sufficient oxygen should be provided to maintain biological activity. In order to have complete nitrification, a stoichiometric oxygen (O_2) demand of 4.33 mg O_2/mg NH_4^+-N is required; for higher ammonia concentrations, a constant oxygen feed may be required. Systems with high nitrates in the raw water may not be suitable for biotreatment as ammonia is converted to nitrate in a 1:1 ratio by ammonia oxidizing bacteria. Additional treatment for nitrate removal may be required if high levels of ammonia removal (6 - 8 ppm) are needed.

The treatment objectives and water quality targets of the biotreatment systems should be clearly defined for ammonia, and other constituents including iron and manganese. The secondary disinfectant should also be specified, if chloramines are used for disinfection.

15.5.2 Breakpoint Chlorination

Breakpoint chlorination is an effective technique for the removal of ammonia in raw water. Ammonia, when in contact with chlorine, reacts rapidly to form chloramines. Chlorine reacts with NH_3 to form monochloramine (NH_2Cl). The additional free chlorine then reacts with monochloramine to form dichloramine ($NHCl_2$), and then trichloramine (NCl_3). Chlorine dosing past the breakpoint results in free chlorine residual. Breakpoint chlorination is thus the addition of chlorine to water until the chlorine demand has been satisfied to reach the breakpoint. Chlorination can then be achieved by using chlorine-based disinfectants, such as chlorine gas and sodium hypochlorite. Refer to Section 11.7.2 –Chloramine Formation for details on breakpoint chlorination.

Breakpoint chlorination is cost effective for removal of water with low ammonia levels, however, removal of higher levels of ammonia may become cost prohibitive and increase DBP formation. The presence of 1 mg/L of ammonia nitrogen in raw water may require 8 to 10 mg/L of chlorine dose to achieve breakpoint chlorination.

15.5.3 Ion Exchange

Ion exchange may be used for ammonia removal from water; however, media should be selected with high ammonium exchange capacity. Zeolites are good options for ammonia removal: in particular, clinoptilolite is a natural zeolite which is most commonly used for ion exchange removal of ammonia. Zeolites can be regenerated using brine. Since only the ionized ammonium form can be removed by the ion exchange process, the pH of water needs to be maintained at 7.2 - 7.6.

Water that is high in hardness will have decreased treatment efficiency due to the simultaneous affinity and removal of calcium, magnesium and ammonium ions. There are selective zeolites that will preferentially remove ammonia in high hardness water, however, use of these media may result in high levels of sodium in the treated water. Ion exchange is a viable method especially when low cost minerals can be used as an exchanger and water has low hardness. Section 15.2.3 – Ion Exchange provides further considerations for ion exchange.

15.6 Radionuclides

Natural sources of radionuclides are responsible for greater than 98% of radiation exposure, excluding medical exposure. Radionuclides may occur naturally in groundwater through contact with rocks or soils that have naturally occurring radioactive materials (NORM) but can also be the result of anthropogenic activities in both groundwater and drinking water. While generally rare, the radionuclides most likely to be found in Canadian drinking water supplies are uranium, lead-210, radium-226, tritium, strontium-90, iodine-131, and cesium-137. Refer to the *Canadian Drinking Water Quality Guidelines* for MAC values.

Water systems should conduct predesign studies and pilot tests to determine the treatment and waste disposal options appropriate for their situation. Table 15-4 provides removal efficiencies for treatment processes that are commonly used to treat radionuclides (note removal efficiencies were observed for point-of-entry (POE) or point-of-use (POU) systems).

Constituent concentrations in the waste streams will be a key consideration in disposal and should be estimated through desktop calculations and where possible through testing (bench and/or pilot scale). Refer to Chapter 14 – Waste Residuals Handling and Treatment for more details on residual handling.

Table 15-4 Radionuclide Removal Methods (sourced from MWH, 2015)

Method	Removal Efficiency (%)		
	Radon	Radium	Uranium
Activated alumina			90 %
Aeration, packed tower or diffused bubble	To 99%		
Aeration, spray	70 to 95%		
Coagulation - filtration			80 to 98%
GAC Adsorption - decay	62 to 99%		
Electrodialysis		90%	
Greensand		25 to 50%	
Hydrous manganese oxide filter		90%	
Ion exchange		81 to 99%	90 to 100%
Lime softening		80 to 92%	85 to 99%
Reverse osmosis		90 to 95%	90 to 99%

15.6.1 Granular Activated Carbon Radon Removal

Radon will decay to form radioactive decay products once adsorbed onto GAC beds. The first four decay products have short half-lives (less than 30 minutes) and are associated with beta and gamma emissions. The fifth decay product is Pb-210, which has a half life of 22 years and will accumulate on the GAC bed over time. GAC beds can be used for radon removal for many years assuming no limiting water quality conditions exist.

Designers should consider measures to reduce operator exposure to radon and radon decay products if GAC units are to be used. Possible measures include automating the treatment system to allow the operator to control the system remotely, adding vessel shielding, or installing physical barriers to prevent casual contact. Disposal of the spent GAC can present a challenge, depending on the contaminants present and the extent of contaminant accumulation. The Designer should consult with relevant authorities to determine the appropriate disposal method(s) for spent GAC, and refer to Chapter 14 – Waste Residuals Handling and Treatment.

15.7 Heavy Metals

Heavy metals present drinking water health risks as they tend to bioaccumulate within humans when consumed. The most common heavy metals in drinking water are lead (Pb) and copper (Cu) as they are leached from plumbing and distribution system components, including watermains, fixtures, and faucets. Other heavy metals such as mercury, chromium, and selenium may be present in source water; however, they are less common and require specialized treatment processes for removal. The treatment considerations for these parameters are not discussed within this section; however, Designers should use industry standards and best management practices to achieve the MACs set out in the GCDWQ.

Corrosion control should be performed to produce non-corrosive water and minimize lead (Pb) and copper (Cu) leaching within the distribution system. Corrosion control studies should assess the effectiveness of pH and alkalinity control, hardness, and the addition of phosphate or silica-based corrosion inhibitors. Every effort should be made to reduce the lead level in drinking water to as low as reasonably achievable (ALARA). Refer to Chapter 12 – Internal Corrosion Control, for details on corrosion control methods.

15.7.1 Household Water Treatment Devices

As the primary source of lead and copper is leaching from plumbing and distribution components, household water treatment devices can be effective in removing these metals at the tap. This includes carbon-based filters, RO devices, and distillation treatment devices. Refer to Chapter 21 – Small Systems for further guidance on point-of-entry and point-of-use systems.

15.8 Fluoride

15.8.1 Fluoride Addition

Sodium fluoride, hydrofluosilicic acid (also known as fluosilicic acid or hexafluosilicic acid) and sodium silicofluoride may be used for fluoridation. These compounds are highly corrosive and require specific considerations. In addition to these guidelines, the Designer should refer to a fluoride manual such as

AWWA Manual of Water Supply Practices M4 – Water Fluoridation Principles and Practices and the *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Fluoride.*

Where fluoride addition is practiced, a fluoride dosage of 0.8 mg/L is recommended and should not exceed 1.2 mg/L. The dose selection is dependent upon the local climate; higher temperature regions having high water consumption should target a dose of 0.8 mg/L, and colder temperature regions should conversely target a dose of up to 1.2 mg/L. Water systems that fluoridate should maintain fluoride concentrations between 0.5 mg/L and 0.9 mg/L in the distribution system. If there is naturally occurring fluoride in the source water, the total concentration of naturally occurring fluoride plus added fluoride should be within this range. This requirement ensures that fluoridation is tightly controlled, effective, and reliable.

When fluoridation is practised, adequate controls should be maintained at all times to provide a fluoride ion concentration in treated water to meet the optimum concentration in the latest edition of the GCDWQ. The monthly average and daily variation should be within ± 0.1 mg/L and ± 0.2 mg/L of the targeted concentration, respectively.

Any Water Supplier proposing to add fluoride to a potable water supply should apply for and obtain approval from their Health Authority. The following information should be included in the application for approval:

- .1 A description of the proposed fluoridation equipment;
- .2 A statement identifying the fluoride compound that is proposed to be added;
- .3 A description of chemical storage and ventilation;
- .4 A description of the water metering used at the water treatment plant;
- .5 The generic name of the chemical to be used as the source of fluoride ion, and its fluoride content;
- .6 A current chemical analysis of the fluoride content of the raw water;
- .7 The name and qualifications of the person directly responsible for the operation of the proposed fluoridation process;
- .8 The type of equipment proposed at the water treatment plant to determine the fluoride concentration of the water; and
- .9 A description of the testing procedure to be used to determine the fluoride level of the water.

15.8.2 Design Considerations

When designing fluoride systems, Chapter 13 – Chemical Application should be referenced in addition to the following considerations:

- .1 At least two diaphragm operated anti-siphon devices should be provided on all fluoride saturator or fluosilicic acid feed systems;
  - a. One diaphragm operated anti-siphon device should be located on the discharge side of the feed pump;
  - b. A second diaphragm operated anti-siphon device should be located at the point of application unless a suitable air gap is provided;
- .2 A physical break box may be required in high hazard situations where the application point is substantially lower than the metering pump. In this situation, either a dual head feed

pump or two separate pumps are required and the anti-siphon device at the discharge side of the pump may be omitted;

.3 Scales, loss-of-weight recorders or liquid level indicators, as appropriate, accurate to within 5% of the average daily change in reading should be provided for chemical feeds;

.4 Feeders should be accurate to within 5% of any desired feed rate;

.5 Fluoride compound should not be added before lime-soda softening or ion exchange softening;

.6 The point of application if into a horizontal pipe, should be in the lower half of the pipe, preferably at a 45^{o} angle from the bottom of the pipe and protrude into the pipe one third of the pipe diameter;

.7 Water used for sodium fluoride dissolution should be softened if hardness exceeds 50 mg/L as calcium carbonate;

.8 Fluoride solutions should be injected at a point of continuous positive pressure unless a suitable air gap is provided;

.9 Saturators should be of the up-flow type and be provided with a meter and backflow protection on the makeup water line;

.10 Consideration should be given to provide a separate room for fluosilicic acid storage and feed;

.11 Dust control:

a. Provision should be made for the transfer of dry fluoride compounds from shipping containers to storage bins or hoppers in such a way as to minimize the quantity of fluoride dust which may enter the room in which the equipment is installed;
b. The enclosure should be provided with an exhaust fan and dust filter, which places the hopper under negative pressure. Air exhausted from fluoride handling equipment should discharge through a dust filter to the outside atmosphere of the building;
c. Provision should be made for disposing of empty bags, drums or barrels in a manner which will minimize exposure to fluoride dust;

.12 Testing equipment:

a. Equipment should be provided for measuring the quantity of fluoride in the water;

.13 Metering: Metering of the total water to be fluoridated should be provided, and the operation of the feeding equipment is to be controlled unless specifically exempted. Control of the feed rate should be:

a. Automatic/proportional controlled, whereby the fluoride feed rate is automatically adjusted in accordance with flow changes to provide a constant pre-established dosage for all rates of flow; or
b. Automatic/residual controlled, whereby a continuous automatic fluoride analyzer determines the residual fluoride level and adjusts the rate of feed accordingly; or
c. Compound loop controlled, whereby the feed rate is controlled by a flow proportional signal and residual analyzer signal to maintain a constant residual;

.14 Record of Performance Monitoring: Accurate daily records should be kept. These records should include:

a. the daily reading of the water meter, which controls the fluoridation equipment or that which determines the amount of water to which the fluoride is added:
    i. the daily volume of water fluoridated;
    ii. the daily weight of fluoride compound in the feeder;
    iii. the daily weight of fluoride compound in stock;
    iv. the daily weight of the fluoride compound fed to the water;

v. the fluoride content of the raw and fluoridated water determined by laboratory analysis, with the frequency of measurement as follows:
   - treated water being analyzed continuously or once daily;
   - raw water being analyzed at least once a week;

.15 Sampling: The following sampling procedures should be undertaken to monitor the fluoride dosing for consistency:

a. A sample of raw water and a sample of treated water should be forwarded to an approved independent laboratory for fluoride analysis once a month; and
b. On new installations or during start-ups of existing installations, weekly samples of raw and treated water for a period of not less than four consecutive weeks should be submitted to a designated laboratory to determine the fluoride concentration.

15.8.3 Removal of Naturally Occurring Fluoride

Control options for excess fluoride levels in drinking water include blending of fluoride-rich waters with waters of low fluoride content, the selection of low-fluoride source water and removal of excess fluoride concentration by treatment processes at the water supply or household level. Where fluoride is naturally occurring and above the GCDWQ or other regulatory requirements, fluoride should be removed by an acceptable means to less than the required limit. Reference should be made to the *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Fluoride.*

A wide range of technologies such as activated alumina (AA), reverse osmosis (RO), lime softening, and conventional ion exchange, are capable of reducing excess fluoride levels from drinking water. Coagulation has been shown to reduce fluoride; however, it is less practical than other approaches.

15.8.3.1 Coagulation Techniques

Although not highly effective, inorganic coagulants such as aluminum sulphate (alum) or a ferric salt, may be able to reduce fluoride in drinking water. These processes require very large concentrations of coagulant for fluoride removal.

Fluoride removal by alum coagulation is affected by factors such as a coagulant dose and pH. Experimental data has demonstrated that the optimum pH range for removal of fluoride is between 6.2 and 7.0.

Due to the high quantity of coagulant required, and the cost of the chemicals, this process has limited applications, especially for small treatment systems. The high coagulant use would result in the generation of a large volume of sludge, which would require pre-treatment and disposal.

15.8.3.2 Ion Exchange

15.8.3.2.1 Activated Alumina

The most practical municipal-scale technology for the reduction of excess fluoride concentrations in drinking water is adsorption with activated alumina (AA). Activated alumina shows a high affinity and selectivity towards fluoride ions; the adsorption process is similar to conventional ion exchange. Full-scale and pilot-scale studies have demonstrated that effluent concentrations of fluoride below 1.0 mg/L are achievable using AA adsorption.

In AA adsorption, raw water is continuously passed through packed media beds (in series or parallel), and the fluoride ions are exchanged with the hydroxide ions bound with the alumina. Factors such as pH, influent fluoride concentration, media particle size, and competing ions (arsenic, selenium, silica, hardness ions) have a significant impact on fluoride removal. In addition, the effectiveness of the process is also a function of the flow rate, the empty bed contact time (EBCT), and media regeneration.

When employing AA technology, operational issues that should be considered include:

.1 AA sourced from "cemented alumina beds" which tends to dissolve as a result of the regeneration process should be avoided;
.2 Fouling of the AA bed with particulates may occur depending on influent water quality, resulting in an increase in head loss across the media bed *(USEPA, 1984, 2002)*; and
.3 Metal hydroxides, suspended solids, carbonates and adsorbed silicates can reduce the adsorption capacity of AA.

If present, iron and manganese should be sufficiently oxidized and filtered prior to the AA beds to reduce fouling. Additional considerations include chemical handling requirements, pH adjustments, and regeneration of exhausted AA beds; due to these complexities, AA may not be viable for small water systems. Refer to the U.S. EPA design manual *Removal of Fluoride from Drinking Water Supplies by Activated Alumina* for more details on AA adsorption.

15.8.3.2.2 Anion Exchange

Factors affecting fluoride removal by anion exchange technology include the influent fluoride concentration, the concentration of competing ions, and media regeneration. Refer to Section 15.2.3 – Ion Exchange for further ion exchange design guidance.

15.8.3.2.3 Bone Char

Bone char - a blackish, porous, granular material with a specific affinity for fluoride - can be used for water with high alkalinity and high total dissolved solids (TDS), but imparts an undesirable taste to the water. Full scale installations (2 units in series) have demonstrated reduction of fluoride from 9 - 12 mg/L to 0.6 mg/L.

Bone char is soluble in acid and the recommended pH to prevent loss of the media is approximately 7.0. The presence of arsenic ions could reduce fluoride removal efficiency.

15.8.3.3 Reverse Osmosis and Nanofiltration Processes

Reverse osmosis and nanofiltration (NF) technologies have been shown to be effective methods for the reduction of fluoride concentrations below 1 mg/L in drinking water.

The performance of the membrane systems depends on the quality of the raw water, the type of the membrane, molecular weight cut-off, and recovery of the system. The presence of iron, manganese, silica, scale-producing compounds, and turbidity could negatively affect system performance. A pre-treatment of the feed water is required to prevent scaling and fouling of the RO membranes. The RO product water typically requires post-treatment consisting of pH and alkalinity adjustments.

15.8.3.4 Lime Softening

Lime softening is more applicable for fluoride reduction in source waters with high magnesium concentrations. If the raw water has a low magnesium content, magnesium salt may be added.

Lime softening is an expensive process due to the large quantity of chemicals used and is not recommended unless there is also a need to reduce hardness in the raw water. These systems also create significant quantities of sludge, which require pre-treatment and disposal, and add to the cost of the process.

15.8.3.5 Electrodialysis Reversal

Electrodialysis is an electrochemical separation process in which ions are transported through semi-permeable membranes under the influence of an electric potential. In electrodialysis reversal (EDR) the polarity of the electrodes is changed periodically across the ion exchange membranes. Pilot and full-scale applications of these processes have demonstrated fluoride removal to meet regulatory requirements. For design criteria, refer to *AWWA M38: Electrodialysis and Electrodialysis Reversal*.

15.9 Saltwater Intrusion

Saltwater intrusion occurs when saline water enters a freshwater aquifer due to either natural processes or human activities. Treatment options for saltwater can include freshwater injection (although not typical for B.C.) or reverse osmosis (RO) membrane filtration, and is typically costly. The type of RO depends on raw water quality: sea water RO membranes have the highest removal but also the highest operating pressure, while brackish water RO membranes have a lower salt rejection. Refer to Chapter 8 – Filtration for further information on membrane filtration.

Pursuant to *WSA 58 (2)*, a person must not operate a well in a manner that causes or is likely to cause the intrusion of saline groundwater, sea water or contaminated water into:

(i) the aquifer from which that well diverts water,
(ii) another aquifer, or
(iii) a stream that is hydraulically connected to an aquifer referred to in subparagraph (i) or (ii).

For further recommendations on preventing saltwater intrusion, refer to Section 6.3.1.7.1 – Saltwater Intrusion as well as the *Best Practices for Prevention of Saltwater Intrusion* and current advisories for coastal areas located here: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/groundwater-wells-aquifers/groundwater-wells/information-for-well-drillers-well-pump-installers/well-drilling-advisories.

15.10 Nitrite and Nitrate

The most common sources of nitrite and nitrate are human activities, including agricultural activities, septic systems, and wastewater treatment. Refer to the *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Nitrate and Nitrite* by Health Canada for MACs.

The following section describes treatment processes that can effectively reduce nitrite and nitrate concentrations when designed properly. However, primary consideration should be given to non-treatment alternatives to resolve nitrite and nitrate contamination. This includes obtaining water from an alternate source, introducing better control of nitrogen fertilizer application, and better containment of septic systems.

15.10.1 Blending

Blending of two or more sources can be used to decrease the nitrite/nitrate concentration in the resultant water. Note that nitrate levels in groundwater may vary over time. As different source waters have different raw water characteristics, blending studies and pilot testing should be conducted to determine the compatibility of the sources and the optimum blending ratio. Corrosion problems can result from mixing two different waters, therefore a corrosion study is recommended when the two water sources are blended in an existing system. Refer to Chapter 12 – Internal Corrosion Control for more information.

15.10.2 Electrodialysis Reversal (EDR)

Electrodialysis is an electrochemical process that involves applying a direct current between a stack of alternating anion-selective membranes and cation-selective membranes. As the feedwater travels through the stack, anions (such as nitrate) are removed by anion-selective membranes. The polarity and hydraulic channels are periodically reversed to keep the membranes clean. For design criteria, refer to *AWWA M38: Electrodialysis and Electrodialysis Reversal*.

15.10.3 Biological Denitrification

Biological denitrification is commonly used in wastewater treatment processes in which nitrate is reduced to nitrogen gas (N_2). Anoxic conditions are required, so DO must be < 0.1 mg/L. Depending on the type of bacteria involved, additional nutrients (carbon, hydrogen, or sulphur) may be required to maintain the required biomass.

Some treatment plants in Europe and the United States have successfully used biological denitrification in drinking water treatment. A fluidized bed bioreactor or fixed bed bioreactor can be used. In either case, water flows through media which supports bacterial biofilm growth.

15.10.4 Ion Exchange

Nitrate is a negatively charged ion which can be removed through ion exchange using an anion resin. A salt brine is used to periodically regenerate the resin. The volume of water that can be treated by the anion resin prior to regeneration is a key design parameter. Designers should use a pilot test to confirm an estimated volume of water that can be treated before exhaustion. Refer to Section 15.2.3 – Ion Exchange for further design guidance.

The concentration of other anions (sulphate, chloride etc.) in the water should also be considered, as these ions will compete with nitrate for exchange sites on the resin. In particular, ion exchange resins have a higher affinity for sulphate than nitrate. If the resin is not regenerated in time, other anions will displace the nitrate. This can cause the concentration of the nitrate in the treated effluent to exceed the untreated water in an effect known as chromatographic peaking. High levels of dissolved solids may also interfere with the ion exchange process.

Anion exchange will initially decrease the pH and alkalinity, which may increase the corrosivity of the water. Corrosion control treatment may be required.

15.10.5 Reverse Osmosis (RO)

Reverse osmosis is used primarily for very low flows due to the high cost and high volume of reject water. RO rejects many dissolved ions, including nitrate. Refer to Chapter 8 – Filtration for details of reverse osmosis design guidance.

15.11 Emerging Contaminants

New water contaminants of concern continue to emerge, and as laboratory analysis methods improve, some chemicals, constituents, and microbial agents can be detected at very low levels in drinking water. The intent of this chapter is to bring attention to emerging contaminants that may be present in drinking water so that Designers and Water Suppliers can assess risk and plan for mitigation as needed.

While different effects (e.g. fate in water systems) of anthropogenic chemicals and microbiological organisms have been discovered, it is not always clear if these emerging contaminants pose concerns to human health at these low concentrations. Regulatory Authorities and health professionals have established health advisory limits for some contaminants which may become regulated in the future, and research continues to clarify maximum acceptable concentrations and associated health effects. Recent emerging contaminants of concern in drinking water sources include:

- .1 Persistent organic pollutants (POPs) such as polybrominated diphenyl ethers (PBDEs used in furniture), pesticides (DDT, Aldrin etc.), and polychlorinated biphenyls (PCBs used in coolants);
- .2 Pharmaceutical and personal care products (PPCPs) including prescription and over-the-counter medications;
- .3 Veterinary medicines such as antimicrobials and antibiotics;
- .4 Endocrine-disrupting chemicals (EDCs) including synthetic hormones such as estrogens and androgens;
- .5 Microplastics composed of polymers such as PET (polyethylene terephthalate), PP (polypropylene), and PE (polyethylene);
- .6 Nanomaterials: particles ranging in size from 1 to 100 nanometers used in drug delivery, aerospace, and cosmetics, including materials such as titanium dioxide (TiO_2) and carbon nanotubes;
- .7 Perfluoroalkyl and polyfluoroalkyl substances (PFAS); and
- .8 Emerging environmental pathogens such as amoebae, fungi, and opportunistic premise plumbing bacterial pathogens.

Designers and Water Suppliers should remain informed of the emerging contaminants that may be present in drinking water and their potential human health effects, risk of occurrence within source waters and future treatment options. As research and applied science expand the evidence based practice related to specific contaminants, Designers and Water Suppliers should continue to assess the risk and mitigation methods to protect the public from such contaminants.

Designers should consider selection of water sources which minimize emerging contaminants and include provisions for advanced treatment options if needed in the future. The selection of the treatment process will differ depending on the target contaminant. Note that many emerging contaminant-related studies have only been conducted at the laboratory scale, and pilot testing should be performed to determine site-specific technology selection and operating conditions. The Designer should also consider the impact of waste streams on the environment and identify proper disposal methods.

The following sections describe the more widely studied technologies for emerging chemical contaminant removal in drinking water; however, they may be expensive and difficult to operate. For further information, refer to *Treatment Technologies for Emerging Contaminants in Water:* A Review (Rodriguez-Narvaez et al., 2017), *Drinking Water Treatment for PFAS Selection Guide* by AWWA, and *Removal of Endocrine Disruptor Chemicals Using Drinking Water Treatment Processes* by the USEPA.

15.11.1 Adsorption

Adsorption by activated carbon - either granular or powder - is the most widely studied emerging contaminants removal method. In general, activated carbon has provided good results for removal of various organic compounds such as POPs and EDCs (Rodriguez-Narvaez et al., 2017). Activated carbon may be paired with other removal technologies, such as coagulation and filtration, for enhanced emerging contaminant removal. The source of the raw material for the activated carbon is an important factor as different sources result in significantly different removal rates.

A similar technology is biochar, which is a charcoal-based material often used for soil amendment. Biochar has different selectivity and may be more efficient at removing certain ECs compared to activated carbon. Other adsorbents including clay and zeolites have also been studied to a more limited capacity.

15.11.2 Membrane Technologies

Membrane technologies that have been shown to remove emerging contaminants include ultrafiltration (UF), nanofiltration (NF), forward osmosis (FO), and reverse osmosis (RO). UF is generally more effective at removing polar, highly water-soluble ECs. NF has also been shown to effectively remove organic contaminants such as DDT *(Pang et al., 2010)*. Membrane material also impacts removal efficiency of different ECs.

RO and FO have both shown effective removal of organic compounds at low concentrations. RO has been reported to be more efficient than FO, as it can remove particles as small as 1 nm and colloidal particles. For both RO and FO, efficiency increases as pore size decreases.

15.11.3 Advanced Oxidation Process

Bench scale testing has found ozone/H_2O_2 based AOPs applied before coagulation to be effective in removing PPCPs EDCs when performed in conjunction with clarification and filtration (Rahman et al., 2010). Ozone/H_2O_2 based pre-coagulation AOP has also shown the potential to remove trace pharmaceuticals. See Section 15.4.3 – Advanced Oxidation Process for more information.

Other AOP methods such as the Fenton reaction, a catalytic process where H_2O_2 reacts with Fe^{2+} (usually provided in the form of $FeSO_4$), to form OH*, have also been shown to remove organic emerging contaminants. However, there are no known full-scale WTPs using Fenton reaction-based AOPs due to the low pH required and sludge production.

16 Transmission and Distribution

16.1 General

This chapter provides design guidance for transmission and distribution systems for water supply systems. Distribution systems should be designed to protect and maintain microbiological water quality. Distribution system design considerations should include main sizing, provision of multidirectional flow, valving for distribution system control, setbacks from potential contaminants, and provisions for flushing and maintenance to maintain water quality and minimize loss of service to customers. Distribution systems should be designed to maximize turnover rates and to minimize residence times while maintaining the required pressure and flows to provide high reliability and to reduce water quality problems.

Other approval authorities such as local governments may have standards that are more stringent than these guidelines. The Designer should, therefore, ensure that they are aware of the requirements of all other approving authorities before commencing design.

16.2 Water Instability Due to Biological Activity

Treated drinking water quality should ideally undergo minimal changes throughout the distribution system. However, biologically unstable water may experience deteriorating quality during distribution; for example, biodegradation of organic matter, development of biofilms and reduction of sulphates to sulphides can pose aesthetic and health risks.

Biological stability can be encouraged by maintaining a free and/or combined chlorine residual throughout the distribution system. Further information about secondary disinfection or 'residual disinfection' can be found in Section 11.1.2 – Secondary Disinfection and in the Ministry of Health's *British Columbia Guidelines (Microbiological) on Maintaining Water Quality in Distribution Systems*.

Reducing the amount of natural organic matter (NOM) and specifically biodegradable dissolved organic carbon (BDOC) prior to treated water entering the distribution system should also be considered to prevent the development of biologically unstable water. Chapter 7 – Pre-sedimentation, Coagulation, Flocculation and Clarification, Chapter 8 – Filtration and Chapter 15 – Parameter Specific Treatment should be referenced for methods of removing BDOC and NOM.

Further information on characterizing biological activity can be found in Health Canada's *Guidance on Monitoring the Biological Stability of Drinking Water in Distribution Systems*.

16.3 Design Criteria

16.3.1 Layout Considerations

Distribution system layouts are usually designed in one of three configurations: arterial-loop systems, grid systems and tree systems. Tree systems often have more dead ends and as such are generally not recommended.

Wherever possible, water distribution systems should be designed to eliminate dead ends by making appropriate tie-ins or looping whenever practical. Water quality problems associated with dead ends include taste and odour concerns, decay of disinfectant residual, bacterial growth, increased corrosion, changes in pH and collection of sediment. Where dead-ends mains cannot be avoided, the Designer should take steps to ensure the water quality issues have been addressed.

Isolation valves should be strategically installed to allow for the maintenance of service through alternate routing while repairing a section of watermain.

16.3.2 Interconnections

If interconnections between distribution systems or different water supply sources are planned, consideration should be given to:

- The differences in water quality and characteristics; and
- The implications of mixing different waters; examples include mixing water from a distribution system where chloramination is used with water from a system where free chlorination is used for secondary disinfection, or when differing water qualities could cause corrosion when combined.

16.3.3 System Pressures

All transmission mains, primary distribution mains, distribution mains and service mains, including those not designed to provide fire protection, should be sized based on a hydraulic analysis of flow demands, municipal by-laws, and pressure requirements. For complex systems that include interconnected piping networks, the Designer should use computer modelling to calculate:

.1 Head loss through various bends and fittings in transmission mains and distribution piping;
.2 The elevation of the highest developable location within the serviced properties, with specific consideration to avoiding the potential for negative pressures occurring within service lines.

16.3.3.1 Minimum Pressures

Unless otherwise specified by municipal bylaws or Water Supplier design standards, water systems should be designed to maintain:

.1 A minimum pressure of 140 kPa (20 psi) at ground surface level at all points in the distribution system under maximum day demand plus fire flow conditions.
.2 Normal and peak hourly demand operating pressures in the distribution system between approximately 345 to 480 kPa (50 to 70 psi) and not less than 275 kPa (40 psi).

16.3.3.2 Maximum Pressures

Unless otherwise specified by municipal bylaws or Water Supplier design standards, water systems should be designed so that:

.1 Maximum operating pressures in the distribution system do not exceed 850 kPa (123 psi) to avoid damage to household plumbing and unnecessary water and energy consumption; and
.2 Pressure reducing devices are provided when static pressures exceed 850 kPa (123 psi).

16.3.3.3 Transient Pressures

Transient pressures can develop within transmission mains and distribution networks due to sudden flow velocity changes resulting from pump starts and stops, power failures, or rapid valve operation. The

Designer should consider the following when designing pumping and valve control facilities to prevent damage to water system components:

.1 Control motor/pump speeds during starting and stopping operations by use of variable frequency drives or motor soft starters;
.2 Control pumped system flow velocity changes by use of one or a combination of hydraulic pump control valves, surge anticipating valves or online surge vessels;
.3 Control valve opening and closing speeds to prevent rapid changes in flow by use of gear reduction mechanisms, pneumatic or electric actuation rate of change;
.4 Pumping systems should be designed to minimize pressure surges;
.5 Pipes and joints should be designed to withstand the maximum operating pressure plus the pressure surge that would be created by stopping a water column moving at the maximum operating velocity; and
.6 Transient pressures vary depending upon the hydraulic flow rate, change in flow velocity, pipe diameter, pipe wall thickness and pipe material used in the distribution system.

Transient analysis should be undertaken for long transmission lines, mains near pump stations, mains that service multiple large consumers, mains with regularly operating on/off valves or PRVs and where high pressure or high velocities warrant an analysis.

16.3.4 Friction Factors

For new pipe conditions, the Designer *s*hould refer to the most recent versions of the following AWWA Manuals:

.1 Manual of Water Supply Practices M9 – Concrete Pressure Pipe;
.2 *Manual of Water Supply Practices M11 – Steel Water Pipe: A Guide for Design and Installation*;
.3 *Manual of Water Supply Practices M23 – PVC Pipe: Design and Installation*;
.4 *Manual of Water Supply Practices M41 – Ductile-Iron Pipe Fittings*;
.5 *Manual of Water Supply Practices M45 – Fiberglass Pipe Design*; and
.6 *Manual of Water Supply Practices M55 – PE Pipe - Design and Installation*.

In evaluating existing systems for expansion, the Hazen-Williams coefficients (C-factors) should be determined by actual field tests wherever possible. Where these data are not available, the Designer may choose to use the Hazen-Williams C-factors shown in Table 16-1 for the design of water distribution systems with pipes made of traditional materials, or when estimating pressure losses in existing systems.

Table 16-1 Hazen-Williams C-factors

Diameter – Nominal	C-Factor
150 mm (6 in)	100
200 mm – 250 mm (8 to 10 in)	110
300 mm – 600 mm (12 to 24 in)	120
Over 600 mm (over 24 in)	130

Source: *Design Guidelines for Drinking-Water Systems 2008, Ontario Ministry of Environment*

Alternatively, the *Designer* may choose to use other methods of calculating friction factors such as the Darcy-Weisbach equation or the Manning equation, noting the relevant assumptions for the calculation method used.

16.3.5 Pipe Diameter

All watermains, including those not designed to provide fire protection, should be sized according to a hydraulic analysis based on flow demands and pressure requirements, as well as the depositional nature of the water with respect to long term watermain carrying capacity. Any deviation from the minimum requirements listed in Table 16-2 should be justified by hydraulic analysis. The actual inside pipe diameter should be used in the hydraulic calculations.

Table 16-2 Minimum Pipe Diameters

Condition	Minimum Diameter
Systems with fire protection	Minimum size of watermain should be 150 mm, except beyond last hydrant where 100 mm diameter is acceptable, however the number of services should be limited; or As determined to maintain the required pressure, flows, and water quality under normal operating conditions.
Systems without fire protection	Minimum size of watermain should be 100 mm diameter where a dead-end termination would preclude the possibility of future extension; or As determined to maintain the required pressure flows, and water quality under normal operating conditions.

The minimum size of watermains may also be dictated by the types of available equipment for cleaning watermains (e.g. swabs or pigs). In all cases, pipe diameters should be such that a flushing velocity of 0.8 m/s can be achieved for cleaning and disinfection procedures.

Larger size mains may be necessary to allow the withdrawal of the required fire flow while maintaining the minimum pressure specified in Section 16.3.3 – System Pressures.

16.3.6 Velocity

The maximum design velocity for flow under maximum day conditions for transmission mains, primary distribution mains, distribution mains and service mains should be 1.5 m/s. The maximum fire flow velocity should be 3.0 m/s, unless otherwise specified by municipal bylaw or Water Supplier design criteria. Energy requirements, transient propagation, and system life-cycle cost analysis may warrant consideration of alternate maximum velocity selection.

Flushing devices should be sized to achieve a minimum cleansing velocity of 0.8 m/s in the watermain being flushed.

16.3.7 Flushing and Swabbing

Flushing hydrants or devices are recommended for systems that are not capable of providing fire flow and for dead-ended watermains and areas where the degradation of water quality may be possible due to low consumption/flow conditions. Flushing devices should by sized to provide flows that have a velocity of at least 0.8 m/s in the watermain being flushed. No flushing device should be directly connected to any sewer.

The Designer *s*hould take into account operational procedures such as unidirectional flushing and watermain swabbing when designing looped watermain systems. In watermain loops, unidirectional flushing (strategic valve closing to direct flow to promote flushing velocity) may be required to produce the required flushing velocity. Valve placement to promote unidirectional flushing velocities should be considered in the design stage.

Swabbing should be considered for rural long-distance low-flow pipelines where it is not practical to obtain adequate cleaning with flushing alone. Swabbing is an effective method used to clean the interior surface of watermains. For small diameter mains without hydrants, swab launching and retrieval ports should be included in the design. Valve specifications also need to be considered. Butterfly valves cannot be used as they will trap the swab.

16.3.8 Fire Protection

When fire protection is to be provided, fire flow and system design should consider local bylaw requirements and the latest edition of the Fire Underwriters survey *Water Supply for Public Fire Protection* (also see *AWWA Manual M31 Distribution for Fire Protection*, 1998. ISBN 0-89867-935-4).

16.3.9 Crossing Obstacles

Due to physical constraints along the watermain alignment, there may be a variety of obstacles that will affect the design of the watermain. Considerations include, but are not limited to, the following:

16.3.9.1 Road Crossings

It is recommended for all new watermains crossing existing roads, and all new roads crossing existing watermains, that:

- .1 The minimum cover from the top of the pipe is determined based on regional frost depth, municipal by-laws, internal pressure, deflection, external loading and buoyancy;
- .2 Backfill methods and materials are approved;
- .3 The watermain is properly bedded to ensure structural support of the pipe;
- .4 Drainage is adequate; and
- .5 Ditches crossing watermains should provide minimum cover of 1.0 m or the watermain should be insulated for frost protection and the regional frost depth and municipal by-laws should be reviewed. Refer to Section 16.6.2.2 – Stormwater Ditch Crossings for additional information.

The Ministry of Transportation and Infrastructure (MOTI) should be contacted for design standards and permitting for MOTI-owned roads.

16.3.9.2 Railway Crossing

When a watermain is crossing under a railway, the railway owner should be contacted as design standards and permitting can be owner-dependent. Reference can be made to Transport Canada's *Standards Respecting Pipeline Crossings Under Railways*.

16.3.9.3 Surface Water Crossings

Surface water crossings, whether above or underwater, and areas subject to flooding, require special consideration and approval.

16.3.9.4 Above Water Crossings

For above water crossings, the pipe should be adequately supported and anchored, protected from damage, vandalism and freezing, and accessible for repair or replacement.

16.3.9.5 Underwater Crossings

For underwater crossings, a minimum ground cover of 1500 mm should be provided over the pipe. Consideration should be given to the potential for the stream bottom to change because of scour or dredging. When crossing watercourses which are greater than 5 m in width, the following should be provided:

- .1 The watermain should be of special construction, having flexible, restrained or welded watertight joints; or, the watermain should be placed in a casing/sleeve pipe which is approved for potable water use, and has the same or greater pressure rating as the watermain;
- .2 Valves should be provided at both ends of the water crossing so that the section can be isolated for testing or repair; the valves should be easily accessible, not subject to flooding and should be within a properly constructed chamber; and
- .3 A method for sampling or monitoring of leakage on either side of the isolation valves to allow insertion of a small meter to determine leakage and for sampling purposes.

16.3.10 Location of Pipes in Geologically Vulnerable Areas

Earthquakes and landslides have caused watermains to fail, leading to depressurization of distribution systems, boil water advisories, and significant service. Although transitory seismic waves and strong ground shaking can cause some buried pipelines to fail, buried pipelines are at most risk when they are subjected to permanent ground displacements. The most common causes of permanent ground displacement are:

- .1 Liquefaction and lateral spread;
- .2 Landslide;
- .3 Settlement;
- .4 Fault rupture; and
- .5 Subsidence or uplift.

Designers should prioritize making transmission and distribution systems that serve water for essential services earthquake-resilient, so that these pipelines remain functional after seismic events. Essential services include medical facilities; power plants; fuel refining, storage, and distribution facilities; food production, storage, and distribution facilities; emergency response command and communication centers; firefighting; and emergency shelters.

Designers can reduce or mitigate seismic risk by:

.1 Identifying where pipeline alignments cross through regions of potential permanent ground displacement or strong ground shaking intensity;
.2 Designing to seismic values listed in the NBC;
.3 Using seismic-resistant pipe systems that can accommodate expected permanent ground displacements and strong ground shaking;
.4 Making ground improvements where possible;
.5 Using flexible couplings that permit differential movement when pipelines attached to structures, such as tanks and vaults, move differentially with respect to the ground;
.6 Providing adequate support and bracing to structures that support above-ground pipelines;
.7 Installing redundant facilities and/or looped piping;
.8 Using appropriate valving to isolate vulnerable areas;
.9 Installing pipe within a reinforced pipe tunnel; and
.10 Encasing with polyethylene.

Some pipes, such as butt-fused HDPE (*AWWA 2015a*), molecularly oriented PVC (*AWWA 2009b*), and seismic joint ductile iron pipe, are much less prone to failure in earthquakes and landslides (Water Supply Forum 2015). The Designer can also consider using specialized, flexible expansion joints that can accommodate significant ground motion, especially near where watermains enter structures such as reservoirs and booster pump stations.

In areas with the potential for permanent ground displacement or strong ground shaking, the Designer should seek the services of a qualified Geotechnical Engineer or other Qualified Professional to assist in material selection and addressing other seismic design aspects.

16.3.11 Materials

16.3.11.1 Standards and Materials Selection

All materials used in the construction and operation of drinking water systems including pipe, fittings, valves and fire hydrants, and materials used for the rehabilitation of watermains should conform to the latest standards issued by the CSA, AWWA, ASTM, NSF/ANSI, or NFPA.

Special attention should be given to selecting pipe materials which will protect against both internal and external corrosion.

In selecting pipe material, the Designer should consider the following factors:

.1 Proven performance of the material;
.2 Working pressure rating;
.3 Trench foundation conditions;
.4 Location and other site-specific factors;
.5 Internal and external corrosion resistance;
.6 Soil conditions:
    a. Chemical composition and its effects on pipe material;
    b. Corrosivity (need for cathodic protection);

c. Ability to provide thrust restraint;

.7 Drinking water corrosivity;
.8 Water temperature variations;
.9 Behavior of the pipe material in case of transient pressures and catastrophic failure;
.10 Costs (capital, operating, maintenance and other costs);
.11 Available labour skills; and
.12 Availability of suitable fittings and appurtenances acceptable to/or recommended by the pipe manufacturer, as well as spare parts and/or repair pieces.

When non-metallic pipes are selected, the Designer should consider the use of pipe tracers (such as tracer wire) for locating purposes.

16.3.11.2 External Corrosion Prevention/Reduction

External corrosion prevention and reduction should be considered for watermain installations. External corrosion prevention can include protecting watermains and fittings by encasement, such as wraps and coatings, and/or cathodic protection. Protection against galvanic corrosion should be considered when pipes and apparatuses of differing materials are connected.

The design and installation of watermain encasement and cathodic protection should be per the manufacturer's recommendations and as determined by a qualified professional in the field of corrosion protection.

Watermains are especially susceptible to corrosion in the following installations:

.1 If soils are found to be aggressive, and the choice of materials is limited and subject to corrosion;
.2 Across a bridge crossing in salt water (coastal) environments or other harsh environments;
.3 In colder locations where salt is used to de-ice roads; and
.4 Near or crossing a light railway, and/or major oil or natural gas pipelines protected by impressed current.

For further information on external corrosion control guidance, refer to *AWWA's M27 – External Corrosion Control for Infrastructure Sustainability*.

For guidance on optimizing water quality to minimize corrosion, refer to Chapter 12 – Internal Corrosion Control.

16.3.11.3 Permeation by Organic Compounds

When distribution systems are installed in areas where groundwater and/or soils are contaminated with lower molecular weight organic solvents (such as toluene and benzene) or petroleum products, materials which do not allow permeation of the organic compounds should be used for all portions of the system, including pipe, joint materials, O-rings, gaskets, hydrant leads and service connections.

Certain pipe materials - especially polyvinyl chloride (PVC), polyethylene (PE and HDPE), and polybutylene (PB) - are susceptible to permeation by these contaminants. Elastomeric gaskets made of ethylene propylene diene monomer (EPDM) used to join ductile iron pipe are susceptible to permeation as well. However, nitrile-butadiene rubber (NBR) is resistant to permeation by organic solvents and petroleum products, so ductile iron pipe with these types of gaskets should be used if potential permeation is an issue.

16.3.11.4 Re-Use of Materials

Watermains and appurtenances which have been used previously for conveying potable water may be reused, provided they comply with all applicable sections of Chapter 16 – Transmission and Distribution and have been restored practically to their original condition. Additional approval may be required.

16.3.11.5 Joints

The Designer should consider the following when designing joint systems for buried water piping:

- .1 Packing and jointing materials should meet the standards of the CSA/AWWA and the regulator.
- .2 Mechanical joints or plain end pipe in combination with couplings having slip-on joints with rubber gaskets is preferred.
- .3 Welded joints may be provided for carbon steel or stainless steel pipe systems.
- .4 Ductile iron should have push-on joint with gasket, conforming to the latest edition of *AWWA Standard C151 Ductile-Iron Pipe, Centrifugally Cast*.
- .5 PVC pipe should have push-on joint with gasket, conforming to the relevant *AWWA Standard C900* or *C905*.
- .6 High density polyethylene pipe should use flanged, electro-fusion or thermal butt fusion joints.
- .7 Lead-tip gaskets should not be used. Repairs to lead-joint pipe should be made using alternative methods.
- .8 Manufacturer approved transition joints should be used between dissimilar piping materials.
- .9 Flanged joints may be used in conjunction with fittings such as valves and/or bends where thrust restraint is needed.
- .10 Transition coupling should be provided to allow for vertical deflection at structures or where differential settlement of soils is expected to occur. Double joint articulating transition fittings may be needed for installations that could be subject to significant lateral or vertical deflection, as may be experienced under seismic loading.
- .11 Refer to Section 16.7.3 – Thrust Restraint for guidance on thrust restraint design considerations.

16.3.11.6 Pipe Strength

Distribution system piping must be selected to withstand operating and transient pressures, as discussed in Section 16.3.3 – System Pressures. Buried watermains are also subjected to external loads imposed by the trench backfill, frost loading and superimposed loads (static and/or dynamic). The watermain pipe selected for a particular application should be able to withstand, with a minimum safety factor of 2, all of the loading condition combinations to which it is likely to be exposed. Pipe strength designations and the methods for selecting the required pipe strength vary with the types of materials used.

The Designer should evaluate pipe supplier information and consult references such as CSA, AWWA and NSF/ANSI standards, and distribution design manuals.

16.4 Distribution System Components

16.4.1 Watermains

16.4.1.1 Transmission Mains

Transmission mains in water supply systems are typically large in diameter, carry large flows under high pressure and are long in length, therefore their designs should address:

.1 Sizing for ultimate future design flows;
.2 Sizing and layout to ensure adequate supply and turnover at water storage facilities;
.3 Elimination of customer service take-offs;
.4 Minimization of branch take-offs to help maintain flow and pressure control;
.5 Air relief at high points and drain lines at low points;
.6 Isolation valving to reduce the length of pipe required to be drained in a repair or maintenance shut down;
.7 Potential transient pressures;
.8 Master metering; and
.9 Climate change risk and vulnerability.

16.4.1.2 Primary Distribution Mains

Primary distribution mains typically receive flow from transmission mains or pressure control facilities (booster pumps or pressure reducing valves) and supply water to one or several local distribution mains as well as to customer services. Primary distribution mains provide a significant carrying capacity or flow capability to a large area.

For primary distribution mains, the Designer should consider:

.1 Implementing a minimum “dual” feed system of primary distribution mains to supply large distribution systems;
.2 Looping and isolation valving to maintain services with alternate routing in the event of repair or maintenance shut down;
.3 Area metering or individual service metering;
.4 Air relief at significant high points;
.5 Sizing for future extensions; and
.6 Elimination of dead ends.

16.4.1.3 Local Distribution Mains

Local distribution mains typically provide water service to customers through a network of pipelines fed by the primary distribution mains. For local distribution mains, the Designer should consider:

.1 Looping and isolation valving to maintain service with alternate routing in the event of repair or maintenance shut down;
.2 Adequate valving to provide an efficient flushing program;
.3 Elimination of dead ends; and
.4 Pressure surge relief (requirements can be addressed by storage in the distribution system or other acceptable means).

16.4.2 Valves

The Designer should consult with the owner of the system with respect to valve locations at intersections, line valve spacing, types of valves permitted, direction of rotation to open and the maximum size of valve permitted in a valve box.

16.4.2.1 Valve Placement

A sufficient number of valves should be provided on watermains to minimize inconvenience and contamination during repairs. Valves should be located at not more than 150 m intervals in commercial and industrial districts and at not more than one block or 240 m intervals in other districts. Where systems serve rural areas and where future development is not expected, valve spacing should not exceed 2 km.

In distribution system grid patterns, to minimize disruption during repairs, intersecting watermains should be equipped with shut-off valves as indicated in Table 16-3.

Table 16-3 Shut-Off Valves in Distribution System Grid Patterns

Type of Intersection	Number of Valves
"T" intersection	At least 2
Cross intersection	At least 3

16.4.2.2 Valve Standards

There are many different types of valves available and the Designer should consider the specific application during valve selection. As a minimum, manufacturer recommendations regarding appropriate valves for an application should be considered, with confirmation from the manufacturer that the valves conform to relevant AWWA standards. The Designer should ensure that open/close directions are consistent throughout the water supply system and meet the requirements of the water supply system owner.

For large diameter water supply or pressure zone isolation valves (400 mm diameter or larger), consideration should be given to providing valved reduced-size bypass piping that can be used to avoid local stagnation and assist with open/close operations. Bypass sizing can be determined according to *AWWA C-500 Metal-Seated Gate Valves for Water Supply Service*.

Valves 300 mm in diameter or less may have access provided to the operating nut via a valve box and stem assembly, but it is recommended that all valves larger than 300 mm in diameter be placed in valve chambers. All air release valves and drain valves should also be located in chambers. To minimize the number of chambers required, combinations of valves can be located within a single chamber.

16.4.2.3 Air Release & Vacuum Relief Valves

Air release/vacuum relief valves should be provided at high points in distribution and transmission lines (relative to the hydraulic gradient) where air can accumulate. The valves should conform to *AWWA Standard C512 Air Release, Air/Vacuum, and Combination Air Valves for Water and Wastewater Service*. Automatic air release valves should not be used in situations where flooding of the access chamber may occur unless equipped with an inflow preventer conforming to *ANSI/AWWA Standard C514 Air Valve and Vent Inflow Preventer Assemblies for Potable Water Distribution System and Storage Facilities*. Where the need for an automatic air release valve is uncertain, a manual air release valve or hydrant can be installed initially and later replaced with an automatic valve if significant air accumulation is found.

The open end of an air release pipe from manually operated valves should be extended to the top of the chamber and provided with a screened downward-facing elbow if drainage is provided for the chamber.

The open end of an air release pipe from automatic valves should be:

- extended to at least 300 mm above grade and provided with a screened downward-facing elbow to ensure it cannot be flooded or blocked, or
- equipped with an inflow preventer conforming to the ANSI/AWWA C514 Standard.

The Designer should ensure the distribution system is protected from backflow contamination through the intended operation of the vacuum relief or combination vacuum/air relief valve. The design should not provide a pathway for distribution system contamination; for example, through backsiphonage from an air-vacuum relief valve with a vent located inside an undrained pit or from a pump house drain.

Discharge piping from air relief valves should not connect directly to any storm drain, storm sewer or sanitary sewer. Vents should be equipped with an appropriate air gap above the highest possible water level. Proper drainage away from the vent outlets is necessary.

16.4.2.4 Drain Valves

With large diameter mains, drain valves positioned at low points may be required to permit main repairs. Small diameter watermains can generally be drained through hydrants by using compressed air and/or by pumping. It is recommended that drain valves are also flood proofed and not connected to storm drain or ditch, or storm sewer or sanitary sewer.

16.4.3 Water Quality Monitoring Stations

The Designer should consider the provision of dedicated sampling stations within the distribution system to facilitate water quality monitoring. When selecting sampling site locations, the Designer should target locations with representative conditions including challenging conditions within the system such as increased hydraulic retention times, dead-ended mains, temperature variations, and materials of construction etc.

The following sampling station features are recommended:

.1 Use of distribution piping, not household plumbing;
.2 The sampling station should be located in a space that:
    1. The water supplier controls or owns;
    2. Is safely accessible for the water sampler; and
    3. Promotes drainage to allow for adequate flushing before sampling;
.3 The length of the connection from the sampling station to the watermain should be as short as possible;
.4 A dedicated standpipe with a smooth-nosed sample tap is preferable; and
.5 The sample tap should be in a lockable enclosure and be otherwise protected from the weather and tampering.

16.4.4 Kiosks and Chambers for Valves, Meters and Blow-offs

16.4.4.1 Location and Drainage of Chambers

Kiosks, chambers, or access points containing valves, blow-offs, meters or other such appurtenances to a distribution system should be designed to reduce or eliminate confined spaces and not be located in areas subject to flooding or in areas of high groundwater. Where such locations are unavoidable, measures should be taken to prevent infiltration of surface water or groundwater.

Chambers should be drained, if possible, to the surface of the ground where they are not subject to flooding by surface water, or to underground absorption pits. Drains should be equipped with a backflow prevention device and screening to prevent the entry of insects, birds, and rodents.

16.4.4.2 Kiosk and Chamber Construction

Kiosk and chambers for air relief and vacuum valves, flow monitoring/measuring devices and pressure reducing valves should:

- .1 Provide a durable, watertight structure with easy and safe access;
- .2 Include watertight gaskets where a pipe passes through a chamber wall: flexible rubber "A-Lok" type for cast-in-place concrete or mechanical expansion insert type for pre-cast concrete;
- .3 Be protected against freezing and frost heave;
- .4 Include gravity or pump drainage;
- .5 Be lockable to avoid safety and vandalism concerns; and
- .6 Not connect directly to any storm or sanitary sewer.

The Designer should consider venting and drain appurtenances between line valves to eliminate air locks during watermain disinfection procedures and watermain restoration procedures.

16.4.4.3 Pressure Reducing Valve Stations

Pressure reducing valve stations should be designed and constructed to provide:

- .1 By-pass capability;
- .2 Isolation valves on the upstream and downstream piping for the pressure reducing valve;
- .3 Above ground if possible to prevent confined space entry requirements; and
- .4 Upstream and downstream pressure gauges.

16.4.5 Hydrants

All fire hydrants should be of the "self-draining" dry-barrel type and should conform to the latest edition of *AWWA Standard C502: Dry-Barrel Fire Hydrants*. Designers should coordinate with the local bylaw requirements for acceptable products when designing and selecting water hydrants and ensure all components are lead free. Watermains that are not designed to carry fire flows should not have fire hydrants installed.

All fire hydrants should be provided with adequate thrust blocking to prevent movement caused by thrust forces.

16.4.5.1 Location and Spacing

Fire hydrants should be provided at each street intersection, in the middle of long blocks and at the end of long dead-end streets. The required hydrant spacing decreases as the fire flow requirement increases. Hydrants should, therefore, be placed much closer together in high risk, high density areas than in low density residential areas. The maximum lineal spacing between hydrants should be 300 m for rural areas, 50 m for single family land use zones and 100 m for multi-family and commercial zones, unless otherwise specified by municipal bylaw or Water Supplier design standards.

For more detailed information on hydrant spacing, the Designer should refer to *Water Supply for Public Fire Protection* by the Fire Underwriters Survey and the Owner for municipal requirements.

16.4.5.2 Valves and Nozzles

Fire hydrants should have a bottom valve size of at least 125 mm, one 113 mm pumper outlet and two 63 mm outlets.

Outlet and nozzle sizes should be standardized throughout the water distribution system. Specific requirements should be coordinated with the local Fire Authority.

16.4.5.3 Hydrant Leads

The hydrant lead should be a minimum of 150 mm in diameter. Auxiliary valves should be installed on all hydrant leads to allow for hydrant maintenance and repair with a minimum of disruption.

16.4.5.4 Drainage

In areas where the water table will rise above the hydrant drain ports, the drain ports should be plugged. The barrels should be kept dry to prevent water contamination and freezing from damaging the barrel. Where hydrant drains are not plugged, they should drain to the ground if soil conditions allow, or to a dry well/drainage pit provided for that purpose. Hydrant drains should not be connected to or located within 3 m of sanitary sewers or storm drains.

16.4.6 Services and Associated Plumbing

16.4.6.1 Plumbing

Water services and plumbing should conform to relevant local bylaws, *BC Plumbing Code*, or to the applicable *National Plumbing Code*. Solders and flux should be lead free.

16.4.6.2 Consumer Connections (Laterals and Curb-Stops)

In selecting the diameter of a service connection, the Designer should consider the following factors:

- .1 Peak water consumption in the building serviced;
- .2 Total length of service line from the watermain to the building connection;
- .3 Watermain pressure under peak demand conditions;
- .4 Loss of head resulting from length and condition of pipe, fittings, and backflows preventers and meters;
- .5 Maximum velocity of flow should not exceed 4.5 m/s, the Designer should confirm the maximum velocity does not exceed that of the valves, fittings and pipe;
- .6 A stop and drain curb stop should not be used if the groundwater table is high as it could

create a cross connection; and

.7 There should be no joints between the curb stop and the building, if possible.

The recommended minimum size of service line for single-family residences is 19 mm. Larger residences and buildings located far from the watermain connection should have a 25 mm or larger service. Considerations should also be made for the anticipated water demand of the property when sizing the service line, such as the use of automatic sprinklers. For details on proper water sizing of service lines, refer to a publication such as *AWWA Manual of Water Supply Practices M22 – Sizing Water Service Lines and Meters*.

The Designer should consider the provision of two services with an isolation valve between the connections to help ensure redundancy to sensitive users (such as hospitals, long-term care facilities, etc.) in the event of a service line failure.

Water service lines should be constructed of materials conforming to *AWWA Standard C800: Underground Service Line Valves and Fittings*. Municipalities should be consulted regarding local preferences and requirements.

All water services should be equipped with a corporation stop and a curb stop. The curb stop should be provided with a curb box. Backflow prevention devices should be installed on service connections where there is a high risk of contamination to the potable supply system resulting from backflow or back pressure. The Water Supplier should be consulted to determine specific cross connection control program requirements.

All consumer connections should be a minimum separation distance of 3 m from outdoor fuel tanks.

16.4.6.3 Booster Pumps

Refer to Chapter 18 – Pumping Facilities.

16.4.6.4 Service Meters

Consideration for service metering with an approved metering device should be made based on the Water Supplier's billing and data collection needs.

16.4.7 Bulk Fill Stations

Water loading stations and temporary water services should be protected against potential backflow, which may allow contamination to enter the distribution system, in accordance with the requirements of *CAN/CSA-B64.10-01/B64.10.1-01 Manual for the Selection and Installation of Backflow Prevention Devices/Manual for the Maintenance and Field Testing of Backflow Prevention Devices*.

Bulk water loading stations present unique challenges since the fill line may be used for filling both potable water vessels and other tanks or contaminated vessels. To prevent contamination of both the public supply and potable water vessels being filled, the following principles should be met in the design of bulk water loading stations:

.1 Vessels and water hauling equipment should be equipped with an air gap or reduced pressure type backflow preventer in accordance with *CAN/CSA-B64.10/B64.10.1.*

.2 The piping arrangement should prevent contaminants being transferred from a hauling vessel to another subsequently using the station, and:

  .1 Hoses should not be contaminated by contact with the ground;
  .2 A loading station should be designed to provide access only to authorized personnel; and
  .3 Access to a loading station should be strictly controlled to minimize water safety and security concerns.

16.5 Cross Connections and Backflow Prevention

16.5.1 Cross Connections

Precautions should be taken in the design of water distribution and plumbing systems to prevent the entrance of contaminants into the drinking water system. All Water Suppliers should have a cross connection control program.

Contaminants can enter water supply systems from various sources including cooling water systems, pump seal water systems, industrial process piping and groundwater. Steam condensate, cooling water from engine jackets or water used in conjunction with heat exchange devices should not be returned to the drinking water supply.

Deterioration can also occur from entry into the system of untreated water due to watermain de-pressurization conditions allowing contamination through vents or other appurtenances.

To control contamination from non potable piped systems, cross connection control/backflow prevention measures and/or equipment are necessary.

For information on cross connection control, the Designer should refer to the *CSA Standards B64.10/B64.10.1*, and the *BC Plumbing Code*. If further resources are required, the *AWWA Manual of Water Supply Practices M14 – Backflow Prevention and Cross-Connection Control Recommended Practices* and *USEPA Cross-Connection Control Manual*, 2003 can be referenced.

16.5.2 Backflow Prevention

Backflow preventers should be installed at any location where a connection is made to a drinking water system. Backflow preventers should be installed per the latest edition of the *Cross-Connection Control Manual* published by AWWA (Western Canada Section).

There are several types of backflow prevention devices available including air gaps, double check valve assemblies, reduced pressure principle devices, dual check valves, atmospheric vacuum breakers and pressure vacuum breakers. For applications involving health hazards, only air gaps or reduced pressure principle devices should be used.

For information on backflow prevention equipment, the Designer should refer to:

.1 Applicable municipal by-laws;
.2 Canadian Standards Association (CSA) standards:
  - *CAN/CSA-B64 SERIES-01 Backflow Preventers and Vacuum Breakers*;
  - *CAN/CSA-B64.10/B64.10.1 Manual for the Selection and Installation of Backflow*

  - *Prevention Devices/Manual for the Maintenance and Field Testing of Backflow Prevention Devices*; and
  - B64.10S1-04/B64.10.1S1-Supplement #1 to CAN/CSA-B64.10-01/CAN/CSA-B64.10.1-01;

.3 BC Plumbing Code;

.4 AWWA Standards :
  - *C510: Double Check Valve Backflow Prevention Assembly*; and
  - *C511: Reduced-Pressure Principle Backflow Prevention Assembly*; and

.5 *AWWA Manual of Water Supply Practices M14 – Backflow Prevention and Cross-Connection Control Recommended Practices*.

16.6 Separation Distances

This section describes good engineering and construction practice to reduce the potential for contaminated water to enter the distribution system. Contaminated ground and surface water may enter the water distribution system at leaks or breaks in components such as piping, vacuum air release valves, blow-offs, fire hydrants, meter sets, and outlets during negative internal or positive external pressure conditions. Water pressure in part of the system may be reduced to a potentially hazardous level due to shutdowns in the system, main breaks, heavy fire demand, high water usage, pumping, storage or transmission deficiency and negative surge pressures.

The relative location of sewers (including stormwater and sanitary sewers/force mains) and watermains (including appurtenances) and types of material used for each system are important considerations in designing a system to minimize the possibility of contaminants entering the water distribution system. The use of and adherence to good engineering practice will reduce the potential for health hazards.

The Designer should consider the following for adequate separation:

.1 Water and sewer pipe materials, type of joints and pipe identification;
.2 Soil conditions (e.g. in-situ soil and backfilling materials, and compaction techniques);
.3 Additional structural support for pipes;
.4 Service and branch connections into the watermain and sewer line;
.5 Compensating variations in horizontal and vertical separations;
.6 Space for water and sewer pipe repair and alterations;
.7 Pipe off-set around manholes;
.8 Location of the groundwater table and trench drainage techniques; and
.9 Other sanitary facilities such as septic tanks and tile fields.

The Designer should demonstrate reasonable efforts to conform with the separation distances recommended in this section, and should consult with the Issuing Official early in the design process. In exceptional cases, reduced separation distance may be allowed with additional protective measures, as decided on a case-by-case basis.

For the purposes of this section,

.1 Sanitary sewer is defined as ‘a gravity pipe carrying untreated wastewater’;
.2 Force main is defined as ‘a pipeline that conveys wastewater under pressure from the discharge side of a pump to a discharge point’;
.3 Stormwater sewer is defined as ‘a gravity pipe, natural ditch or roadside ditch (including

highway and driveway culverts if connected to ditch) carrying surface water runoff to a point of discharge'; and

.4 Stormwater management systems are defined as 'management systems for capture, diversion and/or treatment of stormwater runoff' and can include basins, tanks, filters, infiltrators, storm drains, vortex separators, seepage manholes and swales, among other options.

16.6.1 Parallel Installation

16.6.1.1 General Parallel Installation Guidelines

New watermains and raw water supply lines should be laid in separate trenches with at least 3 m horizontally, measured edge to edge, and at least 450 mm vertically above, any parallel pipeline conveying:

.1 Untreated or treated wastewater (sanitary sewer and force mains);
.2 Hazardous fluids such as petroleum products, industrial wastes, and wastewater sludge;
.3 Stormwater sewers; and
.4 Non-potable water ("purple pipe").

Exceptions to these guidelines may be considered only where unusual conditions are present (e.g. bedrock, existing utility congestion, archaeological sites), and where the Designer can demonstrate that all reasonable efforts have been made to avoid the conflict. In these scenarios, consult with the Issuing Official to determine appropriate protective measures.

Examples of situations for parallel construction with gravity sewers are outlined in Table 16-4, with recommended protective measures in Table 16-5. The following definitions apply:

.1 D_{wm} = diameter of watermain;
.2 Horizontal separation = horizontal distance measured from edge-to-edge of pipes;
.3 Vertical separation (V) = Elevation of bottom of watermain minus the elevation of the crown of the parallel pipe. Refer to Figure 16-1; and
.4 Any overlap ($V < 0$) may require protective measures to block any leaked contamination.

Note that:

.1 Horizontal separation of < 1 m is not typically accepted; and
.2 Vertical separation of $< -D_{wm}$ (watermain crown below crown of parallel pipe) is not typically accepted when horizontal separation is < 3 m, and is otherwise discouraged where avoidable.

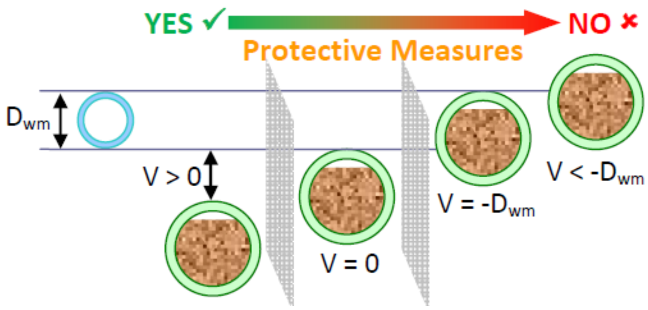
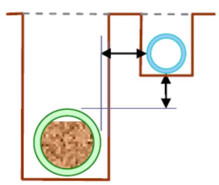
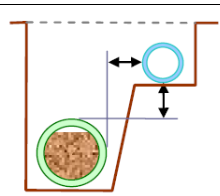
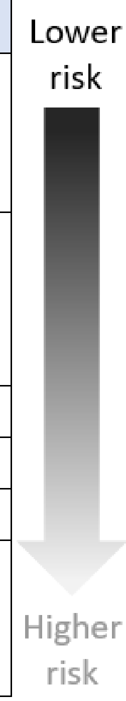


Figure 16-1 Vertical separation of watermain (blue pipe) and parallel pipe (green filled pipe). A continuous hydraulic barrier (grey plane) is shown for different vertical separations between pipes.

Table 16-4 Parallel Installation Configurations for Gravity Sewers

Configuration		Horizontal separation	Vertical separation	Scenario for Table 16-5
Separate trenches (separately dug trenches in undisturbed soil with granular bedding around pipes)		> 3 m	> 450 mm	None, unless site-specific risks present (e.g. high water table)
		> 3 m	< 450 mm Vertical separation < $-D_{wm}$ discouraged where avoidable	None, unless site-specific risks present (e.g. high water table)
		1 to 3 m	> 450 mm	B
		1 to 3 m	$-D_{wm}$ to +450 mm	A, B
Common trench (watermain sits on bench of undisturbed soil)		> 1 m	> 450 mm	B
		> 1 m	0 to +450 mm	A, B



Recommended protective measures are shown in Table 16-5. Note that if the configuration falls into both Scenario A and B, at least one protective measure from both scenarios should be implemented. A specific protective measure (or combination of measures) from Table 16-5 may be required depending on site conditions and specific risks (e.g. soil types, high water table).

Table 16-5 Recommended Protective Measures

Scenario	Recommended Protective Measures
A (inadequate vertical separation when horizontal separation is <3 m)	• Continuous hydraulic barrier (e.g. clay soil, geomembrane) or equivalent between pipes (see Figure 16-1), or • Place water pipe, or parallel pipe, or both, in sleeve or casing pipe with watertight end seals. Casing pipe should be installed in accordance with best practices, including provisions for securing the pipe with spacers, skids or equivalent to protect pipe from movement and provide ease of removal for repair. Casing pipe must be a material that is approved for use as watermain and must be of the same or greater pressure rating as the water line. Isolation valves should also be included, as well as corrosion protection if necessary.
B (inadequate horizontal separation and/or pipes in same trench)	• Increase the pipe strength of watermain, or parallel pipe, or both by a class, or • Wrap watermain joints with heat shrink plastic, or pack watermain joints with compound and wrap with petrolatum tape by qualified installers in accordance with the latest version of *AWWA C217*, and *AWWA C214* or *AWWA C209*,* or • Use jointless pipe (e.g. solid pipe, welded joints, HDPE pipe with fusion-welded joints) for the watermain, parallel pipe, or both.

* It should be noted that the relevant AWWA standards define tapes/coatings in terms of their ability to protect pipes against corrosion. Third party testing against infiltration of waterborne pathogens has not been established for these products, and the use of joint wrapping/packing as a protective measure is at the discretion of the Issuing Official.

16.6.1.2 Force Mains

Due to the increased health risk posed by leakage of force mains and the potential spread of pressurized sewer main breaches, reducing separation distance from watermains is not recommended. Force mains should be positioned with no less than 3 m horizontal separation to watermains. Where watermains and force mains cross, the watermain should be at least 450 mm above the force main (see Section 16.6.2).

16.6.1.3 Bedrock Trenching

Achieving separation distances for parallel piping may be difficult in cases of natural geographical obstacles (i.e. bedrock for trenching or blasting). Reduced separation distance may be allowed with additional protective measures on a case-by-case basis. The Designer should refer to Table 16-5 for protective measures.

In all rock trenches, drainage should be provided to minimize the effects of impounding of surface water and/or the leakage from sewers in the trench.

16.6.1.4 Sewer Manholes, Inlets, and Structures

A watermain should not pass through or come into contact with any part of a sanitary or stormwater sewer manhole, inlet or structure (including stormwater management systems). Watermains should be located at least 3 m horizontally from sewer manholes, inlets and structures.

Where the normal separation distances are not possible, the bottom portion of manholes, manhole connections to sewers, service connections to sewers and joints in sewage service connections should be designed not to leak and confirmed via testing (e.g. hydrostatic tests). If the horizontal separation is less than 3 m, the Designer may need to assess if thermal protection of the watermain is required (e.g. if manhole extends below frost line). Horizontal separation less than 1 m is not recommended.

16.6.1.5 Stormwater Conveyance and Treatment

Stormwater sewers, including stormwater piping and natural ditches, should be considered equivalent to sanitary sewers for parallel separation: 3 m horizontal separation should be maintained from watermains. For natural ditches, horizontal separation may be measured from the bottom of the ditch.

Watermains should also maintain 3 m separation from stormwater management systems. Where a local government has implemented an Integrated Stormwater Management Plan or included stormwater management as part of a Liquid Waste Management Plan, reduced separation distance between green rainwater infrastructure and watermains may be proposed. Protective measures from Table 16-5 may be required.

Watermains should not be installed directly in stormwater ditches or under ditch bottoms; this is also in accordance with the Ministry of Transportation *Utility Policy Manual* (2019) specifications for water and sewer line installations (18.3.2(b)(v)).

16.6.1.6 Tunnel Construction

If a tunnel is of sufficient size to permit a person to enter it, a sewer and watermain may be placed in the tunnel provided the watermain is hung above the sewer. If the tunnel is sized only for the pipes or is subject to flooding, then the installation is only acceptable if both watermain and sewer are sleeved with appropriate pipe casing. Sleeves should extend until the watermain and parallel pipe achieve acceptable horizontal separation outside of the tunnel and should be sealed to the pipes at either end.

16.6.2 Sewer and Stormwater Crossings

16.6.2.1 General Pipe Crossing Guidelines

Where a watermain crosses sanitary or stormwater sewer piping, the watermain should be laid a minimum vertical distance of 450 mm above the sewer, measured between the outside of the watermain and the outside of the sewer. The length of water pipe should be centered at the point of crossing so that joints in the watermain will be equidistant and as far as possible from the sewer, crossing perpendicular if possible.

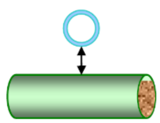
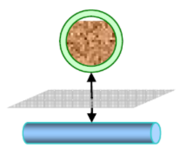
Exceptions to these guidelines will be considered only where unusual conditions are present (e.g. bedrock, existing utility congestion, archaeological sites), and where the Designer can demonstrate that all reasonable efforts have been made to avoid the conflict. In these scenarios, consult with the Issuing Official to determine appropriate protective measures.

Note that:

- .1 Watermains should cross above sewer pipes whenever possible;
- .2 Vertical separation of less than 150 mm is not typically accepted;
- .3 Force mains should not cross above watermains; and
- .4 Watermains should be at least 450 mm above force mains at crossings.

Examples of crossing installation situations for gravity sewers are outlined in Table 16-6.

Table 16-6 Crossing Installation Configurations for Gravity Sewers

Configuration		Vertical Separation	Pipe Joints Requiring Protection	Additional Bedding Structural Support	Additional Notes
Watermain above sewer pipe		> 450 mm	None	No	None
		150 to 450 mm	Watermain joints	Yes	None
Watermain below sewer pipe		> 450 mm	Both watermain and sewer joints	No	**Hydraulic barrier should be installed in trench between sewer and watermain[1]**
		150 to 450 mm	Both watermain and sewer joints	Yes	

1. Continuous hydraulic barrier (e.g. clay soil, geomembrane or equivalent) should extend no less than 300 mm beyond outer edge of watermain on both sides, such that the trench bedding width is protected.

As noted in Table 16-6, additional bedding structural support may be required when vertical separation is between 150 – 450 mm, in order to protect the watermain and sewer from excessive deflection of joints, settling, or breaking.

Protective measures should be applied for all joints within 3 m distance, measured normal (perpendicular) to the opposite pipe (refer to Figure 16-2). Specific protective measure (or combination of measures) from the list below may be required depending on site-specific conditions and risks. Example protective measures for pipe joints are as follows:

.1 Wrap watermain (and sewer, when required) joints with heat shrink plastic or pack watermain joints with compound and wrap with petrolatum tape in accordance with the latest version of *AWWA C217*, and *AWWA C214* or *AWWA C209*. For existing sewers, the distance for protective measures may be reduced to 1.5 m from the new watermain to avoid excessive excavation (see Figure 16-2);
.2 Construct gravity sewer of higher-class pressure pipe (equivalent to watermain) or reinforced concrete pipe using flexible gaskets. Pipe should be pressure and leakage tested manhole-to-manhole in accordance with manufacturer recommendations;
.3 Encase either watermain or sewer inside casing pipe sleeve with watertight end seals. The casing pipe must be a material that is approved for use as watermain;
.4 Use jointless pipe (e.g. solid pipe, welded joints, HDPE pipe with fusion-welded joints) for watermain, or parallel pipe, or both; and
.5 Use mechanically restrained joints.

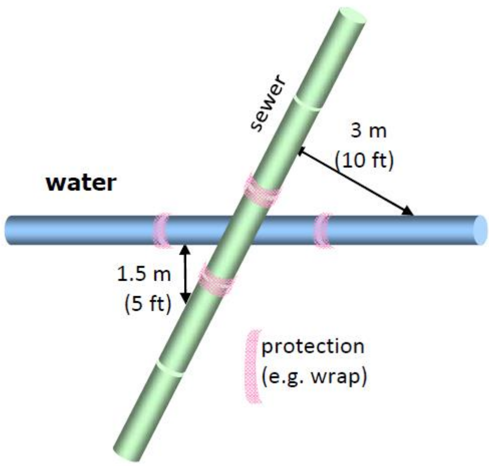


Figure 16-2 Joint wrapping at a crossing of a new watermain (all joints within 3 m perpendicularly from sewer) and an existing sewer (all joints within 1.5 m perpendicularly from watermain).

16.6.2.2 Stormwater Ditch Crossing

For natural or road ditches, 1 m depth of cover is required between the ditch bottom and the watermain, in accordance with the Ministry of Transportation *Utility Policy Manual* (2019) specifications for water and sewer line installations (Table 17-1). If less than 1.0 m depth of cover is provided, the watermain should be insulated for frost protection.

Joint protection and risk mitigation are required for watermains installed below stormwater ditches:

.1 The length of water pipe should be centered at the point of crossing so that joints in the watermain will be equidistant and as far as possible from the ditch, crossing perpendicular if possible;
.2 A hydraulic barrier should be installed in the trench between the ditch and watermain; and
.3 Watermain joints should be protected as described above and in Figure 16-2.

16.6.2.3 Unacceptable Installations

No water pipe should pass through or come in contact with any part of a sewer access/maintenance hole, septic tank, tile field, subsoil treatment system or other source of contamination.

Concrete encasement of sewer or stormwater piping (per 2019 MMCD Vol II *Standard Detail Drawing G6* and as specified in Section 31 23 01) is not recommended for watermain crossing. While the intent is to provide structural support and hydraulic seal, differential soil settlement often leads to stress and failure at pipe joints. A continuous hydraulic barrier (e.g. clay soil, geomembrane or equivalent) and joint protection as listed in Section 16.6.2.1 – General Pipe Crossing Guidelines should be provided instead.

16.6.3 Other Sources of Contamination

Designers should exercise caution when locating watermains at or near certain sites such as sewage treatment plants, industrial complexes, or near water treatment backwash ponds. Minimum horizontal separation distances should be maintained from on-site sewage disposal systems as specified in the *Sewerage System Standard Practice Manual Version 3*:

.1 3 m from dispersal systems, watertight treatment or pump tanks;
   a. May be reduced to 1 m separation if the watermain is sleeved with a suitable continuous pipe, extending to the minimum standard setback distance and sealed to the watermain pipe at each end. No joints for the sleeping pipe (other than fusion welded joints) are to be used within the setback distance. The sleeving pipe is to be of the same or greater pressure rating as the water line; and

.2 7.5 m from BC zero discharge lagoons, regardless of use of pipe sleeving.

New watermains should not be installed within 30 m of the nearest edge of any sanitary landfill or hazardous waste disposal site, within 10 m of any underground hazardous material storage tank, sewage lift station, groundwater recharge project site, or within 7.5 m of municipal wastewater drain fields.

The Designer should establish specific design requirements for locating watermains near any source of contamination and coordinate planned activities with the Issuing Official.

Separation requirements from property service lines (including sewer and stormwater laterals) should conform to BC Building Code and/or the *Design Guidelines for Rural Residential Community Water Systems* (former Ministry of Forests, Lands, Natural Resource Operations & Rural Development).

16.6.4 Utilities

A minimum horizontal separation of 1.0 m should be maintained between watermains and utilities, including electrical conduits, gas mains, and telephone conduits. Bylaws, local engineering specifications, or authorities having jurisdiction may require larger setbacks, especially for deep excavations with wide trenches.

16.7 Installation

16.7.1 Bedding

Continuous and uniform bedding should be provided in the trench for all buried pipe. Pipe and fittings should not be laid when the trench bottom is frozen, under water or when trench conditions or weather are unsuitable.

Granular bedding, pipe surround, backfill material and installation procedures should conform to 2019 MMCD Vol II specifications for waterworks (with the exception that concrete encasement for watermain crossing is not accepted, see Section 16.6.2.3 – Unacceptable Installations). At a minimum, backfill material should be tamped in layers not exceeding 150 to 250 mm around the pipe and to a sufficient height above the pipe to adequately support and protect the pipe. Large stones (75 mm or greater) found in the trench should be removed for a depth of at least 150 mm below the bottom of the pipe.

16.7.2 Cover

With the exception of those watermains which will be taken out of service and drained in winter, the minimum depth of cover over watermains and service connections, including that portion on private property, should be greater than the depth of frost penetration. On services, this depth should be measured to the goose neck when it is vertical. If, for economic or practical reasons, it is not possible to install watermains below the frost line, the design should ensure that the watermain will be unlikely to freeze by insulating around the pipe, and the watermain will not be damaged by heaving or increased trench loads caused by frost penetration. Applicable temperature loss calculations should be performed to ensure the water will not freeze. Large diameter watermains (over 300 mm) without service connections and that are not dead ends may be installed so that the frost-free depth corresponds with the springline of the pipe rather than the crown.

The increased external loads caused by frost may cause beam breaks in the pipe when bedding is non-uniform. For this reason, care should be taken in the selection of pipe materials, pipe classes, bedding types and the proper installation and compaction of the bedding to the springline.

16.7.3 Thrust Restraint

Adequate restraint should be provided in water distribution systems to prevent pipe movement and subsequent joint failure. In the case of non-restraining mechanical and/or slip-on joints, this restraint should be provided by adequately sized thrust blocks positioned at all plugs, caps, tees, line valves, reducers, wyes, hydrants and bends deflecting 22.5^{o} or more. Depending upon internal pressures, pipe sizes, pipe material and soil conditions, bends of lesser deflection may also require thrust blocking.

Calculations to determine the size of thrust blocks and valve support blocks should use the results of soil bearing capacity tests performance by a qualified professional, when such tests are available. In the absence of such test results, the standard soil bearing capacities listed in Table 16-7 may be used.

Table 16-7 Allowable Soil Bearing Capacity (Ontario Building Code)

Scenario	Maximum Allowable Bearing pressure, kPa
Dense or compact sand or gravel	150
Loose sand or gravel	50
Dense or compact silt	100
Stiff clay	150
Firm clay	75
Soft clay	40
Till	200
Clay shale	300
Sound *rock*	500

Thrust block material should resist deterioration from moisture or corrosive soil. Alternative approaches that can be used to prevent joint failure include:

.1 Using pipe and jointing methods capable of resisting the forces involved (such as welded steel pipe, or polyethylene pipe with thermal butt-fusion joints); or
.2 Using joint restraining methods, such as metal tie rods, clamps or harnesses.

When designing thrust blocks and other restraint systems, the Designer should ensure:

.1 That transient pressures are added to the normal operating pressures when calculating the thrust forces (if velocity of flow is very high, dynamic thrust should also be calculated); and
.2 Adequate corrosion protection is provided for external clamps and tie rods.

The safe bearing values of soils should be reduced substantially from the figures in Table 16-7 if shallow trenches are used or if bearing against disturbed soils. For further discussion of thrust blocking and joint restraint design, refer to the pipe manufacturer catalogue and other sources such as AWWA standards.

16.7.4 Watermain Grade

When installing a watermain, grades should be straight lines between defined deflection points. Elevations should be recorded. Where possible, the minimum grade of watermains should be 0.1%. Grading should be designed to minimize the number of high points. When the slope equals or exceeds 10%, provide anchorage, joint restraints, trench dams and trench drainage. Provide geotechnical engineering reports where appropriate.

16.7.5 Horizontal Directional Drilling

Horizontal directional drilling (HDD)/boring is an alternative method of installation for watermains crossing obstacles or in deep installations.

For horizontal directional drilling, pipe wall thickness/strength should be selected in conformance with *ASCE F1962-20 (Standard Guide for Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossing)* when pipe diameter is larger than 300 mm. For pipe diameters less than 300 mm, pipe wall thickness/strength should be selected in conformance with *ASCE Manual of Practice 108 (Pipeline Design for Installation by Horizontal Directional Drilling, Second Edition, 2014)*.

16.7.6 Pressure and Leakage Testing

All types of installed pipe should be pressure tested and leakage tested in accordance with the latest edition of *AWWA Standard C600 Installation of Ductile-Iron Mains and their Appurtenances*, or as required by local Authorities.

16.7.7 Disinfection

All new, cleaned or repaired watermains should be disinfected in accordance with *AWWA Standard C651 Disinfecting Watermains.* The specifications should include detailed procedures for the adequate flushing, disinfection, and microbiological testing of all watermains before being put into service. In an emergency or unusual situation, the disinfection procedure should be discussed with the DWO.

16.7.8 Commissioning

Following successful testing and disinfection of watermains, the new system should be commissioned with due consideration of resulting pressure and flow changes and other parameters that may be experienced within the water supply system. Reference should be made to Chapter 3 – General Design Guidance.

17 Water Storage

17.1 General

This chapter provides design guidelines for water storage structures for various stages of treatment, which include but are not limited to applications for raw water intake storage, clear wells, wet wells, and distribution reservoirs. The materials and designs used for water storage structures should provide stability, durability, and protection to the quality of the stored water. Structures should follow the current AWWA standards concerning storage tanks, ground storage reservoirs, clearwells, and elevated tanks wherever they are applicable. Refer to Chapter 21 – Small Systems for guidance on water storage for small systems.

For direction on membrane liners, reference should be made to *AWWA D130, Standard for Flexible-Membrane-Lining and Floating-Cover Materials for Potable Water Storage.*

As part of the preliminary design phase for a water storage facility, the following should be considered:

.1 Material selection;
.2 Water storage type;
.3 Volume;
.4 Shape;
.5 Number of cells;
.6 Geotechnical report on the foundation conditions; and
.7 Design standards.

17.2 Types of Water Storage

All types of water storage used in treatment plants or for distribution water storage should be designed as treated water storage structures to meet requirements in Section 17.3 – Design Criteria for Treated Water Structures.

Tanks may be exempt from this requirement if they contain water that will receive full treatment for which the plant is designed, such as a pre-sedimentation basin at a surface water treatment plant, or water that will not be returned to the treatment process and is separated from the treatment plant by appropriate cross-connection control measures.

Storage tanks should be sized (together with distribution system storage capacity) to minimize on/off cycling of the downstream equipment. Plant storage should be sized such that distribution system demands and in-plant water use (e.g. filter washing, chemical systems, and domestic use) can be met while maintaining relatively constant flow through the plant rather than fluctuating filtration rates.

17.2.1 Wet Well

A wet well is a below-grade structure often located within the treatment building that provides storage for finished, potable water. Wet wells are typically used to provide a steady volume and operating conditions for pumping purposes to either a distribution system or a distribution reservoir and can also include storage for contact time and backwash water.

When designing a wet well, the following items should be considered:

.1 Wet well storage should be sized in conjunction with the distribution system storage to equalize water use in the system and minimize cycling of the treatment plant;
.2 Wet wells should not be located adjacent to untreated or partially treated water when the two compartments are separated by a single wall;
.3 Pipes carrying non-potable water should not be installed through storage facilities containing drinking water; and
.4 Wet wells should be equipped with an overflow and a vent and be designed as treated water structures per Section 17.3 – Design Criteria for Treated Water Structures.

17.2.2 Clearwell

A clearwell, as defined in *AWWA's M48 Waterborne Pathogens*, is a reservoir of treated water that is relied on to provide chlorine contact time (CT) for primary disinfection. A clearwell is typically required when the minimum required CT cannot be met in the distribution mains prior to consumption.

When designing a clearwell, the following items should be considered:

.1 Baffling factor, minimum operating depth and maximum flow rate selected to provide adequate contact time (T) to meet the required CT value;
.2 A secondary cell to allow maintenance on one cell. Otherwise, the plant should be designed with a means to enable short periods of operation with the clearwell out of service;
.3 When a clearwell is also used to provide filter backwash, consideration should be given to the additional volume required to backwash several filters in rapid succession, and/or at worst-case conditions, such as when peak demand for treated water and backwash water requirements coincide;
.4 Adequate measures to limit or prevent short circuiting or dead spots;
.5 Clearwells should not be located adjacent to untreated or partially treated water when the two compartments are separated by a single wall;
.6 Pipes carrying non-potable water should not be installed through storage facilities containing drinking water; and
.7 Clearwells should be equipped with an overflow and vent and be designed as treated water structures per Section 17.3 – Design Criteria for Treated Water Structures.

17.2.3 Distribution System Storage

A distribution storage tank provides containment for finished potable water that supplies a drinking water distribution system and can often provide storage for fire flow. Distribution storage tanks come in various constructions, e.g. below-grade, above-grade, or elevated water tower structures. The materials of construction can be, and are not limited to, concrete or coated steel. Distribution system storage should be designed as treated water structures per Section 17.3 – Design Criteria for Treated Water Structures.

17.2.4 Hydropneumatic Tanks

Hydropneumatic tanks are pressurized vessels containing water and air or a membrane/bladder that is used to regulate system pressures to meet the system's water demand. Hydropneumatic (pressure) tanks as the main water storage are acceptable only in very small water systems (fewer than 50 connections), Refer to Chapter 21 – Small Systems for small systems applications. Hydropneumatic tanks should not be used for providing equalization, contact time for primary disinfection, or fire protection purposes. Hydropneumatic tanks help to reduce on-off cycling of pumps. Fire flow requirements for systems without fire flow storage are to be provided by a separate fire pump with a capacity that is equal to or greater than the fire flow requirement.

When designing a hydropneumatic system, the following should be considered:

.1 Pressure tanks should meet applicable American Society of Mechanical Engineers (ASME) code requirements or an equivalent requirement for the construction and installation of unfired pressure vessels. Non-ASME, factory-built hydropneumatic tanks may be allowed if approved by the Issuing Official. The maximum allowable working pressure should be marked on each tank;

.2 The capacity of the well or booster pumps in a hydropneumatic system should be equal to the peak instantaneous demand;

.3 The effective drawdown volume of the hydropneumatic tank, should be sized to limit pump cycling to the manufacturer recommendations. The effective drawdown volume, in litres, should be equal to or greater than the volumetric equivalent of 10 minutes of operation of the largest pump. For example, a 750 L/min pump should have a minimum 7,500 L pressure tank, unless other measures (e.g. variable speed drives in conjunction with the pump motors) are provided to meet the maximum demand;

.4 Hydropneumatic tanks without a bladder diaphragm should be sized with a water to air ratio of 2:1;

.5 Tanks should be constructed of non-corroding materials or have suitable protective coating for components in contact with water.

.6 For tanks larger than 500 L, an access manhole should be provided. Where practical, the access manhole should be 600 mm in diameter.

.7 Each tank should include a drain, a pressure gauge, water sight glass (non-bladder tanks only), automatic or manual air blow-off, and a means for adding air;

.8 Bladders to be constructed of heavy duty butyl rubber material suitable for contact with potable water;

.9 A pressure relief valve should be installed on each tank and be capable of handling the full pump flow at the pressure vessel design limit. The pressure relieving device should prevent the pressure from rising more than 10% above the maximum allowable working pressure of the system;

.10 Pressure gauges should have a range of no less than 1.2 times the pressure at which the pressure relieving device is set to function;

.11 Hydropneumatic tanks should have bypass piping to permit operation of the system while a tank is being repaired or maintained;

.12 Control equipment consisting of a pressure gauge and pressure operated start-stop controls for the pumps should be included. A shut-off valve should not be installed between the pump and the pressure operated start-stop controls; and

.13 Hydropneumatic tanks should be located above the normal ground surface and installed with sufficient space around the tanks for inspection and maintenance. Hydropneumatic tanks should be installed in a location under ownership of the Water Supplier, and not at a private residence.

17.3 Design Criteria for Treated Water Structures

Designers should consider the following criteria for the design of treated water structures.

17.3.1 Location

.1 Storage facilities should be located on the highest point of the servicing pressure zone. The lowest elevation of the floor and sump floor of storage structures should be placed above the 200-year flood elevation or the highest flood of record, whichever is higher; and where possible at least 600 mm above the groundwater table. If high groundwater table is an issue, refer to Section 17.3.19 – Drainage to mitigate risks of flooding, hydrostatic uplift, and contamination;

.2 For large distribution systems, the placement of one storage tank at a central location should be evaluated against smaller units with equivalent total volume in other parts of the system;

.3 The Designer should be aware that flow reversals may create sediment uptake and dispersal. This may be a more significant concern when the storage tank is located at an extremity of the distribution system.

.4 Sewers, drains, standing water, and similar sources of possible contamination should be kept at least 15 m from the structure. Gravity sewers constructed of watermain quality pipe, pressure tested in place without leakage, may be used at distances of less than 15 m, but no closer than 6 m;

.5 The bottom of storage structures should be placed at or near the normal ground surface. If the bottom of a storage structure is below the normal ground surface, adequate provisions should be made to protect the structure from hydrostatic uplift forces and surface water contamination;

.6 Consideration should be given to:

- .1 Zoning compliance, building code compliance, and community acceptance;
- .2 Positive site drainage away from the structure to prevent runoff ponding in close proximity to the structure;
- .3 Public access and associated safety and security requirements;
- .4 Site access;
- .5 Vehicle access;
- .6 Disposal of reservoir overflow and drain discharges;
- .7 Geotechnical engineering field investigations including:
  - a. Site drainage;
  - b. Foundation design requirements;
  - c. Soil type and soil-bearing strength;
  - d. Groundwater table elevation;
  - e. Soil stability, liquefaction, or slope failure analysis;
- .8 Natural hazard considerations including:
  - a. Avalanche;
  - b. Earthquake;
  - c. Flood;
  - d. Landslide;
  - e. Tree fall;
  - f. Tsunami; and
  - g. Windstorms.

17.3.2 Sizing of Treated Water Structures

The following provides guidance on sizing, and can fill information gaps where no local bylaws for storage sizing exist:

.1 Storage facilities should have sufficient capacity, as determined from engineering studies, to meet domestic demands, and where fire protection is provided, fire flow demands.
.2 Dimensional requirements for bolted and welded steel tanks are specified in *AWWA Standards D103 Factory-Coated Bolted Carbon Steel Tanks for Water Storage* and *D100 Welded Carbon Steel Tanks for Water Storage*, respectively;
.3 Where possible, two cells should be provided to allow maintenance time on one cell without interrupting the supply of water. Some systems may have adequate redundancy within the distribution system to be capable of supplying water to the service area by alternate means while maintenance is conducted within a storage tank;
.4 Where appropriate for larger distribution systems, hydraulic and water quality models should be used for sizing new storage facilities and for selecting locations for re-chlorination facilities if needed;
.5 Excessive storage capacity should be avoided to prevent potential water quality deterioration problems;
.6 When selecting storage tank configuration and layout, Designers should consider water quality within the tank under seasonal changes in water demand; and
.7 If a storage structure is a type where only the upper portion of the water provides a useful function, the remaining lower portion is considered dead storage. Where dead storage is present, there should adequate measures taken to circulate the water through the tank to maintain water quality and prevent freezing. Unusable dead storage should be avoided wherever possible.

17.3.2.1 Sizing Treated Water Storage for Systems Providing Fire Protection

.1 Fire protection is a municipal responsibility, and the municipality may elect to provide for higher fire flow requirements or entirely forgo fire protection by way of the drinking water distribution system. The Designer should therefore consult the *Water Supplier* and relevant legislation to be aware of all applicable requirements;
.2 Where fire protection is provided, fire flow storage requirements should be considered within the storage facility sizing. Fire protection storage capacity is indicated in *Water Supply for Public Fire Protection* by Fire Underwriters Survey. The required total effective storage should be based on the following formula:

Total Treated Water Storage Required = A + B + C (as per MMCD)

Where,

A = Fire protection storage capacity, as required above;
B = Equalization Storage (25% of maximum day demand);
C = Emergency Storage (25% of A + B); and

.3 The maximum day demand in the previous equation should be calculated using the factors in Table 17-1, unless there is existing flow data available to support the use of different factors. Where existing data is available, the required storage should be calculated based on an evaluation of the flow characteristics within the system.

Maximum Day Demand (MDD) = Average Day Demand (ADD) x Maximum Day Factor

Table 17-1 Maximum Day Peaking Factors

Equivalent Population [1]	Maximum Day Factor
500 – 1000	2.75
1,001 – 2,000	2.50
2,001 – 3,000	2.25
3,001 – 10,000	2.00
10,001 – 25,000	1.90
25,001 – 50,000	1.80
50,001 – 75,000	1.75
75,001 – 150,000	1.65
Greater than 150,000	1.50

Note [1]: When determining the equivalent population for commercial or industrial areas, it is recommended that the area occupied by the commercial/industrial complex be considered at an equivalent population density to the surrounding residential lands.

.4 Configure water storage facilities such that:

a. The equalization storage volume (B) is located between the top water level (TWL) of the storage facility and the elevation necessary to satisfy the minimum and maximum static pressures within the distribution system.
b. The fire (A) and emergency (C) component volumes (i.e. A + C) are located at the elevation required to achieve minimum allowable system pressures under the maximum day plus fire flow conditions; and
c. Should an elevated tank with a booster pumping station at the base be proposed, the equalization volume (B) would be similar to the above. The fire (A) and emergency (C) components can be below the minimum static requirements elevation provided the booster pump is designed/sized to increase system pressures to the minimum required system pressures under the maximum day plus fire flow condition.
d. Refer to Section 16.3.3 – System Pressures for guidance on distribution system pressure requirements.

17.3.2.2 Sizing Treated Water Storage for Systems Not Providing Fire Protection

The minimum storage capacity (or equivalent capacity) for systems not providing fire protection should be equal to the maximum daily demand. This requirement may be reduced when the source and treatment facilities have sufficient capacity with standby power to supplement the peak demands of the system.

17.3.3 Pressure Considerations

Storage facilities should be designed to maintain adequate pressure in the distribution system at the peak water demand in the event of a power failure or other emergency to lessen the potential for system contamination. The maximum variation between high and low levels in elevated distribution system storage tanks should be such that the normal pressures in the distribution system do not exceed the minimum and maximum static and dynamic pressure requirements listed in Section 16.3.3 – System Pressures. The Designer *s*hould coordinate with local by-laws for the required supply-side management to maintain the required static and dynamic pressures within the distribution system.

17.3.4 Controls & Implementation

.1 Adequate instrumentation to:
- Monitor and control water levels in each cell of the storage facilities;
- Control pump on-off cycles or gravity flow to and from the tank to maintain the system pressure and avoid overflow;
- Provide notification of overflow and low-level alarms in a central or remote location with 24-hour surveillance (i.e. SCADA or audible);
- Alarms should be activated by separate and independent devices;
- Local level indicators should be provided by a pressure gauge on the tank piping, a level indicating transmitter, or other means; and

.2 For elevated tanks, level control instrumentation should be sufficiently precise to prevent wasting storage or tank overflows. Altitude valves or equivalent controls should be installed on elevated storage when more than one tank is required within a single supply pressure zone or where the storage facility would overflow at the allowable high distribution system pressure.

17.3.5 Management of Water Quality and Age

Water quality degradation in distribution system storage facilities, such as loss of disinfectant residual, microbial growth, formation of disinfection by-products, nitrification, and taste and odour problems can result from short-circuiting, incomplete mixing, high water age, or a combination thereof. Distribution system storage facilities should be designed to eliminate short-circuiting and stratification and achieve adequate mixing.

The Designer should consider the following to prevent water quality degradation within water storage facilities:

.1 Size, locate and orient the inlet piping to facilitate proper mixing by jet theory during the filling cycle;

.2 Inlet piping may include:
   a. Multiple orifices to facilitate even mixing during filling cycles; or
   b. Orifices which are sized and oriented to achieve a sufficient mixing energy at the fill point to promote good mixing within the storage facility;

.3 Adequate mixing to avoid stagnation and/or freezing due to seasonal variations in water temperatures, turn-over rates and operational setpoints;

.4 A maximum turn-over rate of 3 to 5 days should be targeted, or as required to prevent disinfectant residual loss during low demand periods;

.5 Supplemental mixing may be provided by way of a recirculation pump or submersible mixer;

.6 CFD modelling should be used to inform the piping design for non-standard configurations or large water storage facilities (i.e. > 10 ML);

.7 Tracer studies may be used to verify the mixing performance and adequacy of the design;

a. Complete mixing can be defined as when the tracer coefficient of variation (COV) is less than 5% (Rossman and Grayman, 1999) where COV is defined as:

$$COV = \frac{Standard\ deviation\ of\ tracer\ concentration\ in\ storage\ cell}{Mean\ tracer\ concentration\ in\ storage\ cell}$$

.8 Treated water storage design should facilitate fire flow and pressure requirements and meet maximum daily demand, while maximizing daily volume turnover to minimize water age. The Designer should exercise informed judgement in deciding the appropriate turnover time in the storage facility to maintain biological stability throughout the distribution network. Supplemental disinfection of water leaving storage may be required to maintain secondary disinfection within the distribution network.

.9 Supplemental mixing for floating storage systems to maintain homogeneous mixing under all operating conditions.

Designers may refer to the publication "*Maintaining Water Quality in Finished Water Storage Facilities*" by the AWWA Research Foundation for additional design considerations to maintain stored water quality through design.

17.3.6 Protection from Contamination

The Designer should consider the following to protect against contamination:

.1 All treated water storage structures should have suitable watertight roofs which exclude birds, animals, insects, and excessive dust. Waterproofing the tank below grade; flexible membrane materials meeting the requirements of *AWWA D130 Geomembrane Materials for Potable Water and/or concrete admixtures* may be considered as possible waterproofing alternatives;

.2 Gravity underdrains to capture surface water runoff may be considered, provided that pumping of the drainage water will not be required and underdrains discharge to daylight; and

.3 The installation of appurtenances, such as antenna, should be done in a manner that ensures no damage to the tank, coatings or water quality, or corrects any damage that previously occurred.

17.3.7 Inlet and Outlet

The Designer should consider the following:

.1 Separate inlet and outlet pipes should be provided that facilitate the positive circulation of water within the reservoir;

.2 Inlet and outlet pipes should be located on opposite sides to each other to minimize short-circuiting and optimize mixing in the tank. If they cannot be placed on opposite sides, consideration should be given to maximize mixing within the reservoir; for example, including multi-orifice inlet piping or inlet jet propagation to achieve adequate mixing during a standard filling cycle;

.3 Where there is more than one cell, each cell should include an inlet and an outlet to facilitate operation of either cell. Sufficient provisions should be provided to operate with one cell out of service; and

.4 Piping material should be used for pipelines constructed directly below the reservoir and extending to at least 3 m from the perimeter. The pipe material should be chosen for longevity, with corrosion and seismic considerations in mind, as replacement of this pipe will be costly.

17.3.8 Overflow

The following should be considered in the design of the storage overflow:

.1 The possibility of downstream contamination should be assessed, and the appropriate permitting authority should be consulted prior to design, refer to Chapter 1 – Introduction;

.2 All water storage structures should be provided with an overflow which is brought down to an elevation between 300 and 600 mm above the ground surface, and discharges over a drainage inlet structure or a splash plate. The overflow discharge location should be located so that any discharge is visible. The discharge of the overflow pipe must not be directed to natural water bodies nor connected directly to any drain, sanitary sewer or storm sewer;

.3 All overflow pipes should be equipped with an alarm to alert the operator of an overflow event;

.4 All overflow pipes should be equipped with a backflow preventer. Use of a solid flapper or duckbill valve should be considered to minimize air movement and ice formation in the tank. When a solid flapper is used, a screen should be provided inside the overflow. If a duckbill valve is used, a screen is not required. Provisions should be included to prevent the flapper or duckbill from freezing shut;

.5 When an internal overflow pipe is used on elevated tanks, it should be located within or adjacent to the access manway, such that it is visible from the outside when the access hatch is open. For vertical drops on other types of storage facilities, the overflow pipe should be located on the outside of the structure;

.6 The overflow should open downward and be equipped with a twenty-four mesh (0.70 mm openings) non-corrodible insect screen and a suitable rodent guard, installed within the pipe at a location least susceptible to damage by vandalism. A mesh-fitted mechanical flap valve is acceptable provided the flapper is supplied with non-corroding and non-seizing hinges. The flap valve should be spring loaded or counterweighted, so it closes and forms a tight seal after the overflow event;

.7 The overflow pipe should be of sufficient diameter to permit waste of water in excess of the maximum filling rate; and

.8 Discharge of chlorinated water to ground or surface water must be avoided. Dechlorination should be provided as required to meet the discharge requirements of the authority having jurisdiction.

17.3.9 Drains

Treated water storage structures which provide pressure directly to the distribution system should be designed so they can be isolated from the distribution system and drained for cleaning or maintenance without causing a loss of pressure in the distribution system.

As much as possible without adversely affecting distribution water quality, the storage structure should be drained into the distribution system to minimize wasting of potable water. However, drains should be provided with provisions for dechlorination prior to ground-surface discharge for water which cannot be drained into a distribution system. There should be no direct connection to a sewer or storm drain allowed in a water storage structure. If a gravity drain is provided, an air gap should be maintained at the outlet. Floors should be sloped towards the sump to facilitate cleaning.

17.3.10 Access

Treated water storage structures should be designed with reasonably convenient access to the interior for cleaning and maintenance. At least two access hatches should be provided where space permits. A minimum 900 mm x 1050 mm opening is recommended. The number and location of access hatches should comply with WorkSafeBC requirements.

.1 For elevated storage tanks,
  - The roof access hatches should be:
    - framed at least 100 mm above the surface of the roof at the opening; and
    - fitted with a solid watertight cover, which overlaps the framed opening and extends down around the frame at least 50 mm, be hinged on one side and have a locking device.
  - All other access ways should be bolted and gasketed;

.2 For ground-level facilities,
  - The roof access hatch should be:
    - elevated at least 600 mm above the top of the tank or groundcover;
    - equipped with frame that is at least 100 mm high and fitted with a solid, watertight, non-removable hinged cover(s) which overlaps the framed opening and extends down around the frame at least 50 mm.
      - Alternatively, the cover should have a perimeter trough and drain to allow drainage away from the reservoir; and
    - equipped with vandal-proof locking device.
  - All accesses should have a high degree of security to prevent unauthorized access, such as tamper-proof locks, intrusion alarms and cameras.

17.3.11 Vents

Treated water storage structures should be vented. The overflow pipe should not be considered a vent. Open construction between the sidewall and roof is not permissible.

Vents for reservoirs should:

.1 Allow air into the tank at a rate greater than the rate at which water is filled and withdrawn in order to avoid the development of vacuum/pressure within the tank;
.2 Prevent the entrance of surface water and rainwater;
.3 Be fitted with fine aperture (less than 1.0 mm) non-corrodible screen to prevent the entrance of insects, birds and other animals. The screen should be installed within the pipe at a location least susceptible to vandalism;
.4 Open downward with the opening at least 600 mm above the roof or sod. For cold-climate installations, vents should be made tall enough to overcome the design snow depth in the area to prevent clogging; and

.5 On elevated tanks, be fitted with an automatically resetting pressure-vacuum relief mechanism.

17.3.12 Roof and Sidewall

The roof and sidewalls of all water storage structures should be watertight with no openings except properly constructed vents, manholes, overflows, risers, drains, pump mountings, control ports, or piping for inflow and outflow. Particular attention should be given to the sealing of roof structures which are not integral to the tank body, including access tubes.

The following should be considered in the design of the roof and sidewalls:

.1 Any pipes running through the roof or sidewall of a metal storage structure should be welded or properly gasketed. In concrete tanks, these pipes should be connected to standard wall castings which were poured in place during the forming of the concrete. These wall castings should have seepage rings imbedded in the concrete;
.2 Openings in the roof of a storage structure designed to accommodate control apparatus or pump columns should be curbed and sleeved with proper additional shielding to prevent contamination from surface or floor drainage;
.3 Valves and controls should be located outside the storage structure so that the valve stems and similar projections will not pass through the roof or top of the reservoir;
.4 The roof of the storage structure should be sloped to facilitate drainage. Downspout pipes should not enter or pass through the reservoir. Parapets, or similar construction which would tend to hold water and snow on the roof, will not be approved unless adequate waterproofing and drainage are provided;
.5 For reservoirs with concrete roofs, if a minimum slope of 2% is not provided, reservoir roofs should be made watertight with the use of a waterproof membrane or similar product. If used, the coating or roofing system should allow for relief of vapour pressure. The Designer should refer to *AWWA D115 Tendon-Prestressed Concrete Water Tanks for concrete dome roof design* and *D130-11(R19) for Geomembrane Materials for Potable Water Applications*;
.6 For elevated tanks, the use of heat trace cables on the roof may be necessary to prevent the build-up of ice;
.7 Metal and domed roofs should be inspected closely for leaks during commissioning and during operation. The Designer should refer to *AWWA D103 Factory-Coated Bolted Carbon Steel Tanks for Water Storage* for structurally supported aluminum dome roof design; and
.8 When earthen cover is used on concrete reservoirs, it should be sloped to facilitate drainage.

17.3.13 Construction Materials

The material used in reservoir construction should meet *NSF/ANSI Standard 61*: at a minimum, the cement and additives should meet *NSF/ANSI 61 Drinking Water System Components – Health Effects*. Porous materials, including galvanized corrugated steel, wood and concrete block, are not suitable for treated water contact applications.

Pre-manufactured tanks, including those made from polyethylene, fiberglass, and steel, should be constructed in compliance with the design criteria in Section 17.3 – Design Criteria for Treated Water Structures. All tank penetrations should be factory-installed to ensure watertightness.

The following building codes and design guidelines should be referenced:

.1 *The BC Building Code*;
.2 *ACI 350/350R Code Requirements for Environmental Engineering Concrete Structures, and Commentary*;
.3 *PCA: Circular Concrete Tanks Without Prestressing*;
.4 *AWWA D110 Wire- and Strand-Wound Circular Prestressed-Concrete Water Tanks*;
.5 *AWWA D115 Tendon-Prestressed Concrete Water Tanks*;
.6 *AWWA D100 Welded Carbon Steel Tanks for Water Storage*;
.7 *AWWA D103 Factory-Coated Bolted Carbon Steel Tanks for Water Storage*; and
.8 *ACI 350.3/350.3R Seismic Design of Liquid Containing Concrete Structures*, and Commentary

17.3.14 Seismic Design

The following should be considered for seismic design:

.1 Watertight structure and fully operational mechanical equipment, following a 475-year return period earthquake; and
.2 Repairable damage and no uncontrolled release of water following a 2475-year return period earthquake.

17.3.15 Safety

Safety should be considered in the design of the storage structure. As a minimum, the design should conform to the *BC Building Code* and any applicable municipal bylaws.

.1 Ladders, ladder guards, balcony railings, and safely located entrance hatches should be provided. Access to roof hatches and vents should be provided. The design should incorporate easily accessible fall arrest systems for use by employees or emergency response workers to access the exterior and interior of the storage tank. When a fixed ladder is used, the bottom should be located at least 3.5 m above ground to prevent the entrance of unauthorized personnel. Design of tank access, including platform, railings, ladders, and fall arrest systems, should conform to WorkSafeBC;
.2 Riser pipes over 200 mm in diameter located inside the tank should have protective bars over the openings for fall prevention;
.3 Railings or handholds should be provided where persons must transfer from the access tube to the water compartment. Fall protection should be provided in accordance with WorkSafeBC standards; and
.4 Confined space entry should be avoided where possible. If not possible, design should include risk management systems that satisfy the WorkSafeBC confined space requirements *(OHS Regulation, Part 9: Confined Space)*.

17.3.16 Freezing

Treated water storage structures and their appurtenances, especially the riser pipes, overflows, and vents, should be designed to prevent freezing which will interfere with proper functioning. Equipment used for freeze protection that will come into contact with the treated water should meet *NSF/ANSI Standard 61 Drinking Water System Components – Health Effects*. If a water circulation system is used, it is recommended that the circulation pipe be located separately from the riser pipe.

17.3.17 Internal Catwalk

Every catwalk over treated water in a storage structure should be located above the top water level and have a solid floor with sealed raised edges to 100 mm, and should be designed to prevent contamination from shoe scrapings and dirt.

17.3.18 Silt Stop

The discharge pipes from water storage structures should be located in a manner that will prevent the flow of sediment into the distribution system. Removable silt stops should be provided.

17.3.19 Drainage

The area surrounding a ground-level structure should be graded in a manner that will prevent surface water from standing within 15 m. Perimeter and underdrain systems may be required to prevent hydrostatic uplift under the tank floor when empty. Drainage from this system should be directed into a manhole to provide an effective means of monitoring any leakage from the tank. If a gravity drain is insufficient to prevent hydrostatic uplift, other means such as observation wells and pumping down the water table may also be considered to prevent groundwater entry into the tank.

17.3.20 Painting and/or Cathodic Protection

Proper protection should be given to metal surfaces by paints or other protective coatings, by cathodic protective devices, or by both.

.1 Paint systems should meet *AWWA Standard D102 Coating Steel Water-Storage Tanks* and be certified to *NSF/ANSI Standard 61 Drinking Water System Components – Health Effects*. Interior paint should be applied, cured, and used in a manner consistent with the NSF/ANSI approval. After curing, the coating should not transfer any substance to the water which will be toxic or cause taste or odour problems. Prior to placing in service, an analysis for volatile organic compounds is advisable to establish that the coating is properly cured. Consideration should be given to 100% solids coatings;

.2 Wax coatings for the tank interior should not be used on new tanks. Recoating with a wax system is strongly discouraged. Old wax coatings should be completely removed before using another tank coating; and

.3 Cathodic protection of steel water structures should be provided and conform to the provisions of *AWWA Standards D104* and *D106* for corrosion protection standards for steel reservoirs. Consideration should be given to potential ice damage to cathodic protection equipment. Cathodic protection should be designed and installed by competent technical personnel, and a maintenance contract should be provided.

17.3.21 Disinfection

The following should be considered when disinfecting treated water structures:

.1 Treated water storage structures should be disinfected in accordance with *AWWA Standard C652 Disinfection of Water Storage Facilities*. Two or more successive sets of samples taken at 24-hour intervals should indicate that the water is microbiologically satisfactory before the facility is placed into operation. Following disinfection and prior to placing the tank into service, water should be tested for total coliform bacteria and chlorine residual. If the test for total coliforms is negative and the chlorine residual meets the requirements of the Issuing Official, the tank may be placed into service. If the test shows the presence of coliform bacteria, two or more successive sets of samples, taken at 24-hour intervals, should indicate the water is microbiologically satisfactory before the storage facility is placed into operation;

.2 The disinfection procedure specified in *AWWA Standard C652 Chlorination Method 3*, which allows use of the highly chlorinated water held in the storage tank for disinfection purposes, is not recommended. The chlorinated water may contain various disinfection by-products which should be kept out of the distribution system. If this procedure is used, it is recommended that the initial heavily chlorinated water be neutralized and discharged to waste; and

.3 Disposal of heavily chlorinated water from the tank disinfection process should be discussed with the Ministry of Environment and Climate Change Strategy and/or the Ministry of Water, Land and Resource Stewardship prior to disposal; dechlorination to below 0.02 mg/L total residual chlorine before discharge is often required.

17.3.22 Provisions for Water Quality Monitoring

Smooth-nosed sampling tap(s) should be provided to facilitate collection of water samples for both bacteriological and chemical analyses. The sample tap(s) should be easily accessible. Sample lines should be stainless steel from the sampling point to the sampling tap. Sample tap(s) should be located to collect representative samples.

Provision for online water quality monitoring should be considered in relation to the overall system characteristics and monitoring program.

17.3.23 Security

Fencing, locks on access manholes, and other necessary precautions (e.g. alarms and security cameras) should be provided to prevent trespassing, vandalism, and sabotage. Consideration should be given to the installation of high strength, cut resistant locks or lock covers to prevent the direct cutting of a lock. Reference should be made to Section 5.10 – Site, Building and Digital Security for more information.

18 Pumping Facilities

18.1 General

This chapter provides design considerations for pumping facilities, including general pump station design as well as guidance for raw water, treated or booster pumping stations. Pumping facilities should be designed to maintain the quality of pumped water, the hydraulics of the system and to protect against interruption of service by natural hazards. Subsurface pits or pump rooms and inaccessible installations should be avoided. No pumping station should be subject to flooding.

The design of a pumping facility must conform to the latest applicable *BC Building Code* (BCBC) and to post-disaster standard as described within the BCBC.

18.1.1 Preliminary Design

The following should be considered during the preliminary design phase:

.1 Location;
.2 Capacity;
.3 Number and type of pumps;
.4 Operator requirements;
.5 Preliminary piping layout;
.6 Type and appearance of structure;
.7 Foundation conditions;
.8 Maintenance requirements and access;
.9 Energy requirements;
.10 Standby power;
.11 HVAC; and
.12 Controls and monitoring.

18.2 Pump Stations

18.2.1 General Pump Station Design Considerations

Both raw and treated water pumping stations should:

.1 Have adequate space for the installation of additional units if needed, and for the safe servicing of all equipment;
.2 Be of durable construction, fire, and weather resistant and with outward-opening doors;
.3 Have floor elevation of at least 150 mm above finished grade;
.4 Provide a suitable outlet for drainage without allowing discharge across the floor, including pumping glands, vacuum air relief valves, or other appurtenances with liquid discharges;
.5 Piping should be designed such that each pump has an individual suction line or that the lines should be so manifolded that they will ensure similar hydraulic and operating conditions;
.6 Building floors should be sloped to a suitable drain, and drain in such a manner that the pumped water will not be contaminated;
.7 Building drains should be constructed in such a way as to prevent any potential break or leakage from contaminating the pumped water and should not be built within water-bearing structures; and

.8 Have a sump pump supplied to ensure that any miscellaneous water entering the station is removed. Sump pump systems should be alarmed for flood conditions (i.e. high water level alarms).

18.2.2 Location

The following should be considered when selecting the location of the pump station:

.1 The pump station should be elevated to a minimum of 1 m above the 100-year flood elevation, or 1 m above the highest recorded flood elevation, whichever is higher, or protected to such elevations; unless a hydraulic analysis is completed to identify a more appropriate elevation. The impact of climate change should be considered when locating a pumping station. See Chapter 4 – Climate Change Risk Assessment and Adaptation for further climate change considerations;
.2 The site should be readily accessible at all times unless permitted to be out of service for the period of inaccessibility;
.3 The site should be graded around the station to lead surface drainage away from the station and away from the source water; and
.4 The pump station should be protected to prevent vandalism and entrance by animals or unauthorized persons. The pump station should be located within a secure area such as a locked building or fenced area.

18.2.3 Wet Well Design

The following should be considered in the design of a wet well:

.1 The floor should be sloped to a sump for easy cleaning and draining;
.2 The well should be covered and protected from contamination;
.3 Well access routes should be adequately sealed against liquid penetration;
.4 A 100 mm curb should surround any floor openings to prevent floor drainage entering the well, and the well should be adequately vented;
.5 Design should include two pumping compartments or other means to allow the well to be taken out of service for inspection, maintenance or repair, while still maintaining a portion of the station capacity in service;
.6 Be watertight; and
.7 Suction pipe inlets should be designed in accordance with good design practice to prevent vortexing, air-entrainment, inlet interference and other phenomena that may interfere with proper operation and pumping.

18.2.4 Equipment Servicing

Pump stations should be provided with:

.1 Space around all of the equipment to allow for safe servicing;
.2 Crane-ways, hoist beams, eyebolts, or other adequate facilities for servicing or removal of pumps, motors, or other heavy equipment;
.3 Openings in floors, roofs or wherever else is needed for the removal of heavy or bulky equipment;
.4 Equipment or other facilities as needed, for the proper maintenance of the equipment; and

.5 Equipment should be labeled such that the pumps and valves in the station are tagged to correspond to the maintenance record and for proper identification.

18.2.5 Stairways and Ladders

Stairs are preferred in areas where there is frequent traffic or where supplies are transported by hand. Ladders can be used when access is required less than once per year. Stairways or ladders should:

.1 Be provided between all floors, and in pits or compartments which will be entered;
.2 Conform to the requirements of the *BC Building Code*;
.3 Be provided with adequate safety equipment;
.4 Have handrails on both sides, and treads of non-slip materials;
.5 Comply with Occupational Health and Safety requirements; and
.6 Be designed to facility proper egress from the space in the event of an emergency.

18.2.6 Heating

Provisions should be made for adequate heating for:

.1 The comfort of the operator;
.2 The safe and efficient operation of the equipment; and
.3 Preventing freezing.

18.2.7 Ventilation

Adequate ventilation should be provided to manage the climate conditions within all facilities. Ventilation systems should be designed to conform to relevant provincial and/or local codes and ASHRAE standards. Adequate ventilation should be provided for all facilities for operator comfort and dissipation of excess heat from the equipment. Forced ventilation of at least six changes of air per hour should be provided for:

.1 All confined rooms, compartments, pits and other enclosures below ground floor; and
.2 Any area where an unsafe atmosphere may develop or where excessive heat may build up.

A vent or a vent system should be provided for all structures containing process equipment. The vents should be equipped with a 180° bend with an insect screen at the outlet. For vents on critical structures, the design should incorporate solid/liquid protection against entry into the vent by vandalism or sabotage.

18.2.8 Dehumidification

Dehumidification should be provided in areas where excess moisture could cause hazards for operator safety, or damage to equipment and piping.

18.2.9 Lighting

The following should be considered in the design of pump station lighting:

.1 Pump stations should be adequately lighted throughout to facilitate proper operation and maintenance of the equipment;
.2 Moisture resistant lighting should be considered;

.3 Provision of multiple lighting levels may also be considered for various duties, such as minimum lighting for walkthroughs and minor checks and high-level lights for major maintenance;
.4 Emergency lighting and illuminated exit signs should be provided at appropriate locations in case of power failure;
.5 Exterior lighting should be provided in accordance with local bylaws with consideration to deter vandalism and facilitate maintenance; and
.6 All electrical work should conform to the requirements of the *Canadian Electrical Code* or to relevant provincial and/or local codes.

18.2.10 Sanitary and Other Conveniences

All pumping stations that are manned for extended periods should be provided with potable water, and lavatory and toilet facilities as allowed by provincial and/or local codes. Plumbing must be installed using backflow prevention devices to prevent contamination of a public water supply. Acceptable options for the disposal of wastewater include, but are not limited to, a municipal system, on-site sewage disposal systems, or a holding tank.

18.2.11 Standby Power

Refer to Section 19.4 – Standby Power and Uninterruptable Power Supply (UPS) for design recommendations.

18.2.12 Fire Pumps

Fire pumps are only required for closed systems or systems without adequate storage. Where required, the Designer should provide fire pump drivers equipped with a secondary power source demonstrated to meet an acceptable performance standard similar to NFPA 20 Standard for the *Installation of Stationary Pumps for Fire Protection*.

18.2.13 Safety

Pump stations should be designed in such a manner as to ensure the safety of the operators and maintenance staff in accordance with the *B.C. Occupational Health and Safety Regulation*. Eyewash and safety showers should be provided where potentially harmful chemicals are present in the pumping facility. Refer to safety design considerations in Chapter 5 – Facility Recommendations.

When designing a pump station, the following should be considered for safety:

.1 Any moving equipment should be covered with suitable guards to prevent accidental contact;
.2 Equipment that starts automatically should be suitably signed to ensure operator awareness;
.3 Local lockouts on all equipment should be supplied so that personnel can ensure that they are completely out of service during maintenance;
.4 Local emergency stops should be provided;
.5 Provision of fire/smoke detectors, fire extinguishers and sprinkler systems (where appropriate);
.6 All stairways and walkways should be properly designed with guardrails; and
.7 Confined spaces should be minimized, where applicable.

18.2.14 Controls

The Designer should consider the following in the design of pump station controls:

- .1 Pumps, their prime movers, and accessories should be controlled to ensure that they will operate in a manner that will prevent motor overload or prevent over pressurization of the pipe system;
- .2 Control systems should limit the number of start/stop sequences (according to the pump and electrical equipment manufacturer recommendations);
- .3 Where duplicate pumps are installed, provision should be made for the inclusion of a P1-alternate-P2 selector on the pump control panel. This would allow for the lead status to alternate whenever a pumping cycle is completed or allow for a particular pump to be selected as continuous lead if more consistent operation is desired for a single unit;
- .4 Provision should be made to prevent energizing the motor in the event of a backspin cycle;
- .5 Electrical controls should be located above grade;
- .6 Equipment should be provided, or other arrangements made to prevent surge pressures from activating controls for pumps or activating other equipment outside the normal design cycle of operation; and
- .7 In closed systems (treated water, booster pumping), a control valve (not normally supplied by the pump manufacturer) should be provided to ensure proper operation of the pump. An air release valve should also be provided in the pump discharge to let the air out of the discharge pipe at pump start-up.

Pressure control is commonly used for pump operation in both open systems and closed systems. However, care should be taken for pump selection when this type of control is used as it can have a significant effect on the operation of a pump; specifically, the Designer should aim to select a process pump characterized with a steep flow rate versus total dynamic head curve (pump curve) or ensure that the pump does not operate on the flat part of the curve. A combination of flow control and pressure control may be used in smaller systems. Temperature and level sensing controls may also be required. Whatever control system is used, operation of the pumps near their maximum efficiency points should be maintained.

An adequately sized pressure relief bypass may be required to minimize pump cycling and prevent pump damage for pumps operating in the shut-off head condition.

18.2.15 Hydraulic Surge Protection

Pumping station headers should be adequately protected from transient pressure surges which may occur if pumps stop on power failure. Protection may be provided either by appropriate control sequencing, valves or hydraulic transient surge tanks. An alarm to the SCADA system should be provided for high pressure and if the pressure relief valve opens.

18.2.16 Meters and Gauges

To help ensure that pumps perform as designed, each pump should have:

- .1 Pressure indicating transmitters and/or pressure switches on the inlet and discharge headers;
- .2 A compound gauge on the suction line;

.3 Pressure gauges on the pump suction and between the pump and the discharge check valve;
.4 Flow meter on the discharge from the pump station capable of measuring total and instantaneous pumping rate, and a method of recording the total volume of water pumped; and
.5 Flow meters should provide a signal suitable for input to a SCADA system and/or a data logger. A straight section of pipe should be installed upstream and downstream of the meter per the meter manufacturer's recommendation to improve accuracy where required.

18.2.17 Valves

Each pump should have valves adequate to permit satisfactory operation, maintenance, and equipment repair. This should include:

.1 Isolation gate valves or AWWA butterfly valves on the suction and discharge side of each pump;
.2 A check valve on the discharge side of each pump;
.3 End connections for pumps, pressure vessels, and large equipment should have dismantling joints or flanged pipe with grooved end couplings. Threaded unions are acceptable for smaller units;
.4 Pressure relief surge anticipation valves, as needed, to prevent destructive hydraulic transients from occurring in the system;
.5 Air relief valves at any high points in the piping; and
.6 Foot valves if necessary. Foot valves should have a net valve area of at least 2.5 times the area of the suction pipe and they should be screened.

18.2.18 Piping Material

The strength, stiffness, ductility, and resistance to water hammer or pump cycling make steel or stainless steel the most suitable choices for exposed piping in pump stations. Plastic pipe such as PVC and HDPE are prone to fatigue failure from pump cycling, become brittle at low temperatures, or lose strength at temperatures that can occur normally in pump stations. For those reasons, if considering the use of PVC or HDPE pipe inside a booster pump station, the Designer should approach with caution.

The design should also address special anchoring or support requirements for equipment and piping. Piping should be protected against surge or water hammer and should be provided with suitable restraints where necessary. Special attention should be made to materials installed beneath building slabs and foundations as these components will be costly and difficult to replace if damaged. The Designer should evaluate these pipes for corrosion potential and provide corrosion mitigation, as appropriate.

All material in contact with the water should meet the *NSF 61 Drinking Water System Components – Health Effects* requirements.

18.2.19 Water Pre-lubrication

When automatic pre-lubrication of pump bearings is necessary and an auxiliary power supply is provided, the design should ensure that pre-lubrication is provided when auxiliary power is in use, or that bearings can be lubricated manually before the pump is started.

18.2.20 Oil or Grease Lubrication

All lubricants which come into contact with the potable water should meet NSF rating H1, H2, or H3.

18.2.21 Seismic Piping Connections

Designers should use seismically appropriate pipe materials and connections for all pipes located within the pump station, directly below it, and within 1 m of the pump station foundation before transitioning with couplings.

18.2.22 Taps on Discharge Piping

Booster pump stations are convenient places to provide water quality monitoring and, if necessary, provide booster chlorination or other water quality adjustments. The Designer should consider installing at least two taps on the common discharge line:

- .1 A sample tap to allow for monitoring water quality; and
- .2 A tap to allow for booster disinfection in an emergency.

18.2.23 Access for Pipe Cleaning and Condition Assessment Tools

As distribution pipes age, they gradually accumulate solids and experience corrosion. As a result, it may be useful to install a pig-launch or other access points (e.g. for examination via CCTV cameras) on the pump station discharge piping.

18.2.24 Pump Station Commissioning

Pumps should be installed properly, vibration levels tested, and pump operation tested at the rated performance. Measured vibration levels can be compared to allowable values listed in *Hydraulic Institute Standard 9.6.4 Rotodynamic Pumps for Vibration Measurements and Allowable Values*. An operational field pump test consists of measuring the pump suction and discharge pressure or head, discharge flow, power input, and speed. Designers then use this information to determine whether there are operational issues with the pumps as outlined in *AWWA E103 - Horizontal and Vertical Line-Shaft Pumps*.

Before a pump station can be placed into service, it must be properly tested, inspected, and disinfected. The specifications for the pump station should clearly identify the disinfection and bacteriological testing requirements. *AWWA C651 Disinfecting Water Mains* can be used for this purpose.

18.3 Raw Water Pumping Stations

18.3.1 Pump Selection

Pumps should be specified so that the full range of flows anticipated can be provided with pumps operating in the vicinity of their optimum efficiency points, with due regard to the hydraulic design of the discharge piping. Pump and component materials should be resistant to abrasive materials within the raw water.

Pumps should be selected to maximize efficiencies at the average head condition, but which can meet the maximum flow and pressure conditions. Adequate control should be provided which is capable of controlling pump operation over the entire range of flows expected.

The pumping units should:

.1 Have ample capacity to supply the peak demand against the required distribution system pressure without dangerous overloading;
.2 Be driven by motors able to meet the maximum horsepower condition of the pumps;
.3 Be provided with readily available spare parts and tools;
.4 Be served by control equipment that has proper heater and overload protection for the air temperatures encountered;
.5 Be selected to operate at flows within ± 10% of the Best Efficiency Point (BEP) of the pump. Operating within this range the hydraulic efficiency and the operational reliability of the pump are not substantially degraded. Within this region, the design service life of the pump will not be affected by the internal hydraulic loads or flow induced vibration; and
.6 Have a hydraulic efficiency above 80%.

18.3.2 Number of Pumps

The number of pumps should be consistent with the pattern of flow required and the method of flow control. A minimum of two pumps should be provided, where one pump is standby. Where practical, it is recommended that at least three pumps be provided for increased operating flexibility. Pump capacities should determined based on achieving treatment capacity with the largest unit out of service.

18.3.3 Flow Control

Pumps should be capable of supplying water over the entire range of flows to be treated. This can be achieved through the provision of pumps with variable speed motors or through control valves. Where substantial seasonal variations in flow exist, it may be necessary to provide duplicate flow control systems - one suitable for very low flows (which normally occur in winter) and one suitable for the plant design flow.

18.4 Well Pumping

Refer to Section 6.3.2 – Well Construction

18.5 Treated Water Pumping Stations

The design criteria for treated water pumping stations generally follow those presented for raw surface water pumping. In addition, the following special considerations apply for treated water pumping stations:

.1 The pumping station should be designed with at least two pumps. With one pump out of service, the remaining pump(s) should be able to deliver the maximum daily design flow, when storage is provided, or peak hourly design flow, when distribution storage is not provided, at the required minimum system pressure defined in Chapter 3 – General Design Guidance;
.2 In order to supply water economically during low demand periods, at least one pump should be provided with a variable speed motor or an appropriately sized, small pump may be installed;
.3 Standby power or an auxiliary gas or diesel powered pump should be provided to supply water during power outages or other emergencies. Fuel should be stored above ground and outside the water treatment plant building;

.4 Pumping facilities should be designed to maintain the potable quality of pumped water;
.5 Subsurface pits or pump rooms and inaccessible installation should be avoided; and
.6 No pumping station should be subject to flooding.

18.6 Additional Design Considerations for Pumps

18.6.1 Suction Lift

The design of suction lift pumps should be avoided, if possible. If unavoidable, suction lift should be within the allowable limits for the pump, preferably less than 5 m.

If suction lift is necessary, provision should be made for priming the pumps. To avoid cavitation, it is important to compare the net positive suction head required (NPSHr) to the net positive suction head available (NPSHa). Total suction head calculated for NPSHr should account for geodetic differences and suction pipe losses.

18.6.2 Pump Priming

Prime water must not be of lesser quality than that of the water being pumped. Means should be provided to prevent either backpressure or backsiphonage backflow. When an air-operated ejector is used, the screened intake should draw clean air from a point at least 3 m above the ground or other source of possible contamination, unless the air is filtered by an approved apparatus. Vacuum priming may be used.

18.6.3 Water Seals

Water seals should not be supplied with water of a lesser quality than that of the water being pumped. Where pumps are sealed with treated water and are pumping water of lesser quality, either an approved reduced pressure principle backflow preventer or a break tank open to atmospheric pressure should be provided. Where a break tank is provided, an air gap of at least 150 mm or two pipe diameters, whichever is greater, should be provided between the feeder line and the flood rim of the tank.

18.6.4 Variable Frequency Drives (VFDs)

Designers should consider VFD pump control. It provides many advantages including energy savings, improved pressure and flow control, and elimination of pressure transients associated with abrupt start/stop of single-speed pumps. Chapter 19 – Electrical should be reviewed for harmonic monitoring and mitigation considerations.

18.7 Booster Pumps

18.7.1 General Design Considerations

The purpose of booster pumping stations is to maintain adequate pressures and flows in water distribution systems as a result of both changes in ground elevation and distance from the source of supply. Temporary booster stations may be provided to maintain adequate system pressure during capital project phasing.

Booster pumps should be located or controlled so that:

.1 They will not produce negative pressure in their suction lines;
.2 Pumps installed in the distribution system should maintain inlet pressure as required in Chapter 16 – Transmission and Distribution under all operating conditions. Pumps taking suction from storage tanks should be provided adequate net positive suction head;
.3 Automatic shutoff or a low-pressure controller should maintain at least 140 kPa (20 psi) in the suction line under all operating conditions. Pumps taking suction from ground storage tanks should be equipped with automatic shutoffs or low-pressure controllers as recommended by the pump manufacturer;
.4 Automatic or remote-control devices should have a range between the start and cut-off pressure which will prevent excessive cycling; and
.5 A bypass is available, and alarms are installed for such conditions.

18.7.2 Redundancy

Each booster pumping station should contain not less than two pumps with capacities such that peak demand can be satisfied with the largest pump out of service.

18.7.3 Metering

All booster pumping stations should be fitted with a flow rate indicator and a totalizer meter which provide signals suitable for input to a SCADA system or data logger.

18.7.4 Inline Booster Pumps

In addition to the other requirements of this section, inline booster pumps should be accessible for servicing and repairs.

18.7.5 Individual Residential Booster Pumps

Private booster pumps should not be allowed for any individual residential service from the public water supply main. Exceptions may be permitted if the design, installation, and operation/management of booster pumps is approved by the Water Supplier, the Water Supplier ensures that booster pumps do not adversely affect pressure in the rest of the distribution system, and the Water Supplier addresses all cross connection concerns.

19 Electrical

19.1 General

This chapter describes design considerations for electrical components of water supply systems. Electrical design should be coordinated with process system requirements to ensure stable and reliable treatment performance. The Designer should refer to relevant industry standards and manufacturer requirements for specific design considerations, and is responsible for compliance with the applicable codes, standards and good engineering practices of the electrical industry.

Electrical design should be based on the following criteria:

.1 Efficiency;
.2 Redundancy/Reliability; and
.3 Safety.

19.1.1 Efficiency

Energy efficient equipment should be selected wherever possible to minimize electrical loading. The Designer should refer to the *BC Energy Efficiency Act* for applicable standards and requirements relating to specific electrical equipment. Where possible, the design should minimize the footprint of electrical equipment.

19.1.2 Redundancy/Reliability

The design should incorporate redundancy to account for failure of critical equipment and to improve reliability. Critical equipment should be identified at the start of design so that redundancy can be incorporated into the design.

19.1.3 Safety

Electrical design should conform to all required safety standards and should incorporate controls to minimize electrical risk where required.

Main switch gear electrical controls should be located above grade in areas not subject to flooding. The Designer should coordinate with the appropriate discipline Designer to determine the flood level and required factor of safety for the area.

The Designer should consider switchgear facility sizing requirements if variable frequency drive (VFD) type equipment is to be employed.

Consideration should be given to providing voltage stabilization in the electrical services to laboratory and/or sensitive process control equipment (for example, UV reactors), since a relatively constant voltage may be required for proper operation.

19.2 Codes and Standards

All electrical work should conform to the requirements of the latest editions of the following codes and standards:

.1 *Canadian Electrical Code (CEC Part 1 and Part 2);*

.2 *Canadian National Building Code (NBC);*
.3 *Canadian National Fire Code (NFC) and applicable sections for the National Fire Protection Association Standards (NFPA);*
.4 *Institute of Electrical and Electronic Engineers (IEEE);*
.5 *American National Standards Institute (ANSI);*
.6 All applicable CSA standards; and
.7 All applicable provincial and local codes and standards.

19.3 Power Distribution

19.3.1 Voltage and Phase

System voltage and phase should be determined by the size of the connected equipment and should take into consideration factors such as cable sizing (voltage drop), ease of installation of conduits and cables, and utility service voltages available in the area. Additional considerations include:

.1 Whenever motor loads are present, three phase power should always be used;
.2 Where larger motor loads are present, generally greater than 25 hp, the use of 600 V should be considered to minimize cable sizing; and
.3 Voltage drops should be minimized to 3% whenever possible to ensure stable operation of equipment.

19.3.2 Power Monitoring and Protection

Power monitoring and protection is required to ensure stable power is being supplied to the site. Power surges, voltage spikes, and dirty power can lead to equipment damage and failure and should be prevented whenever possible. The following should be considered:

.1 Where motors are controlled by variable frequency drives (VFD), harmonic monitoring and mitigation should be considered to reduce the impacts on the utility grid.
.2 A voltage monitor should be used to monitor and alarm on undervoltage, phase loss, phase reversal and phase unbalanced conditions;
.3 Where larger motor loads are present (service sizes greater than 200 amps), a power quality meter should be considered for monitoring and protection. The power quality meter should be capable of measuring harmonic distortions where variable frequency drives or soft starters are used for motor control; and
.4 Surge protection devices (SPDs) should be used to protect sensitive electronic equipment from power surges.

19.3.3 Service Size and Equipment Ratings

In general, equipment should be rated to exceed the operating system parameters. Oversizing of equipment should be considered where future expansion may be a possibility; the Water Supplier should be consulted.

The Designer should consider the following when sizing electrical equipment:

.1 The main electrical service should be sized to run the full operating loads at peak treatment and pumping capacity for the design life, plus an allowance for future load growths;

.2 Overcurrent protective devices should have an interrupting capacity that exceeds the maximum calculated short circuit levels;
.3 Voltage ratings of equipment should meet or exceed system operating voltage;
.4 Distribution equipment should be sized for their downstream loads. Consideration should be given for allowance for future load growths where necessary; and
.5 Space should be provided for future electrical equipment, including Motor Control Centers (MCCs).

19.4 Standby Power and Uninterruptable Power Supply (UPS)

19.4.1 Standby Power

The need for standby power and the extent of equipment requiring operation by standby power should be individually assessed for each facility. A plan should be developed to ensure that average day demand can be met during a power outage, and at a minimum, emergency level lighting and process control operations can be maintained. The following factors should be considered when developing a plan:

.1 Frequency and length of power outages in the area;
.2 Reliability of primary power source;
.3 Available treated water storage capacity within the system;
.4 Type of water storage (underground or elevated); and
.5 Requirements for fire protection.

The standby power supply should be capable of providing continuous electrical power during any interruption of the utility power supply. The standby power supply should be designed with adequate capacity to operate fire and domestic pumps, chemical dosing systems, control and monitoring systems, and heating and lighting systems. Automatic transfer equipment should be provided to make the transition from utility power to the backup power as seamless as possible during power outages.

Adequate fuel supply should be provided for the backup power system. Fuel capacity should be sized to maintain a minimum run time of 8 hours. In remote locations, consideration should be given to a minimum run time of 24 to 48 hours depending on the risk factors associated with the utility power.

For fuel storage, a subbase tank type setup should be used to minimize the installation footprint. The Designer should refer to *CAN/UCL-S601 Standard for Shop Fabricated Steel Aboveground Tanks for Flammable and Combustible Liquids* for tank fabrication and CSA B139 *Installation Code for Oil-Burning Equipment* for tank installation. If additional tanks are required, these may be located underground or inside. Factors such as corrosion potential, leakage and spill protection, and the need for fuel pumps should be evaluated. The design for fuel storage tanks and supply lines must conform to all applicable federal and provincial legislation and regulations.

Fuel storage tanks and generator units should not be located above any water treatment process unit or raw or treated water reservoir.

Where the backup power system is to be installed indoors, proper consideration should be given to the ventilation requirements. The ventilation system should be fully automated and should be sized to the requirements of the backup power system. External pad mounted units in a separate enclosure can also be considered if space, ventilation, or noise requirements cannot be met when installed indoors. Carbon monoxide detectors should be used when fuel-fired generators are used for standby power.

When the facility is located in a residential district, soundproof enclosures should be used to limit sound levels while the standby generator is in operation. The acceptable sound level must be determined by consulting with the local authorities and local bylaws.

Generator units should be mounted on a pad and surrounded by a containment system to retain any fuel spills. A clear space for inspection and servicing of at least one meter on all sides of the unit should be provided.

Standby power systems have peripheral requirements to ensure the backup power system is maintained in operational service. These peripheral requirements should be considered in the design and adequate circuits should be provided. At a minimum, the following accessories should be included:

.1 Battery chargers;
.2 Block heaters;
.3 Remote communications (and/or);
.4 Hard-wired alarm signals.

For small pumping facilities, portable standby units may be used and a fixed exterior electrical connection point should be provided for connection of the portable standby power system.

19.4.2 Uninterruptable Power Supply (UPS)

A UPS system should be provided for all critical controls and instrumentation. The UPS system should be designed to operate by using a true online double conversion system. Protection against voltage variations and surges should be included in the design.

UPS systems should include a bypass system and should provide a battery backup time of at least 30 minutes at full load.

19.5 Site Services

Power outlets should be provided at convenient spacing throughout the facility to provide power for purposes such as maintenance of equipment and extension lighting. Ground fault interrupter (GFI) type outlets should be used in process areas or when located outside.

Outlets supplied by uninterruptible power supply (UPS) or emergency power systems should be located such that they are easily accessible during a power outage.

19.6 Motors

The following should be considered when designing motors:

.1 Each pump should be operated by a motor capable of operating the pump at any point on the head discharge curve. Pump motors rated 1-200 hp should meet the CSA minimum motor efficiency standard. If available, motors should be "premium" energy efficient;
.2 Generally, motors greater than 50 hp should use soft starters or variable frequency drives to minimize motor starting impact to the utility power and mechanical components of the

system. Where a soft starter is used, a bypass contactor should be inherent in the design. Line and load filters should be used with variable frequency drives to limit harmonic effects;

.3 Motors should be located at such a level in the pumping station that they cannot be flooded. Alternatively, immersible motors can be used;

.4 A suitable time delay between pump stop and the subsequent pump start should be provided to allow the shaft to come to a complete stop;

.5 Motors greater than 5 hp should include motor thermostats for motor protection;

.6 Motor space heaters should be considered where motors are located outdoors, in unheated rooms, or in damp areas; and

.7 Power factor correction capacitors should be considered where all direct utility powered motors are used to avoid power use charges due to poor power factors.

19.7 Electrical Controls

The following should be considered when designing electrical controls:

.1 Electrical controls should be located above grade, in areas not subject to flooding. All electrical work should conform to the requirements of the *Canadian Electrical Code* or to relevant provincial and/or local codes;

.2 Pumps, their prime movers and accessories should be controlled in such a manner that they will operate at the rated capacity without dangerous overload. Where multiple pumps are required to run simultaneously, sequential starting should be used to minimize impacts to standby power capacity. Provision should also be made to allow for alternation of pumps either automatically or manually;

.3 Where critical equipment is being controlled, consideration should be given to providing redundant control systems;

.4 Local control panels and stations should be located near their respective equipment and should be easily accessible with adequate clearance around equipment; and

.5 Electrical control equipment located in process and outdoor areas should be rated suitably for use in those conditions.

19.8 Grounding

A complete, permanent, and continuous grounding system should be provided for the electrical system. The grounding system should meet the requirements of the *Canadian Electrical Code*.

19.9 Lighting

The following should be considered when designing facility lighting:

.1 Buildings should be adequately lighted throughout by means of natural light and artificial lighting. Control switches should be conveniently placed at each entrance to each room or area;

.2 Emergency lighting should be provided and should have a minimum run time of 30 minutes after power failure;

.3 Energy efficient lighting should be used, and all process areas should use moisture resistant lighting;

.4 Design lighting levels should be in accordance with the *Illuminating Engineering Society of North America (IESNA)* guidelines;

.5 Exterior lighting should be provided and should be:

a. LED and rated for outdoor and wet locations;
b. Located over entrances and any location where high activity is anticipated (such as parking lots); and
c. Should be operated automatically (timer or photocell) with manual override.

19.10 Power Study

Electrical power studies are performed by Designers to analyze the safety and reliability of electrical networks. These studies can provide valuable insight into a power system and can help to identify areas which require further design engineering.

The following power studies should be conducted:

.1 Short circuit analysis – Electrical faults can lead to severe damage and/or injury to equipment and staff. A short circuit analysis of the power system will allow Designers to determine the interrupting capacities required for individual pieces of equipment in order to withstand the anticipated fault levels;
.2 Protective device coordination – These studies allow Designers to determine settings required for breakers and protective devices so that the system can be designed for optimal reliability. A properly configured protective electrical system ensures all electrical equipment is protected in case of failure;
.3 Arc flash analysis (for systems 240 V or over) – Whenever energized electrical equipment is present, arc flash hazards could exist. An arc flash analysis allows Designers to determine the arc fault currents and arc flash incident energy that could be reduced and controlled during the design. These studies help to improve personnel safety, reliability, and equipment protection;
.4 Harmonic analysis – When nonlinear loads such as VFDs are present in an electrical system, harmonic frequencies may be produced by these devices which could result in power quality issues. Harmonic analysis of the power system helps to determine if these devices are causing power quality problems that could affect other equipment or even the utility grid. Many utilities require a limit to the amount of harmonic distortion that a power system can apply to the grid, and a harmonic study will allow Designers to find and mitigate these power quality issues; and
.5 Grounding study – This study will allow engineers to determine if the substation ground grid design is adequate and meets code requirements. A good grounding grid system is required to ensure personnel safety.

20 Instrumentation and Controls

20.1 General

This chapter describes design considerations for instrumentation and control systems for water supply systems. The Designer should refer to relevant industry standards and manufacturer requirements for specific design considerations, and is responsible for compliance with the applicable codes, standards and good engineering practices of the electrical industry.

The objectives of instrumentation and control are to support the continuous operation of process systems and provide monitoring, protection, and control functions. Process control tools, including monitoring, instrumentation, and alarms ensure that equipment and treatment processes operate safely and reliably. In addition to meeting regulatory monitoring requirements, these tools allow Operators to adjust equipment or process operation and alert Operators when a system may not be functioning properly.

Process/treatment equipment is sometimes supplied with proprietary instrumentation and controls. The WTP instrumentation and control design will need to be able to integrate with these proprietary systems.

Controls should be located above the 200-year flood level to prevent damage to the system.

For considerations on cybersecurity, refer to Section 5.10 – Site, Building, and Digital Security.

20.2 Process Control Narrative

A process control narrative should be produced for all automated process operations. The process control narrative should briefly describe each component of the process system, including treatment and pumping equipment, distribution system components, instrumentation, and sampling monitoring, and recording equipment as applicable. The process control narrative should also identify and explain the basis of control for the system.

Piping and instrumentation diagrams (P&ID) should be developed for all process systems and should include all major and minor processes along with all ancillary process equipment.

Controls and instrumentation should be appropriate for the facility size, complexity, criticality, and number of staff and their skills. To achieve this, the Designer should develop a control philosophy that enables the operations staff to effectively monitor and control the facility and major equipment, the treatment process, water production, and plant wastes, as applicable.

20.3 Instrumentation

Selection of the level of instrumentation and control should be made in conjunction with the Water Supplier, considering factors such as:

- .1 Level of maintenance and calibration required;
- .2 Desired versus required level of automation;
- .3 Data recording, retrieval and storage requirements; and
- .4 Capital costs.

20.3.1 General Instrumentation Design Considerations

Instrumentation design considerations include:

.1 Where analyzers are part of an automatic control loop, the system lag time should be minimized to avoid hunting or other instabilities. Sample line length and transport time to the analyzer should be taken into account for proper loop control.

.2 Designers should keep sample lines as short as possible and use small diameter non-translucent piping or tubing. In general, the sample delay should be less than two minutes between the pipe and instrumentation, as determined based on the criticality (i.e. if the parameter is being used for reporting compared to if the parameter is being used for trending) of the sampled parameter. The sample piping should be configured and adequate appurtenances provided to prevent nuisance readings due to air bubbles or other interference.

.3 Parts in contact with drinking water should be easy to clean and disinfect;

.4 Parts in contact with fluids should be suitable for the conditions, including aggressive chemicals or solids that can cause abrasion;

.5 Instruments should be compatible with the environment in which they are located (e.g. high humidity, temperature, outdoors, and electromagnetic interference);

.6 Instruments should be located so that they provide accurate and reliable data (e.g. straight pipe requirements upstream and downstream) according to the manufacturer specifications;

.7 Provision should be made to measure and control pressure and flow to instruments to ensure these parameters are within the manufacturer's specifications;

.8 Convenient and safe access to the instruments should be provided for monitoring, maintenance, calibration, and testing purposes. Isolation should be provided so that an instrument can be removed and serviced or replaced. A bypass, pipe spool piece or standby unit should be provided if servicing or calibration will disrupt the production of treated water;

.9 Instruments should include a local display or a remote display if instruments are placed in difficult to access or hazardous areas;

.10 Sample points should be located to collect representative and well mixed samples (e.g. after reaction of chemicals has occurred).;

.11 Instruments should be selected to provide reliable data over the entire range required; the turndown of the instrument should be considered in instrument selection. The accuracy and precision required for the process should also be considered (cost generally increases as accuracy increases);

.12 Lifecycle cost, including maintenance and calibration requirements, and hydraulic head loss (pumping costs), should be considered;

.13 Instrumentation should be protected electrically with equipment such as surge protectors and uninterruptable power supplies. Some instrumentation in particular are very sensitive to small changes in the power supply;

.14 Instrumentation should not be located near large electrical motors; and

.15 The use of single analyzers or primary devices on a time-share basis for monitoring multiple points is discouraged especially when the measurement is being used for loop control. However, if adopted, the rate of sample flow to the instrument should be sufficient to give a true indication of the sample value within the time allotted to that sample.

20.3.2 Process Control Instrumentation Considerations

Some processes or parameters require additional considerations, including:

.1 **Flow Rates:** Main process flows are usually measured using mass flow meters, magnetic, ultrasonic, or differential pressure (e.g. venturi) flow meters. Where low head loss is needed, magnetic or ultrasonic meters are preferred. Rotameters are suitable for small flows of liquids and gases.

.2 **Streaming Current Monitors or Zeta Potential Meters**: Water systems use these types of instruments for coagulation control. For on-line instruments, there should be a 1- to 3-minute lag time between coagulant addition and when the sample reaches the sensor;

.3 **Turbidimeters and Particle Counters**: Sample lines to these online instruments should be kept short to keep the delay between sample collection and the instrument to one minute or less. In addition, Designers should provide bench-top equipment for turbidimeters so that operators can perform weekly verification checks. Turbidimeters should be placed in a location that also allows measurement of turbidity during filter to waste;

.4 **Turbidity data recording and trending for filtration plants:** The data logging system should have the capacity to handle long-term turbidity data storage needs. The SCADA should continually monitor turbidity from each individual filter effluent and record the data at least every 5 minutes.

20.4 Control System

A Programmable Logic Controller (PLC) or Distributed Control System (DCS) should be used for monitoring and control of all process systems. Where critical operation is needed, redundant PLC/DCS control systems should be provided. The control system should be designed to supply maximum reliability and safety. A minimum of 10% spare I/O should be provided for the control system to account for future expansion.

The type of control provided for the operation of a facility or process can vary from simple manual control without any automatic function (either local or remote), through semi-automatic control which combines manual control with automatic control for a single piece of equipment, to a fully automatic control system which turns equipment on and off or adjusts operating status in response to signals from instruments and sensors.

In selecting a control system, the Designer and the Owner should consider the following factors:

.1 Manual control systems:
   a. Are simpler to maintain and repair than automatic systems and are lower in initial cost, but require the on-site presence of an operator when producing drinking water; and
   b. The initial low costs may be outweighed by high labour and operating costs, including chemical and energy costs incurred by poorer process control;

.2 Automatic control systems:
   a. Provide a more consistent product with lower labour costs;
   b. Require skilled maintenance;
   c. Should provide a level of reliability appropriate for the control function; and
   d. Should be designed to have the capability to manage any set of conditions which may occur.

The Designer should select a control system based on the risks to public health, the complexity of the processes to be controlled, and should take into consideration the capability and limitations of the knowledge and skill of regular operating staff. If using automatic controls, manual override of critical operation electrical equipment should be included. Evaluation of critical controls should be determined at the start of the project so that adequate manual override controls can be integrated into the overall design.

Automatic remote-control systems should include means for detecting communication failure (e.g. by using "heartbeat" communication integrity confirmation). If communication failure occurs, the Designer should ensure safe mode operation or safe shutdown of the remote part of the system is provided. The Designer should make provisions for the system to resume operation automatically when communication is restored or remain shutdown until attended by an operator. Redundant communication pathways should be considered for critical remote controls, with either automatic or manual switching. Primary instruments (sensors or analyzers) which form part of an automatic control loop (e.g. chemical dosing systems) should have appropriate redundant means of avoiding unsafe operation in case of instrument failure. The design should minimize pressure transients in the water distribution system following shutdowns.

The control system should provide complete monitoring and alarming of all process systems. Trending and recording of major process variables should be implemented. Alarms should be clearly visible on operator Human Machine Interface (HMI) when active and should be recorded in history. An alarm log should be provided and should be accessible through the HMI.

Where process equipment can be directly controlled, an HMI should be available to view effects of any changes to the process. Secondary HMI(s) should be located, as required, to provide the necessary supervisory requirements of the facility. The HMI graphics should be consistent throughout the Water Supplier's system and conform to the *International Society of Automation's ISA101 Human Machine Interfaces for Process Automation Systems*.

20.4.1 Automated Operation

The Designer should consider the consequences and operational response to treatment challenges, equipment failure, and loss of communications or power.

Automated monitoring of all critical functions with major and minor alarm features should be provided; dual or secondary alarms may be necessary for critical functions. The Designer should consider and document if automatic shutdown and manual restart is necessary or desirable, to ensure the safety of the water supply. The control system should have response adjustment capability on all minor alarms. Built-in control system challenge test capability should be provided to verify operational status of major and minor alarms throughout the extreme conditions that can reasonably be expected during facility operation.

Automated shutdowns of high lift pumps due to low concentrations of chlorine residual or other water quality alarms or operational procedures, when sustained, may result in health risks similar to those experienced during power failure. Automated shutdowns should be alarmed and require operator response as quickly as possible.

20.5 Monitoring and Alarming

20.5.1 Monitoring

Facilities should be provided with equipment (including recorders, where applicable) to monitor the equipment as follows:

.1 General:
- a. Containment/chemical spill;
- b. Hazardous gas(es);
- c. Off-specification volume;
- d. Overflow;

.2 Raw water instrumentation:
- a. Low-level switches to shutdown the raw water pumps. These should be hard-wired to the starters;
- b. Running and trip indication for raw water pumps;
- c. System pressure;
- d. Instantaneous flow rate and totalized volume per day;

.3 Rapid mixer:
- a. Running and trip indication;

.4 Flocculators:
- a. Running and trip indication;
- b. Speed (if variable speed type);

.5 Clarification systems:
- a. Flow rate
- b. Re-circulator speed indication;
- c. Speed (if variable speed type)
- d. Running and trip indication;
- e. Level indication;
- f. Blowdown valve status;
- g. Sludge level;
- h. Instrumentation for proprietary types of clarifiers, including ballasted flocculation and DAF, should be as recommended by the manufacturer. However, effluent turbidity and pH are recommended in all cases;

.6 Filtration:
- a. Pressure differential or head loss;
- b. Effluent control valve position;
- c. Filter run time;
- d. Filter status (e.g. on-line, backwash required, in backwash, ready, off-line);
- e. Filtration rate/flow rate;
- f. Totalized flow;
- g. Water level in filters;

.7 Backwash for filtration:
- a. Backwash flow rate and totalized volume;
- b. Air scour/surface wash status;
- c. Air scour flow rate;
- d. Control sequence status, when automated;
- e. Surge protection for air blowers;

.8 Chemical systems:
   a. Running and trip indication for chemical loading, batching and pumping equipment;
   b. Low and high-level alarms in storage bins, silos or tanks;
   c. Level indication for tanks;
   d. Weigh scales for hydrofluosilicic acid day tanks or storage (if no day tank is used);
   e. Weigh scales for gaseous feed chemicals, such as chlorine or sulphur dioxide;
   f. Speed indication on variable speed pumps;
   g. Rotameters for carrier water feed systems;
   h. Chemical feed flow rate is mandatory unless day tank is provided;
   i. Ambient gas alarms (chlorine, ozone);
   j. Gas scrubber indication;

.9 Pumps, mixer and motors:
   a. Bearing temperature;
   b. Mixers speed/power;
   c. Moisture detection (submersible motors);
   d. Power draw;
   e. Run time;
   f. Running and trip indication;
   g. Running status;
   h. Speed (if variable speed type);

.10 UV disinfection:
   a. Ballast power;
   b. Flow rate;
   c. Lamp status;
   d. Off-specification volume;
   e. Run status;
   f. Run time;
   g. UV intensity;
   h. Refer to the Guidelines for UV Disinfection of Drinking Water;

.11 Clear well & distribution pump instrumentation:
   a. Level indication for clear well and other tanks;
   b. Low-level switches to shut down the distribution pumps. These should be hard-wired to the motor starters;
   c. High lift discharge pressure;
   d. Instantaneous flow rate and totalized volume per day;
   e. Minimum water level where it is required for confirmation of primary disinfection CT;
   f. For variable speed pumps, indicate the pump speed;

.12 Miscellaneous instrumentation:
   a. Run time meters on all pumps and major electrically-driven equipment;
   b. Speed, run time, oil pressure and temperature gauges, fault signal switches and manual start and shutdown on engines;
   c. Where the plant is automated or operated remotely from either within the plant or outside, provide open and close limit switches or position on all major valves, status on all major equipment and security instruments including door switches, remote resets, building temperature switches and smoke alarms;

d. All water supplies should have an acceptable means of measuring the flow from each source, backwash water, recycled water, any blended water of different quality, and finished water; and
e. Any additional instrumentation recommended by equipment manufacturers.

For water quality parameters that should be monitored, refer to Chapter 22 – Water Quality Monitoring.

Remote operation of the water treatment facility using supervisory control and data acquisition (SCADA) systems should be considered. The SCADA system should:

.1 Be capable of monitoring and recording on-line instrumentation data;
.2 Be capable of adjusting set points of critical functions and key parameters within the plant;
.3 Be designed with adjustable alarms for monitoring of critical plant functions, key process parameters and/or equipment status;
.4 Be capable of remotely notifying the appropriate individual when problems arise, in addition to the nature of the problem;
.5 Be provided with off-site controls for adjusting critical plant functions;
.6 Only be provided in-conjunction with an available off-site operator with an adequate response time; and
.7 Include appropriate security controls. Refer to Section 5.10 – Site, Building, and Digital Security for more information.

20.5.2 Alarms

Designers should identify alarm conditions, especially for critical process components, where very high or very low levels could lead to unsafe water delivered to customers. Critical alarm conditions for drinking water treatment and supply facilities can include water quality and physical parameters; refer to Chapter 22 – Water Quality Monitoring for guidance on implementing water quality monitoring.

All alarms should be latched until the operator has acknowledged them. If the alarm is indicated by a lamp, it should flash until acknowledged then remain steady until the alarm clears. If it is indicated on a computer screen, an appropriate colour code or symbol should be used to indicate whether it has been acknowledged. Automated systems should log the time at which the alarm occurred, the time it was acknowledged, and the time it cleared. Logs may be printed on paper or recorded electronically.

Valve and equipment status should use a consistent method of symbols and colours, whether the status is indicated through lamps or on a colour computer screen. The colour-coding scheme should be consistent with any existing equipment displays elsewhere in the plant.

As a minimum, the following alarms should be provided:

.1 Raw water
  a. High turbidity
  b. High and low pressure on the raw water line
  c. High and low flow rate
  d. High and low pH (if on-line measurements are provided)
.2 Clarification
  a. High and low water level in clarifiers or flocculators

   b. High torque on process rotating elements (e.g. basin mixers, flocculators, solids contact clarifier recirculator and rakes)
   c. High water level in process basins and open surface channels
   d. High turbidity in clarifier effluent

.3 Chemical systems
   a. High and low level in chemical storage tanks
   b. High and low chemical feed rates
   c. Chlorine gas detection in the chlorine storage, metering and injector rooms
   d. Chlorine scale low weight (where scales are equipped with transmitters)

.4 Filters
   a. High flow rate on each individual filter (also low flow rate on declining rate filters)
   b. High head loss on the filters (if influent flow splitter or constant rate type)
   c. High turbidity on filter effluent and combined effluent

.5 UV disinfection
   a. Refer to *the Guidelines for UV Disinfection of Drinking Water*

.6 Pumps
   a. High and low water levels in each clear well, pump well, and reservoir
   b. Trip or failure to run on each pump and process motor

.7 Residuals management
   a. Sludge density
   b. Flow rate
   c. Temperature

.8 Treated water
   a. High and low pH (if on-line measurements are provided)
   b. High and low chlorine residual on the plant discharge (where on-line measurements are provided)
   c. High and low pressure on the plant discharge line
   d. High and low flow rate
   e. High turbidity
   f. Valve operation failure (where valves are provided with limit switches)

More alarms may be recommended or required where additional treatment processes are provided and/or if pathogen log reduction credits are assigned. Reference should be made to the *Guidelines for Pathogen Log Reduction Credit Assignment* for criteria for each treatment process.

Alarms should be provided for all control system interlocks that can shut down equipment or systems. In plants that are left unattended, an automatic telephone dialler, cellular communication or pager system should be provided for annunciation of alarms.

20.6 Reliability and Security

The design of facilities should be based on the premise that failure of any single component must not prevent the drinking water system from satisfying all applicable regulatory requirements and other site-specific treated water quality and quantity criteria, while operating at design flows.

A water treatment process that is designed with a limited number of treatment barriers, and/or has less treatment contact time than conventional processes, must have a commensurate level of reliability and redundancy of its components.

The Designer should consider the following for designing and documenting the reliability of the proposed drinking water system:

.1 Regulatory requirements and other site-specific treated water quality and quantity criteria during the full range of design flows and operating conditions;
.2 Likelihood of the system having reduced levels of treatment/performance;
.3 Risk to the performance of the system and in turn to the environment;
.4 Risk to public health and safety if the level of treatment and performance of system components are reduced;
.5 Local conditions and constraints, such as accessibility of the site, reliability and redundancy of the power supply, etc.;
.6 Manner and methods by which reliability is provided so that reduced treatment or performance and bypasses can be eliminated;
.7 Individual process unit/equipment reliability and redundancy analysis to define the following:
   a. Critical process units/equipment;
   b. Critical events;
   c. Estimated event duration;
   d. Actions/safeguards;
   e. Effect on treated water quality and/or quantity;
.8 Hardware and software should be selected based on reliability, compatibility and vendor support. Equipment should be robust enough for continuous operation in the plant environment. Hardware and software necessary to facilitate back up of both the system and the collected data should be provided locally. A system and data recovery procedure should be included in the project documentation, which should also be remotely accessible; and
.9 Response capabilities of operations staff, including response times and operation knowledge and skill levels.

The Designer should consider methods of improving reliability through transient protection wherever possible (e.g. mains, filters and transient surge protectors). Radio modem and other data transmission equipment should use methods to ensure the integrity of the data transmitted against corruption/interference. Encryption of signals for data/control security may be considered. When long instrument or equipment wiring is present, induced current protection should be installed.

Network configurations should be designed with security in mind. Protection of fibre optic or local area network (LAN) cabling in conduits should be considered to protect from physical damage. Harmonics and other electrical related disturbances to signal integrity should be taken into consideration.

Power supply design should include back up power by using true online uninterruptible power supply (UPS) or equivalent power systems. Buffered direct current (DC) power supply should be selected. Critical instrumentation should be connected when possible to the same back up power as the control system to allow monitoring during power outages. Consideration of the impacts of power failures on critical instrumentation and control should be taken into account, especially with respect to the reset conditions of the devices.

Surge protection devices should be provided to protect sensitive electronic equipment.

20.7 Communication Networks

Communication networks may assist operations and maintenance personnel with the following functions:

.1 Device diagnostic data;
.2 Remote calibration;
.3 Device alarm status;
.4 Distributed control by locating PLC/DCS in close proximity to devices being monitored;
.5 Plant data can be made available for use by management; and
.6 Loop error is reduced.

20.7.1 Internal Communication Networks

Networks used within the site for controls should be provided as follows:

.1 Control network for PLC/DCS control system using ethernet communications;
.2 Facilities with large numbers of instrumentation and field devices should use device networks utilizing Profibus, HART, or Modbus communications when available, for easier calibration and monitoring of equipment. Smaller and simpler facilities with limited instrumentation or instrumentation not capable of digital communications should use digital and/or analog hardwired signals (i.e. 4-20 mA current loops);
.3 SCADA network utilizing ethernet communications;
.4 Ethernet based networks should use CAT6 connections. Fibre optic cables should be used whenever ethernet cables exceed 90 meters in length; and
.5 Profibus networks should use Profibus PA (Process Automation) instrumentation whenever possible and Profibus DP (Decentralized Peripheral) only if Profibus PA is not available. Provide appropriate Profibus PA to DP gateways or Profibus to Ethernet/IP gateways, as required, to connect Profibus instrumentation to PLCs.

20.7.2 External Communication Networks

The following external networks should be provided as follows:

.1 A telephone line should be provided for site communications, and a second telephone line should be provided for critical alarming functions. If possible, these should be dedicated lines;
.2 Radio communications should be considered for communications to SCADA networks. Alternatively, private cellular communications can also be considered where available; and
.3 If available, internet access to the site should be provided, but should not be used as an emergency line. Internet access can be used for remote access functions where necessary. The Designer should ensure that the necessary security measures are considered when using internet access in this manner.

20.7.3 External Communications Network Reliability

Dedicated networks provide the greatest reliability as communication on the line is reserved entirely for the site. Dedicated lines, however, are becoming increasingly rare and may not be provided by local communications utilities. A private dedicated line can be considered if cost implications can be justified.

Radio communication networks can be extremely reliable as redundancy can be easily incorporated into the design through the addition of multiple radio paths and redundant equipment. The Designer will have to determine the level of redundancy required based on how critical the operation of the site is considered to be, and on local site conditions. A well-designed radio network should be able to provide better than 99.9% reliability.

Reliability of the telephone line is dependent on the provider, location of the site, local conditions, and amount and type of information being transmitted. The Designer *s*hould consider these factors when determining if a telephone system would be adequate for the communication requirements to the site.

21 Small Systems

21.1 General

The recommendations discussed throughout the *Design Guidelines* are applicable to all water systems; however, this section of the *Design Guidelines* provides recommendations specifically for small systems. The DWPR defines a small system as "a water supply system that serves up to 500 individuals during any 24 hour period".

The majority of water systems in B.C. are small systems. Sometimes these systems have limited financial, administrative, and management capacity which creates operational and management challenges that limit their ability to maintain and improve system infrastructure, install adequate treatment to provide potable water, comply with regulatory standards, or to appreciate the health risks associated with their water supply. Given these challenges and wherever possible, small systems should be designed to minimize operational complexity and O&M costs. In general, highly complex treatment systems are not suitable for small systems.

Before designing a new small water system, other options for water supply should be considered: where feasible, amalgamation with regional districts or connection to nearby municipal-scale drinking water systems is highly recommended over a new construction.

The *Small Water System Guidebook* by the Ministry of Health provides extensive guidance to small systems Owners on owning, operating and maintaining a small water system. This chapter in the *Design Guidelines* provides considerations and design recommendations specifically for small systems recognizing the challenges that these systems face. For detailed design guidance on specific treatment technologies, the previous chapters in the *Design Guidelines* should be referenced.

21.2 Approval Process

The approvals needed for small systems are similar to those for larger systems. Proponents planning a small system should consult with their Issuing Official to discuss the scope of the project, the approvals process that should be followed and to determine applicable regulatory requirements. The Issuing Official may choose to simplify the approvals process based on the complexity of the water supply system.

21.2.1 Construction Waiver Request

Under Section 6(3)(c) of the Drinking Water Protection Regulation, an Issuing Official may waive the requirement for a Construction Permit in the case of a small system. The *Drinking Water Officers' Guide* recommends that the Issuing Official consider whether, and to what extent, a Construction Permit is necessary to address potential risks to public health. This may include consideration of all relevant information, such as:

.1 The nature and complexity of the proposed water system;
.2 The source of water that will be used by the system and the potential for a health risk to arise;

.3 The likelihood that the applicant is prepared to accommodate suggestions or requests of the Issuing Official in the absence of any formal legal requirement for the approval of a Construction Permit;
.4 The knowledge and experience of the people undertaking the construction; and
.5 In the case of systems using point-of-entry (POE) or point-of-use (POU) treatment, whether the Issuing Official believes it is necessary to impose conditions respecting construction, design or equipment in order provide reasonable confidence that the POE/POU devices will be able to provide potable water, and where such conditions could not likely be addressed through an Operating Permit.

21.3 EOCP Certification and Operator Training

Under Section 4(2) of the DWPR, small systems are not required to have a Certified Operator to operate, maintain or repair their system because small systems are not prescribed for the purposes of Section 9 of the DWPA which sets out qualification standards for persons operating water supply systems. Despite Section 4(2) and under Section 12(4) of the DWPR, an Operating Permit may require a person to be certified to operate, maintain or repair a small system. For these systems, Designers should contact the Environmental Operators Certification Program (EOCP) early in the design process to discuss operator certification requirements.

For all water supply systems, regardless of size and operational complexity, operators should have the necessary competencies to operate and maintain their drinking water systems. For small systems, small water system courses are available that provide drinking water treatment and distribution training.

21.4 Water Demand

21.4.1 Domestic Water Demand

When determining domestic water demands for a small system, refer to Chapter 3 – General Design Guidance. For consideration, peaking factors are generally higher for small systems and irrigation districts.

As a minimum, the water supply/treatment facility should be designed to meet the projected maximum daily flow requirement of the service area with peak hourly, outdoor use and fire demands met from storage. Where it is possible to develop the water source to meet more than the projected maximum daily flow, the storage volume can be reduced accordingly.

For design purposes, existing reliable records should be used wherever possible. In the absence of local bylaws, reliable records, or information from neighbouring systems, the Designer should calculate the critical demands using the following basic demand parameters:

.1 Average Day Demand (ADD) – The quantity of water used in a system in an average day. The ADD is used to verify source capacity, and to derive peak demands from metering data.

In the absence of metering data, ADD can be estimated using the population served by the water system and values for domestic water demand (volume per person per day):

ADD = population* x domestic water demand

* population value should reflect the design horizon (i.e. expected population change over design period)

Domestic water demand values historically used in system design have ranged from 180 to 1,500 L/(cap·d). With increased use of water metering, conservation and low-use fixtures, the Designer may find values at the low end of this range to be better representative of the system needs.

These values represent the average flow over a 24-hour period; they do not reflect the daily or hourly maximum demands which will exceed the average value by a significant amount. It is essential that the source of supply and the distribution system is capable of meeting these maximum and peak demand rates without overtaxing the source or resulting in excessive pressure loss in the distribution system.

.2 Maximum Day Demand (MDD) – the maximum water flow rate supplied to the system on any given day within a calendar year. A small water system should be designed to supply at least the MDD. The MDD can be calculated as:

MDD = MDF x ADD

Where the maximum day factor (MDF) can be found in Table 21-1;

.3 Peak Hourly Demand (PHD) – The maximum hourly flow rate supplied by a water system. The PHD is a critical design parameter for sizing pipes, pumps and treatment works between balancing storage and customers. The PHD can be calculated as:

PHD = PHF x (ADD ÷ 24)

The peak hour factor (PHF) can be found in Table 21-1.

.4 Fire Flow Demand – the rate of water flow, at a required pressure and for a specified duration, that is necessary to control a major fire. Fire flow demand is calculated based on the Fire Underwriters Survey (FUS) document *Water Supply For Public Fire Protection – A Guide to Recommended Practice*. Fire flow demand is a critical design parameter for determining maximum network flows, verifying minimum system pressures, sizing pipes/pumps/treatment works between fire storage and customers/fire hydrants. Refer to Section 21.4.2 – Fire Flow Demand for more information.

Table 21-1 Small Systems Peaking Factors (sourced from Ontario Design Guidelines 2008)

Population	Dwelling Units Serviced	Night Minimum Hour Factor	Maximum Day Factor (MDF)	Peak Hour Factor (PHF)
30	10	0.1	9.5	14.3
150	50	0.1	4.9	7.4
300	100	0.2	3.6	5.4
450	150	0.3	3.0	4.5
500	167	0.4	2.9	4.3

The MDD and PHD may need to include consideration of outdoor water use (i.e. for gardening or cleaning). For outdoor water use, it should be assumed that a maximum of 25% of the homeowners could be using an outdoor tap at any one time, at a rate of 20 L/min for one hour per day. Where fire protection is provided, then this outdoor use need not be considered.

21.4.2 Fire Flow Demand

When deciding if a small system should be sized for fire flow, the following should be considered:

.1 Availability of an adequate supply of water;
.2 Additional capital and operating costs associated with such a system;
.3 Availability of an adequate fire department, fire service communication and fire safety control facility; and
.4 Alternatives to a piped communal fire facility such as residential sprinkler systems.

For small systems, the Designer should also consider that provision of fire flow can impact residual chlorine in the distribution system due to the need for increased pipe sizes and additional water storage volume.

A small system may often get fire protection from a neighbouring larger municipality if it falls inside a Fire Protection District. The Fire Underwriters Survey™ makes special provisions for classifying the level of fire protection in these cases.

21.4.3 Non-Residential Water Demand

Institutional and commercial flows should be determined by using historical records, where available. Where no records are available, the values in Table 21-2 should be used. For other commercial and tourist-commercial areas, an allowance of 28 $m^3/(ha{\cdot}d)$ average flow should be used to calculate ADD in the absence of reliable flow data.

Table 21-2 Typical Water Demands for Selected Commercial and Institutional Users

Type of Establishment	Maximum Daily Demand (L/d)
Boarding house (per boarder) **Additional kitchen requirements for non-resident boarders**	190 40
Camp: Construction, semi-permanent (per worker) Day, no meals served (per camper) Luxury (per camper) Resort, day and night, limited plumbing (per camper) Tourist, central bath and toilet facilities (per person)	 190 60 380 - 570 190 135
Factory (litres per person per shift)	60 - 135
Highway rest area (per person)	20
Hotel: Private baths (2 persons per room) No private baths (per person)	 190 190
Institution other than hospital (per person)	285 - 475
Laundry, self-serviced (litres per washing (per customer))	190
Motel: Bath, toilet, and kitchen facilities (per bed space) Bed and toilet (per bed space)	 190 155
Park: Overnight, flush toilets (per camper) Trailer, individual bath units, no sewer connection (per trailer) Trailer, individual baths, connected to sewer (per person)	 95 95 190
Restaurant: Toilet facilities (per patron) No toilet facilities (per patron) Bar and cocktail lounge (additional quantity per patron)	 40 12 10
School: Day, cafeteria, gymnasiums, and showers (per pupil) Day, cafeteria, no gymnasiums or showers (per pupil) Day, no cafeteria, gymnasiums or showers (per pupil)	 95 80 60
Service station (per vehicle)	50
Store (per toilet room)	1550
Worker: Construction (per person per shift) Day (school or offices, per person per shift)	 190 60

21.4.3.1 Campground Water Systems

The peak water usage rates in campgrounds will vary with the type of facilities provided (e.g. showers, flush toilets and clothes washers) and the ratio of these facilities to the number of campsites. A peak hour factor of 4 is recommended, and this factor should be applied to the average expected water usage at full occupancy of the campground.

21.4.3.2 Ski and Mountain Resorts

For ski and mountain resorts, the critical peak water demand period typically includes the two weeks over the winter holiday season. Maximum day demands should be considered for at least this entire period (14 consecutive days) and at 100% occupancy rate. Due to the timing of the peak demand period, the MDD is calculated without irrigation provisions. However, water demands for snow making may be applicable *(FLNRORD, 2012)*.

21.4.3.3 Summer Resorts

Golf and other summer use resorts differ from mainly winter use resorts in that the peak demand period typically occurs in the summer season. Therefore, irrigation demands for golf courses, park facilities and other irrigable areas need to be added to indoor demands to derive design parameters. Irrigation demands for golf courses should be determined by a qualified golf course designer. The use of reclaimed water following all applicable sewage regulations and health standards may be applied towards irrigation demands for golf courses and similar facilities *(FLNRORD, 2012)*.

21.4.4 Industrial and Agricultural Water Demand

Industrial water demands are often expressed in terms of water requirements per gross hectare of industrial development when the type of industry is unknown (e.g. new industrial parks). These demands will vary greatly with the type of industry, but common allowances to calculate ADD for industrial areas range from 35 $m^3/(ha{\cdot}d)$ for light industry, to 55 $m^3/(ha{\cdot}d)$ for heavy industry. Peak usage rates will generally be 2 to 4 times the average rate depending on factors such as the type of industry and production schedule. When the type of industry is known, discussions should be held with representatives of the industry to determine water requirements.

Agricultural water demands depend on several different parameters such as evapotranspiration, type of crop, number and type of animals serviced, size of area, soil types, the climatic zone which the Water Supplier is in, and irrigation efficiency. Reference should be made to the *Design Guidelines for Rural Residential Community Water Systems* (FLNRORD, 2012) for guidance on irrigation calculations.

21.5 Source Water Development

The Designer should demonstrate that an adequate quantity of water is available to meet the demands of the water supply system. Chapter 6 – Source Water should be reviewed for recommended best practices on source water selection. This section provides the Designer with information specific to source water development for small systems.

21.5.1 Surface Water

Subject to the source and the requirements of the regulator, a hydrology study by a professional hydrologist may be required to confirm water availability.

The reliable yield of the source, after the flow has been regulated by seasonal balancing storage, should be adequate to supply the maximum day demand during moderate dry periods. A moderate drought is considered to be a 7-day period with streamflow at 10-year drought levels (i.e. the lowest flow rate expected in a 10 year period).

21.5.1.1 Intakes

Intake works should be designed to optimize water quality, minimize maintenance and minimize adverse environmental impacts. They should not obstruct the passage of vessels in navigable waters.

Intakes should be sized to the ultimate capacity of the small system to limit disturbance to the aquatic environment. The capacity of the intake should be the MDD anticipated for the next 50 years. Screens should be easy to clean and designed to meet the requirements of the Department of Fisheries and Oceans regulations. If the flow rate is less than 150 L/s, the intake screens should be designed to meet the requirements set out in the *Freshwater Intake End-of-Pipe Fish Screen Guideline* by the Federal Department of Fisheries and Oceans (DFO).

Submerged intake pipes in rivers and lakes should be graded to prevent accumulation of gases and be adequately anchored and buried. Stream intakes should be sited in a stable reach of the channel, where erosion or deposition will not endanger the works and in such a way that the natural regime of the stream will not be upset. Provision should be made to remove sediment from the pipe by incorporating a back-flushing device. Intakes should also be protected from ice build-up.

Intake works should be protected against unauthorized persons and contamination from domestic, industrial or other harmful wastes or runoff. A fence with signage around the intake is recommended to deter unauthorized personnel. The intake works should be reasonably accessible in all seasons so that the intake can be regularly inspected.

21.5.2 Groundwater

Wells must be designed, located, constructed, tested and disinfected in accordance with the requirements of the Groundwater Protection Regulation (GWPR).Refer to Section 6.3 – Groundwater for more information.

Two wells are recommended, with at least one being capable of providing the MDD. The well(s) should be capable of sustaining the MDD continuously for 100 days without recharge by precipitation. Both wells should be on-line and alternating in use. If both wells cannot provide MDD, at least one day of storage should be provided. Where only a single well is available, provide backup power and shelf spares for the well pump.

21.5.2.1 Well Drilling

Well drilling should be completed by (or under the direct supervision of) a Qualified Well Driller (QWD) registered in British Columbia. The QWD will work in conjunction with (or be supervised by) a

Professional Geoscientist or Engineer registered in British Columbia. Drill cuttings should be collected at regular intervals to determine the depth, thickness and characteristics of aquifers and aquitards (confining layers).

A pumping test is required for each new production well. The objective of the test is to document the actual performance of the well (yield and water quality) and ideally, stress it beyond the desired capacity.

21.5.2.2 Well Location

Production wells should be fully accessible at all times using a statutory right of way written in favour of the Water Supplier. Well sites should not be subject to flooding and site grading should direct surface runoff away from the wellhead. Additionally, wellheads should be extended at least 300 mm above final ground elevation or 1 m above the 100-year flood level or the highest known flood elevation, whichever is higher. Additionally, well casing should extend above typical snow accumulation levels. Provincial regulations stipulate specific construction details for wellheads.

Well location should consider ease of future access for rehabilitation. Specialized well covers are available for cold climates. Electrical equipment, water treatment and disinfection can be incorporated into an adjacent (or centralized) enclosure. Kiosks in lieu of pump houses may be an acceptable alternative.

All wells, pump houses and kiosks should be located within a secure fenced area to prevent vandalism and unauthorized access.

Reference should be made to Chapter 6 – Source Water and the GWPR Handbook for well construction, set back and siting requirements.

21.5.3 Rainwater

Rainwater is defined as water collected from natural precipitation. It is typically harvested by collecting runoff from a catchment area/roof or a capture device designed to intercept rainwater, which is directed into a cistern or storage container, prior to treatment. When using rainwater as a source water, the *Guidance for Treatment of Rainwater Harvested for Potable Use in British Columbia* by the Ministry of Health and the *CSA Rainwater Harvesting Systems Standard* (CSA B805-18/ICC 805-2018) should be referenced. The Canada Mortgage and Housing Corporation (CMHC) *Guidelines for Residential Rainwater Harvesting Systems Handbook* provides additional considerations.

Table 21-3 provides general design considerations for rainwater harvesting systems.

Table 21-3 Rainwater Harvesting Water System Design Considerations (Sourced from Ministry of Health, 2020)

Design Considerations	Reasoning
Collection potential	Amount of available precipitation in the area.
Output demand	Required storage volume for intended use.
NSF/ANSI 61, NSF/ANSI 372, and NSF P151 materials (or third party certification)	Ensures materials adhere to minimum established health effects requirements for any chemical contaminants or impurities that are imparted to the water.
Air gap or backflow preventer	Prevent potential cross contamination with other water supply system(s).
Inlet pre-filter and inlet cover	Prevent entry of debris, roof contaminants and pests into water supply.
First flush diverter*	Reduce contaminants in the harvested water supply.
Food-grade plastic storage	Retains acidic nature of harvested rainwater which can inhibit microbial growth.
Covered or shaded storage	Retains cool temperatures of stored water which can slow microbial growth.
Calmed inlet	Brings oxygenated water to lower levels of tank, preventing stagnation and disturbance of debris at bottom of tank.
Floating intake	Extracts water from just below the surface, where it is cleanest.
Alarm systems	Systems to monitor, alert or shut-off supply when intake or output water quality standards are not being achieved due to power failure or other incidents.
Secured access	Prevents unauthorized access to water supply.

* A first flush diverter, as per Section 3.1 of the CSA/ICC *Rainwater Harvesting Systems* standard, is a device or method for removal of sediment and debris from collection surface by diverting initial rainfall from entry into the storage tank. *NSF/ANSI 61* provides further guidance on how to perform an effective flush. First flush diverters should be installed correctly and maintained regularly to work properly.

21.5.3.1 Quantity

In determining if rainwater is a suitable source water, the Designer should use rainfall data collected over many years, using monthly rainfall data. The size of the catchment area (the size of the roof being used) should be confirmed. The quantity analysis should also include a safety factor to account for potential climate change impacts. Rainfall may not be adequate during all parts of the year and may need to be supplemented with an alternative source (such as bulk filling the storage cistern or providing make-up water from a potable source with an air gap) during the dry season. A feasibility analysis for an alternative source should be conducted.

Figure 21-1 demonstrates how to calculate the volume of water that can be collected from a roof catchment, where the height is the estimated depth of rainfall.

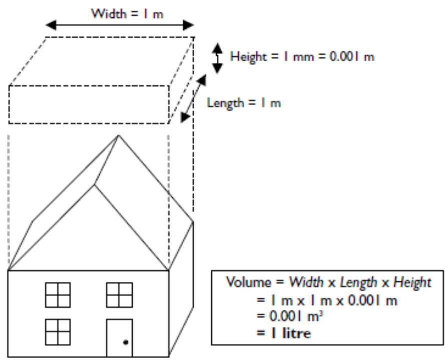


Figure 21-1 Rainwater Catchment Sizing (adopted from Guidelines for Residential Rainwater Harvesting Systems Handbook, CMHC)

For general considerations on small water system demand and system sizing, refer to Section 21.4 – Water Demand. Additional considerations for rainwater quantity forecasting and storage recommendations can be found in the CSA B805-18/ICC 805-2018 standard and the CMHC Handbook.

21.5.3.2 Quality

Rain is acidic and extremely low in dissolved solids and alkalinity. These properties could lead to increased leaching of contaminants from contact materials; therefore, all materials in contact with rainfall, including paints, linings, and coatings, should be certified under *NSF/ANSI 61 Drinking Water System Components – Health Effects* or *NSF P151 Certification of Rainwater Catchment System Components*. Corrosion control measures, such as pH adjustment, should also be considered.

Off-site and on-site contaminants may impact the water quality; as such, it is recommended that a risk identification and assessment is conducted as described in Section 4.4 of the *Guidance for Treatment of Rainwater Harvested for Potable Use*. Sampling should occur during the initial portion of a storm event following arid conditions.

Additionally, the material and cleanliness of the rainfall catchment will directly impact the quality of the water. Due to this, inclusion of a first flush diverter is recommended. Refer to Table 21-3 for more information.

21.5.3.3 Rainwater Harvesting Systems

A rainwater harvesting system is any system used to collect, convey, store, treat and distribute rainwater for use.

Rainwater catchment system design should consider the following:

.1 Smooth and impervious materials are the most efficient for conveying rainwater;
.2 Stormwater design guidelines should be referred to for determining the runoff coefficient of the catchment material;
.3 Systems should be protected against access from unauthorized persons;
.4 Gutters should have leaf screens to prevent debris from entering the system; and

.5 First flush diverters should be installed and maintained regularly.

The *CSA Standard B128.1/B128.2 Design and Installation of Non-Potable Water Systems/Maintenance and Field Testing of Non-Potable Water Systems* should also be referenced for rainwater storage guidance. The following should be considered when storing untreated rainwater:

.1 The inlets, outlets and overflows should have a screen;
.2 Provisions for ongoing inspection, water quality sampling, cleaning and maintenance should be incorporated into the design;
.3 Completely opaque storage should be used to store rainwater to prevent algae growth;
.4 Storage time, excessive stagnation times can adversely affect water quality;
.5 The storage should be accessible for bulk refills;
.6 Storage should be thermally resistant and a light colour to prevent temperature fluctuations in stored water;
.7 Storage tanks should not be placed directly under sanitary, waste or storm drains; and
.8 Storage should be covered and not located in direct sunlight.

21.6 Facilities

Small system facility design and construction should allow convenient, and safe access for removal and service of equipment. A simple layout should be used to minimize operational and maintenance procedures, consider operator health and safety, and limit system replacement costs. Facilities should be in compliance with the *BC Building Code*, the requirements of the *Workers Compensation Board* (WCB) and all other applicable codes, standards and regulations.

21.6.1 Facility Siting

The following should be considered when choosing the site of the facility:

.1 Operator safety, including proximity to high pressure watermains and pumped wells;
.2 Zoning and building code compliance and community acceptance;
.3 Noise pollution considerations if the system is likely to produce significant noise;
.4 Room for expansion;
.5 Operator access for equipment maintenance and operator safety, including space for equipment removal and crane or other lifting aid access;
.6 Reliable power supply and electrical distribution system capacity; and
.7 Geotechnical considerations, including soil stability, slope failure analysis, site drainage etc.

Refer to Chapter 4 – Climate Change Risk Assessment and Adaptation for considerations for the siting of a facility related to climate change.

21.6.2 Facility Design

The following should be considered when designing a facility for a small system:

.1 Provisions for future expansions: for example, providing additional room in the facilities, installing spare pump bases and blind flanges to simplify installation of future equipment;
.2 Provision of adequate space to enable access and working space for all equipment. This includes space required to maneuver tools and equipment necessary to perform the entire spectrum of operation and maintenance procedures. Aisle widths of minimum 1.0 m should be maintained (measured with doors and panel doors swung open) for access ways

throughout to the exit doors. The vertical clearance of the building interior should be 2.4 m minimum;

.3 Provide a wall-mounted thermostat-controlled unit heater to prevent freezing;

.4 Provide adequate ventilation to prevent excessive humidity and maintain safe environmental conditions. Ventilation rates should be based on achieving a minimum of two air changes per hour in unoccupied conditions. Chemical storage rooms should have at least 12 air changes per hour;

.5 A keyed lock should be installed on the door; and

.6 Provide hazard signage on the door to any room containing chemicals warning of the presence and hazard(s) of the chemicals.

21.6.3 Mechanical Equipment

The following should be considered for mechanical equipment for small systems:

.1 PVC and copper piping are the most common process pipe material used in small systems;

.2 All internal piping should be properly supported, using corrosion resistant materials;

.3 Unions and isolation valves should be installed at pressure tanks, booster pumps, and other equipment to allow for equipment removal;

.4 All equipment should be secured to concrete housekeeping pads a minimum of 100 mm above the floor;

.5 The following should be installed:

a. ASME pressure relief valve(s) properly sized based on flow;
b. A totalizing source meter inside the facility;
c. House keeping pads, if pressure tanks are used;
d. Raw water and treated water sampling taps in an accessible location at least 200 mm above the floor;
e. Drain port and valving at low points in internal piping systems. If chemicals are used, drain valves should be contained within sumps;

.6 Pressure gauges should be positioned so they are easily readable;

.7 Gate or ball valves, especially for suction isolation, may be used for smaller sized piping;

.8 Mechanical piping should minimize the number of high points. Any high points in the piping system should be equipped with an automatically operated air release valve; and

.9 Operator facilities, including drinking water and sanitary facilities, may lead to a significant increase in cost for small systems. Where such facilities may be available elsewhere, the Designer should consult with the Owner to determine whether such facilities are necessary.

21.7 Treatment

21.7.1 General Treatment Guidance

Section 6 of the DWPA states that subject to the regulations, a water supplier must provide, to the users served by its water supply system, drinking water from the water supply system that (a) is potable water, and (b) meets any additional requirements established by the regulations or its Operating Permit.

Section 5 (2) of the DWPR states that drinking water from a water supply system must be disinfected by a water supplier if the water originates from (a) surface water, or (b) groundwater that, in the opinion of a drinking water officer, is at risk of containing pathogens.

Table 21-4 provides some general guidance specific to treatment and disinfection for small systems. The respective chapters or guideline documents should be reviewed for detailed guidance on the design of any of the systems.

Table 21-4 General Treatment Guidance for Small Systems

Treatment Method	Small System Treatment Design Considerations	Reference Chapter
UV disinfection	UV reactors should be validated using an accepted validation protocol or certified to NSF Standard 55 Class A. NSF Standard 55 Class B certified systems should not be used for the production of potable water.	Chapter 11 – Disinfection and Ministry of Health *Guidelines for Ultraviolet Disinfection of Drinking Water*
	The NSF Standard 55 does not require Class A certified systems to have a UV monitor. However, provision of a UV monitor and a reference UV sensor may be required to allow for monthly calibration verification checks of the duty UV sensor.	
	For a surface water or GARP water supply, filtration should be installed upstream of UV disinfection to pre-treat water entering the UV reactor, or the water supply should receive a filtration exemption from a Drinking Water Officer.	
	Water entering a UV reactor should meet water quality requirements specified by the UV equipment manufacturer or values listed in the *Guidelines for Ultraviolet Disinfection of Drinking Water*. Pre-treatment or on-site determination of the combined aging and fouling factor may be required.	
Clarification	Plate settlers are the preferred method of clarification; check that the hydraulic upflow rate conforms to the *Design Guidelines* based on projected area.	Chapter 7 – Pre-sedimentation, Coagulation, Flocculation and Clarification
	Static mixers are the preferred type of flash mixer. A water flushing feature should be provided for the flash mixer. The flash mixer design should consider the full range of anticipated flowrates.	
	Hydraulic flocculation is the preferred option. The flocculation design should consider the full range of anticipated flowrates and in cold-water conditions.	
	Check to ensure flushing lines, drains and sludge disposal features are included in the design for flocculators and clarifiers.	
Chemical systems	Sizing a chemical system for a small system is dependent on site-specific criteria, including: 1. Demand of the system; 2. Reserve volume requirements and typical chemical delivery lag times; 3. The rate of decay of the chemical; and	Chapter 13 – Chemical Application

Treatment Method	Small System Treatment Design Considerations	Reference Chapter
	4. Emergency scenarios, where a delay in delivery may affect the availability of the chemical.	
Filtration	Slow sand filters are the preferred method of filtration for small systems if filtration is deemed necessary, followed by rapid rate gravity filters. Pressure filters may be used for contaminant-specific treatment but will not be awarded pathogen log reduction credits.	Chapter 8 – Filtration
	Cartridge filters are suitable low maintenance systems for small systems where the water quality permits their use. Bag filters may be used for pretreatment but will not be awarded pathogen log reduction credits.	
Softening	Confirm if there are other raw water sources available before proceeding with softening. Hardness levels of 250 mg/L or less may not require softening. Where hardness levels exceed this level, consider split treatment and blending. Only ion-exchange softening should be considered.	Chapter 15 – Parameter Specific Treatment
	Check TDS and sodium levels in treated water following ion exchange with respect to health concerns.	
	Check whether pre-treatment is required, particularly if there are high levels of turbidity, iron and manganese in the raw water supply.	
	Review disposal of spent brine during regeneration.	
	Ensure that there is sufficient storage space for sodium chloride in the plant design.	
	Ensure that construction materials are compatible with the aggressive nature of salt.	
Aeration	Consider aeration for taste and odour removal, air stripping of volatile organics, hydrogen sulphide and pre-oxidation of iron and manganese if the pH of the water permits a weak oxidant.	Chapter 9 – Aeration
	A natural or forced draft air system may be used.	
	All aerators should be housed in a heated and protected enclosure.	
	Noise control features should be included if a forced air system is used.	
	Consider a range of water temperatures due to effect on contaminant removal efficiency.	
	Conduct a pilot study to determine the minimum volumetric air to water ratio if there is limited past performance data available.	
	Use corrosion resistant materials in the construction of all aeration equipment.	

Treatment Method	Small System Treatment Design Considerations	Reference Chapter
Iron and manganese control	Recommended oxidizing methods are aeration and the use of strong oxidizers such as sodium hypochlorite. Potassium permanganate is not recommended for small system iron and manganese removal plants due to the safety concerns and the complexity of working with the chemical. The pH of the raw water is a significant parameter for the type of treatment selected.	Chapter 15 – Parameter Specific Treatment
	Cation ion exchange methods are acceptable if the combined raw water iron and manganese levels do not exceed 0.3 mg/L.	
	Silica sand with a blend of manganese dioxide is an acceptable filtration media combination; a minimum cap of 400 mm of anthracite should overlay the silica sand/pyrolusite blend. The filter should act as a contactor and filter, and operational targets should be based on previous pilot work.	
	Check hydraulic loading rates of filters and backwash rates.	
pH adjustment	pH adjustment of water is required if the alkalinity is too low to ensure effective coagulation for subsequent treatment or the water is so aggressive that serious corrosion could occur in the distribution piping or in internal plumbing systems in homes.	Chapter 7 – Pre-sedimentation, Coagulation, Flocculation and Clarification
	When using potassium permanganate, depending on the required dose, solutions should be made up in batch modes using storage tanks with mixers and a metering pump for small feed systems.	
	Where coagulation and flocculation treatment are required, the preferred form of conditioning is through the use of a limestone contactor.	
	Check empty bed contact time and configuration of tank shape, ensure that each contactor has a drain for de-watering.	
	Pre-screening is required for all contactors and a bypass is necessary for blending raw water with conditioned water.	
	Include provision for an efficient air wash and water backwash to remove inert material and sediments from the contactor basin.	
	Where pH adjustment is required for reducing corrosivity, only then alternative treatment solutions should be reviewed such as the addition of sodium hydroxide (caustic soda) or sodium carbonate (soda ash).	Chapter 12 – Internal Corrosion Control
	Final sodium content in water should be tested. If sodium levels are increased to >20 mg/L, it is recommended that the water supplier should inform users, as this could affect those on sodium-restricted diets.	

Treatment Method	Small System Treatment Design Considerations	Reference Chapter
Arsenic removal	Where levels of arsenic exceed 0.025 mg/L in any one raw water sample, an alternative raw water source should be sought. If there is no other source available, then arsenic treatment should be applied to reduce the levels below 0.010 mg/L.	Chapter 15 – Parameter Specific Treatment
	At least two arsenic removal treatment processes should be piloted to determine the optimal form of treatment.	
	Review life cycle costs and complexity of operation in the feasibility analysis. Ensure that accurate test equipment is available to readily measure and record arsenic levels in the raw and treated water.	
	Arsenic is most easily removed when it exists in the pentavalent form, which is related to the pH of the water. Several treatment methods are available; however, the following methods should be explored: 1. Adsorption onto a granular ferric oxide medium; 2. Reverse osmosis; 3. Alum chemical coagulation and sedimentation with pre-oxidation as necessary; and 4. Activated alumina. Removal and handling of rejects and waste streams generated from the treatment process should be assessed for efficiency and safety.	
Residuals Handling and Treatment	Sanitary waste should receive treatment and should be discharged directly to a sanitary sewer system or on-site waste treatment facility.	Chapter 14 – Waste Residuals Handling and Treatment
	Aluminum hydroxide sludge can be discharged to a lagoon. If lagoons/holding ponds/drainage pits are used for filter backwash water, ensure that lagoons are an adequate distance from treatment facilities and do not pose a contamination risk to treated water or the surrounding surface water/aquifer.	
	For sedimentation/clarification residuals, if sufficient land area is available, natural freeze/thaw methods may be considered for dewatering sludge.	
	When designing filtration systems for small systems, backwash volume requirements should be evaluated and considered when designing storage and/or raw water pumping.	
	Waste recycling may be possible, but not if the presence of algae, protozoa, or elevated disinfection by-products is likely.	
	Waste filter backwash water from iron and manganese removal plants can be discharged to a lagoon or a community sanitary sewer (if the Owner of the wastewater system gives approval).	

21.7.2 Pre-engineered Systems

Pre-engineered water treatment systems are especially applicable for small systems where individually engineered treatment plants may not be cost effective. Pre-engineered water treatment components are normally modular process units which are pre-designed for specific process applications and flows. Multiple units may be installed in parallel to accommodate larger flows. Factors to be considered when selecting a pre-engineered water treatment component include:

.1 Demonstration of treatment train/unit process effectiveness under all raw water conditions and system flow demands, especially for winter conditions and northern waters;
.2 Means to optimize treatment and flexibility to handle the process residuals generated;
.3 Sophistication of equipment and the reliability and experience record of the proposed treatment equipment/controls;
.4 Operational oversight that is necessary (i.e. full time operators or automation plan);
.5 Formal commissioning, start-up and follow-up training, operations and maintenance manuals and troubleshooting available from the manufacturer or contractor;
.6 Manufacturer warranty, replacement guarantee and confirmation of meeting performance objectives;
.7 Timely availability of parts and service; and
.8 Estimated annual operating and maintenance costs.

Pre-engineered treatment components may require significant engineering and integration with other components, such as chemical feed, system hydraulics and storage systems, building, electrical and plumbing systems, as well as instrumentation and controls.

21.7.3 Disinfection

Chapter 11 – Disinfection and Chapter 13 – Chemical Application should be reviewed for the design of disinfection systems. The *Guidelines for Pathogen Log Reduction Credit Assignmen*t should be referred to for calculating CT and the assignment of pathogen log reduction credits. The following provides guidance unique to small systems.

21.7.3.1 Chlorination

Chlorination is a recommended method of disinfection for small systems: it is a relatively straightforward chemical addition for primary disinfection, and can also be used to provide a measurable disinfectant residual in the distribution system for secondary disinfection (which helps protect against pathogen contamination and reduces pathogen regrowth in distribution system piping).

The following should be considered in the design of a chlorination system for a small system:

.1 The building should have signs on the doors indicating the presence and hazard of chlorine in the room and in the building;
.2 Chlorine liquid, powder, or pellets should meet AWWA standards and *NSF/ANSI Standard 60 Drinking Water Treatment Chemicals – Health Effects*;
.3 If secondary disinfection is being considered, chlorination equipment should be capable of maintaining a minimum free chlorine residual concentration of 0.2 mg/L in treated water;
.4 CT should be calculated and reviewed against CT requirements to ensure that the system can achieve the targeted pathogen log reduction (refer to the *Guidelines for Pathogen Log*

Reduction Credit Assignment);

.5 Chlorination may be accomplished with a sodium or calcium hypochlorite solution. The use of 6% sodium hypochlorite is the preferred method of chlorination for small systems because it is easy to operate and maintain, and it reduces the need for dilution;

.6 The use of gas chlorination facilities is not recommended for small systems. Gas chlorination should be restricted to water systems that have Operators who are available to operate and maintain the equipment on an ongoing basis, and who are trained and equipped to handle any emergency;

.7 The feed system should be interlocked with the plant system controls to shut down automatically when raw water flows stop;

.8 Spare parts should be made available to replace parts subject to wear and breakage;

.9 The facilities should include a cool, dark, dry, clean, above ground and vented area for the storage and for the use of hypochlorite disinfectant. The facilities should also include covered make-up and feed solution tanks;

.10 Chemical-contact materials and surfaces should be resistant to the aggressiveness of the chemical solution;

.11 Corrosive chemicals should be introduced in such a manner as to minimize the potential for corrosion;

.12 Chemicals that are incompatible should not be stored or handled together;

.13 All chemicals should be conducted from the feeder to the point of application in separate pipes; and

.14 Gravity may be used where practical.

21.7.3.2 Chlorine Feed Pumps

The following should be considered in the design of chlorine feed pumps:

.1 Positive displacement type solution feed pumps should be provided;

.2 Pumps should be capable of operating at the required maximum rate against the maximum head conditions found at the point of injection;

.3 To avoid air locking, small diameter suction lines should be used with foot valves and degassing pump heads;

.4 There should be 100% redundancy in the design of the chlorine feed equipment;

.5 A flooded suction line should be considered for all positive displacement pumps;

.6 Feeders will be able to supply the necessary amounts of chemicals at an accurate rate throughout the range of feed at all times;

.7 Chemical feeders should be as near as practical to the feed point;

.8 Chemical feeders and pumps operate at no lower than 20% of the feed range unless two fully independent adjustment mechanisms, such as pump pulse rate and stroke length, are fitted when the pump operates at no less than 10% of the rated maximum;

.9 The chlorine solution injector/diffuser should be compatible with the point of application to provide a rapid and thorough mix with all the water being treated. The center of a pipeline is the preferred application point. If a variable frequency drive well pump is used, the chlorine dose should be proportional to the flow;

.10 Rubber, PVC, polyethylene, or other materials recommended by the Chlorine Institute should be used for chlorine solution piping and fittings. Nylon products are not acceptable for any part of the chlorine solution piping system; and

.11 The initial feeder pumps should be designed for twice the maximum day demand and at the maximum calculated dosage rate that will be achieved at the plant five years following pump installation. Every five years the feeder pumps should be replaced with pumps of higher capacity to meet twice the maximum day demand that will be reached five years after installation at the maximum dosage rate. The capacity of the replacement feeder pumps would increase until the plant design capacity has been reached. This will allow the pumps to operate more effectively during the low flows the plant will experience during the initial years of plant operation. The replacement of the feeder pumps every five years with greater capacity pumps should be included in maintenance cost estimates for the treatment facilities.

21.7.3.3 Siphon Control

Liquid chemical feeders should be such that chemical solutions cannot be siphoned into the water supply by:

.1 Ensuring discharge at a point of positive pressure;
.2 Providing vacuum relief;
.3 Providing a suitable air gap or anti-siphon device; or
.4 Other suitable means or combinations as necessary.

21.7.3.4 Storage Tanks

Liquid chemical storage tanks should consider the following:

.1 Have a liquid level indicator;
.2 Have an overflow and a receiving basin or drain capable of receiving accidental spills or overflows without uncontrolled discharge. A common receiving basin may be provided for each group of compatible chemicals that provides sufficient containment volume to prevent accidental discharge in the event of failure of the largest tank;
.3 Have ventilation that discharges to the outside atmosphere above grade and remote from air intakes;
.4 Should be stored in compatible liquid storage tanks or the original shipping containers; and
.5 Reusable sodium hypochlorite storage containers should be reserved for use with sodium hypochlorite only and should not be rinsed out or otherwise exposed to internal contamination.

21.7.3.5 Calcium Hypochlorite Puck Feeder and Wellhead Pellet Chlorinators

A calcium hypochlorite puck feeder should be installed in accordance with the manufacturer recommendations.

Similarly, wellhead pellet chlorinators should be installed in accordance with manufacturer recommendations and should have a frost-free hydrant or other means of evacuating the well volume to ensure source water samples may be collected. Frost-free hydrants should be located more than 8 m from the wellhead. Consideration should be given to lining of the well casing if iron precipitation is expected.

21.7.4 UV Disinfection

Ultraviolet (UV) disinfection may be used for small systems. When UV disinfection is used, filtration and/or chemical disinfection might also be necessary depending upon the type of source water being treated and the recommended minimum pathogen log reduction. The *Guidelines for Ultraviolet Disinfection of Drinking Water* and *Guidelines for Pathogen Log Reduction Credit Assignment* should be referenced for further guidance.

21.7.5 Residuals Handling

The Designer should consider the preferred method for management of residual waste streams generated by the proposed water treatment processes based on capital and operational costs, operational complexity, and potential environmental impacts. Consideration to on-site management and treatment or off-site disposal should be informed by the availability of and proximity to off-site facilities such as centralized collection and wastewater treatment systems. For smaller waste volumes, use of on-site storage and truck hauling may be permissible.

The Designer should make provisions for proper handling and disposal of all water treatment plant wastes such as sanitary and laboratory wastes, clarification sludge, softening sludge, iron sludge, filter backwash water, backwash sludge, brines (including softener and ion exchange regeneration wastes and membrane and reverse osmosis wastes), spent filtration media or cartridges, hazardous wastes (including radioactive and arsenic waste), and all other potential process waste streams that may impact the environment and drinking water supply.

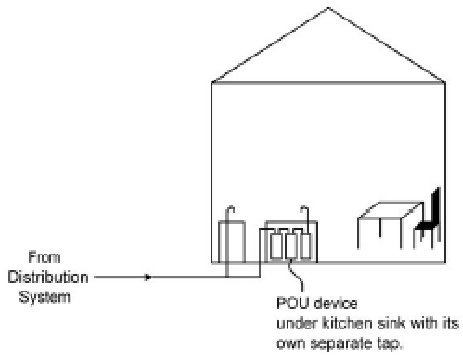
For discharge to a ditch, the Designer should refer to the *British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife & Agriculture* by the Ministry of Environment and Climate Change Strategy and the *Canadian Council of Ministers of the Environment (CCME) Canadian Environmental Quality Guidelines* for discharge water quality guidance.

Backflow prevention measures must be provided as needed to protect the public water supply when designing residuals handling facilities. Reference should be made to Chapter 14 – Waste Residuals Handling and Treatment.

21.7.6 Point-of-Entry and Point-of-Use

For some small systems, it can be cost-prohibitive to provide centralized water treatment to the water users. In this case, a point-of-entry (POE) or a point-of-use (POU) treatment system may be considered. Section 3.1(a) of the DWPR states that a small system is exempt from section 6 of the Act (water supply systems must provide potable water), if (1) each recipient of the water from the small system has a point of entry or point of use treatment system that makes the water potable, and (ii) the water supplier ensures that the location of non-potable water discharge and non-potable water piping are identified by markings that are permanent, distinct and easily recognized.

A POE system is a treatment device applied where drinking water enters a house or building to make the water distributed throughout the house or building potable. A POU system is a treatment device applied to a single tap to make the water distributed by that tap potable. POU devices do not treat all the water taps in a house, and therefore there is a potential health risk to household residents who consume untreated water. As a result, pathogen log reduction credits should not be assigned to POU devices.



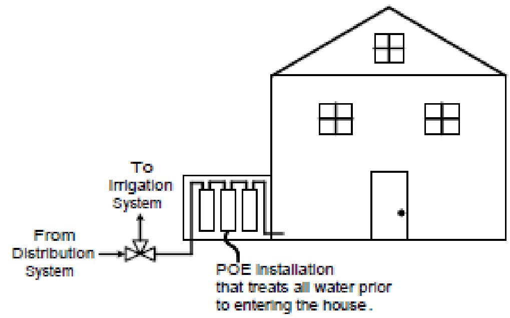


Figure 21-2 Typical Point of Use and Point of Entry systems (sourced from USEPA Point-of-Use or Point-of-Entry Treatment Options for Small Drinking Water Systems)

Before a POE/POU treatment system is implemented, it is important to have a long-term plan in place to manage the risks of using such a system. The administrative tasks required to manage a successful POU or POE treatment strategy, including customer outreach, scheduling, and record keeping, can be time-consuming. The costs associated with these additional tasks should be considered when implementing a POU or POE treatment strategy. As these units are installed and maintained on customer property, frequent interaction with homeowners is required and good public relations are important. A POU user agreement should identify the roles, responsibilities and accountabilities of the Water Supplier and residential consumer.

When considering a POE/POU approach the following should be considered:

- .1 Homeowner buy-in is required to install the equipment on homeowner properties;
- .2 Access by the Water Supplier is required for maintenance and sampling;
- .3 Ownership of the equipment should be agreed upon prior to installation; and
- .4 Treatment objectives should be pre-determined.

Refer to the *Application of "Point of Entry" and "Point of Use" Water Treatment Technology in British Columbia* and the USEPA's *Point of Use or Point of Entry Treatment Options for Small Drinking Water Systems* for further information.

Table 21-5 provides commonly used POE and POU treatment technologies for various water quality parameters of concern. For further guidance on the treatment technology, refer to the respective chapter.

Table 21-5 Commonly Used POE and POU Treatment Technologies

Water Quality Parameter of Concern	Technology	Operational Issues	Chapter Reference
Iron, manganese, copper	Ion exchange	Fouling, competing ions	Chapter 15 – Parameter Specific Treatment
Silica, fluoride, phosphate, sulphate, dissolved iron and manganese	Adsorptive media	Interfering/competing ions	Chapter 15 – Parameter Specific Treatment

Water Quality Parameter of Concern	Technology	Operational Issues	Chapter Reference
Hardness, iron, manganese	Reverse osmosis	Fouling	Chapter 15 – Parameter Specific Treatment
Iron, manganese	Aeration	Fouling, scaling	Chapter 15 – Parameter Specific Treatment
Organics, multiple SOCs or VOCs present	Granular activated carbon	Competing ions	Chapter 15 – Parameter Specific Treatment
Microbial pathogens	UV disinfection	Sleeve fouling and bulb replacement	Chapter 11 – Disinfection

21.7.6.1 POE/POU Certification

When selecting a POU or POE treatment device, the unit should be appropriately certified. The following NSF standards apply to POE/POU devices:

.1 Standard 42: Drinking Water Treatment Units — Aesthetic Effects;
.2 Standard 44: Cation Exchange Water Softeners;
.3 Standard 53: Drinking Water Treatment Units — Health Effects;
.4 Standard 55: Ultraviolet Microbiological Water Treatment Systems (Class A);
.5 Standard 58: Reverse Osmosis Drinking Water Treatment Systems; and,
.6 Standard 62: Drinking Water Distillation Systems.

21.8 Transmission and Distribution

Refer to Chapter 16 – Transmission and Distribution for detailed recommendations. The following design considerations should be made for small systems:

21.8.1 Watermain Layout

Wherever feasible, the Water Supplier's components should be installed within public rights-of-way, existing or planned. Distribution system layouts are usually designed in one of three configurations, including arterial-loop systems, grid systems and tree systems. Tree systems often have more dead ends, and this type of layout is generally not recommended, except for where the alternative would result in significant stagnation times for small systems. Where dead-end sections cannot be avoided, they should be designed with means to provide adequate flushing.

21.8.2 Provision for Cleaning of Rural Pipelines

A means to easily facilitate the cleaning of the interior surface of watermains (such as installing launch points for conducting swabbing or pigging of watermains) should be provided in rural long-distance low-flow pipelines where it is not practical to obtain adequate cleaning with flushing alone.

For small diameter mains without hydrants, swab launching and retrieval ports should be included in the design if swabbing is contemplated in the operations. Valve specifications also need to be considered. Butterfly valves cannot be used as they will trap the swab.

21.8.3 System Pressure

The system should be designed on the basis of providing a minimum pressure of 140 kPa (20 psi) at ground level at all points of the system under all conditions of flow, including MDD plus critical fire flow conditions. Individual PRV devices can be used at each house when the pressure in the house plumbing exceeds 550 kPa (80 psi).

The maximum pressures in the distribution system should not exceed 700 kPa (100 psi) to avoid damage to household plumbing and unnecessary water and energy consumption. When static pressures exceed 700 kPa (100 psi), pressure reducing devices should be provided on mains or service connections in the distribution system. Typically, PRV stations with fire flows should have a fire line PRV for large flows and a smaller bypass PRV for regular flows.

All waterworks should be designed to withstand the maximum working pressure plus the transient pressure to which they may be subjected.

21.8.4 Velocity

Pipe diameters should be such that a flushing velocity of 0.8 m/s can be achieved for cleaning and flushing procedures.

The maximum flow velocity at PHD should not exceed 1.5 m/s. The maximum flow velocity during MDD and fire flow conditions should not exceed 3.0 m/s.

21.8.5 Pipe Material

The pipe materials selected for particular applications should be able to withstand, with a margin of safety, all combinations of loading conditions to which they are likely to be exposed. Water pipes and fittings made of the following materials and meeting the applicable quality standards and specifications set by the AWWA are acceptable for buried applications: PVC, HDPE, ductile iron and reinforced concrete.

21.8.6 Diameter

Pipe sizing should be designed to maintain the appropriate flow and pressure. Minimum diameter should be 150 mm for fire flows and 75 mm for systems without fire flow. Smaller diameters may be considered for dead end mains where water demands are very low, provided the maximum flow velocity remains below 3 m/s and system pressures are maintained per Section 21.8.3 – System Pressure.

21.8.7 Burial Depth

The minimum pipe cover should be greater than the depth of frost penetration but minimum 1.0 m. Minimum pipe cover at ditch crossings should be 0.6 m. Non-buried pipes should be housed in a heated enclosure or protected from freezing through heat tracing.

21.8.8 Services

The minimum diameter of service pipes should be 20 mm and should conform to *AWWA Manual of Water Supply Practices M22 – Sizing Water Service Lines and Meters*. Service pipes should be constructed of standard materials such as PVC, HDPE or copper and should conform to the *AWWA Standard C800: Underground Service Line Valves and Fittings*.

21.8.9 Fire Hydrants

Fire hydrants should only be installed on watermains capable of supplying fire flows. Hydrant leads should have a minimum diameter of 150 mm and should incorporate a hydrant isolation valve. In areas where the groundwater table will rise above the hydrant drain port, the drain port should be plugged.

Flushing hydrants or flushing devices are recommended for small systems that are not designed for fire flows. Flushing devices should be sized to provide flows of at least 0.8 m/s.

21.8.10 Valves

Line valves should be placed throughout the distribution system at each intersection's downstream pipe branch and at maximum linear intervals of 150 m. Where systems serve rural areas and where future development is not expected, the valve spacing should not exceed 2 km. All valves should conform to the relevant AWWA standards. Thrust blocking or other restraints should be provided for online valves.

21.8.11 Separation

Refer to Section 16.6 – Separation Distances for guidance on proper separation of water pipes to possible sources of contamination such as sewers, storm drains, etc.

21.8.12 Air Relief Valves: Valve Meter and Blow-Off Chambers

21.8.12.1 Air Relief Valves

At high points in watermains where air can accumulate, provisions should be made to remove the air by means of hydrants or air relief valves. Automatic air relief valves should not be used in situations where flooding of the maintenance hole or chamber may occur.

21.8.12.2 Air Relief Valve Piping

The open end of an air relief pipe from automatic valves should be extended to at least 300 mm above grade and provided with a 16-mesh screened, downward-facing elbow. The pipe from a manually operated valve should be extended to the top of the pit. Use of manual air relief valves is recommended wherever possible. Discharge piping from air relief valves should not connect directly to any storm drain, storm sewer or sanitary sewer.

21.8.12.3 Chamber Drainage

Chambers, pits or manholes containing valves, blow-offs, meters, or other such appurtenances to a distribution system, should not be connected directly to any storm drain or sanitary sewer. Such chambers or pits should be drained to the surface of the ground where they are not subject to flooding by surface water, or to absorption pits underground (if soil conditions are suitable) at sites not subject to a seasonally high groundwater table.

21.8.13 Truck Loading and Truck Delivery Stations

Water loading stations present increased risk since the fill line may be used for filling both potable water vessels and other tanks or contaminated vessels. To prevent contamination of both the public supply and potable water vessels being filled, the following should be considered when designing water loading stations:

.1 There should be no risk of backflow to the public water supply;
.2 A device should be installed on the fill line to provide an air break and prevent a submerged discharge line; and
.3 The piping arrangement should prevent contaminant transfer from a hauling vessel to others subsequently using the station.

Vehicles and mechanisms for trucked water should conform to the relevant federal and provincial standards and regulations for water vending.

21.9 Treated Water Pumping

Refer to Chapter 18 – Pumping Facilities for complete guidance on pump stations. The following should be considered when designing a treated water pump station for a small system:

.1 For systems that provide inline treatment or do not require treatment, the source water supply pump (e.g. groundwater well or raw water intake supply pumps) may act as the treated water supply pump;
.2 At least two pumps are recommended, with each pump designed to deliver a minimum of the design maximum day demand at the desired head;
.3 Where substantial seasonal variations in flow exist, it may be necessary to provide duplicate flow and pressure pump control systems – one suitable for very low flows (which normally occur in winter) and one suitable for the design maximum flows;
    a. It may be desirable to provide a third domestic high lift pump with this pump sized to meet a lesser flow than the maximum day requirement of the system. In this case, this pump should be designed to lead during lower flow conditions;
    b. During normal periods of domestic demand, the smaller pump would provide an adequate supply of water, while the large pumps would only operate to accommodate higher demands or in the event of failure of the lead pump; and
.4 Where fire protection is to be provided via the communal water supply/distribution facility, an additional high lift pump (fire pump) should be provided and the capacity of that pump should be at least equal to the minimum required fire flow.

In instances where the water balancing storage is not provided in the distribution system, it may be necessary to provide pump(s) sized for the peak domestic demand, or maximum day demand plus the required level of fire flow. In this case, pump operations should be controlled by pressure switches. Pressure regulating valves (PRVs) with pressure relief to the storage reservoir should be provided for relief of high pressures in the distribution system. In many instances, it may be advisable to provide pressure tanks for pump control in order to minimize the number of start-stop cycles (and hence, wear and tear) on the pumping equipment.

21.9.1 Pump Stations

Pump stations should be located and designed accessible, preferably above ground, protected against service interruptions due to fire, flood, lightning strike, vandalism or other hazards, and adjacent to vehicular access. A fence should be provided around the building. Reference should be made to Chapter 5 – Facility Recommendations and Section 21.6 – Facilities for further guidance on facility design.

All pump stations should be designed to provide 100% system capacity redundancy in order to meet the critical design demands in a situation where any one pump is out of service.

The building floor should be sloped and provided with a floor drain sufficiently designed to keep the station functioning and accessible during emergency spill/leakage situations. Aisle widths of minimum 1.0 m should be maintained (measured with doors and panel doors swung open) for access ways throughout to the exit doors. The vertical clearance of the building interior should be 2.4 m minimum.

Electrical controls and panels should be located away from the wet installations but where visual access can be maintained. In larger stations, electrical controls and panels can be located in a separate dry room or compartments with visual access to the installations through glass windows.

Where a well pumping station and chlorine and/or chemical system is to be installed, the preferred layout is for a three-room building which includes a separate chlorine or chemical room, pump room and electrical room. Access to the chlorine or chemical room will be from the outside only with a viewing window between the pump room and chlorine or chemical room. Figure 21-3 below provides a general layout for a chlorination system.

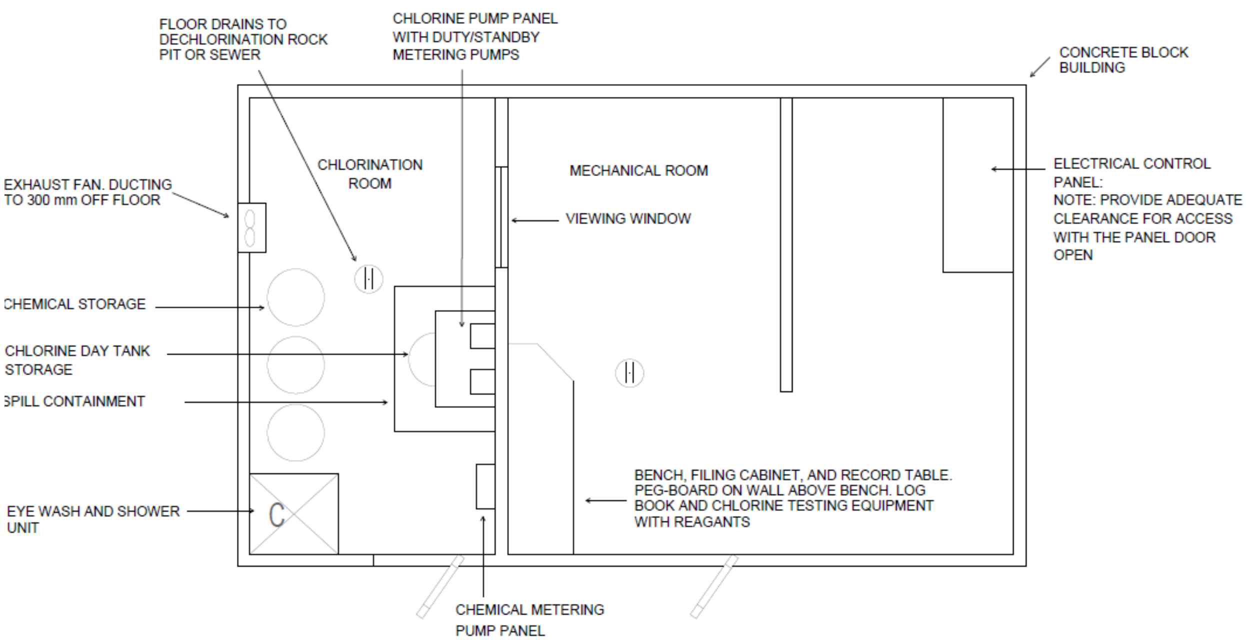


Figure 21-3 Example well pump, chlorine and control building layout, showing details for chlorination room (sourced from Design Guidelines for First Nations Water Works, ISC, 2006)

21.9.2 Controls

The following controls may be provided between the storage reservoir and the high lift and low lift pumping equipment:

.1 A high-level set-point to shut down the low lift pumps when the water level in the reservoir has reached a pre-determined high level; and
.2 Level sensors to operate the low lift pumps sequentially.

Pressure switches should be mounted on the discharge line from the high lift pumping station to operate the high lift pumping equipment sequentially. A pressure gauge should also be installed on the discharge of each high lift pump. Elapsed time meters should be provided for all high lift pumps. Output from the high lift pumping station to the distribution system should be metered with a recording type flow meter. The start-stop operation of the fire pump should be arranged between the Owner and the local fire officials. Indication of the operation status of the pump should be relayed to a central operating point where 24-hour surveillance is provided.

21.10 Treated Water Storage

In sizing storage facilities for small systems, the Designer should also consider the importance of maintaining water quality, preventing freezing during the winter and excessive warming of the water during the summer. Consideration should also be made for the addition of new reservoir cells or tanks in the future, should demand change.

For complete direction on the design of water storage see Chapter 17 – Water Storage. For sizing of the storage, municipal bylaws should be referenced, in the absence of municipal bylaws the Designer can consider the following:

If fire flow is not being provided the following should be considered in sizing treated water storage for small systems:

.1 The minimum effective storage to be provided should be the average day demand flow;
.2 Appropriate allowances for lawn watering and in-plant process requirements, as needed should be added to the minimum volume; and,
.3 An additional emergency storage volume of 25% of the volume calculated for .1 and .2.

If fire flow is being provided, the following should be considered when designing treated water storage for small systems:

1. The minimum volume of the storage facility should be increased by an amount equal to the fire flow demand; and
2. The allowance for lawn watering is not needed where fire protection is provided via the communal water supply and distribution system.
3. An additional emergency storage volume of 25% of the volume calculated for .1 and .2.

21.10.1 Reservoirs

The following should be considered when designing a reservoir for a small system:

.1 Tank materials in contact with potable water should meet *NSF/ANSI Standard 61 Drinking Water System Components – Health Effects*;

.2 Leakage testing and disinfection per accepted standards, such as *AWWA C652 Disinfection of Water Storage Facilities*;

.3 Overflows:

   a. Designed and installed overflow pipe with atmospheric discharge or other suitable means to prevent cross connection contamination;
   b. Overflows should be covered with a 24-mesh non-corrodible screen or mechanical device, such as a flap valve or duckbill valve, to keep animals, insects or other contamination sources out of the reservoir;
   c. Overflows should have a capacity greater than the maximum reservoir influent rate;
   d. Dechlorination should be provided at each overflow;
   e. Designed and installed drain facilities that drain to daylight;

.4 Reservoir roof:

   a. Reservoir roof atmospheric vent, with a non-corroding 24-mesh insect screen;
   b. Watertight roof;
   c. The slope of the reservoir roof should be at least 2% and drained;

.5 Hatches:

   a. Locking mechanism on each point of access into the reservoir;
   b. Weatherproof, insect-proof access hatch and vent;

.6 Accessories:

   a. Reservoir isolation valve(s), which permit isolating the tank from the water system;
   b. Smooth-nosed sample tap on the tank side of the isolation valve;
   c. Access ways and ladders necessary to provide access for safe maintenance;

.7 Inlet and outlet:

   a. A silt-stop on the outlet pipe to keep sediment from entering the distribution system;
   b. Separate inlet and outlet pipes that facilitate a positive circulation of water within the reservoir;

.8 Controls:

   a. High, low-level and overflow alarm system that directly notifies operations personnel; and
   b. A low-level set-point to shut-off the high lift and fire pumping equipment when the water level in the reservoir drops to a pre-determined low level.

21.10.2 Hydropneumatic Tanks

Hydropneumatic tanks are used in small closed systems to maintain acceptable system pressures without the need for frequent stops and starts of the pumps. They should only be used in very small systems.

When considering the use of hydropneumatic tanks, the Designer should consider the implications of loss of pressure in the distribution system in the event of a power outage or pump failure (i.e. the need to issue a boil water advisory). Hydropneumatic tank storage should not be used for chlorine contact or fire protection purposes; fire flows typically by-pass the pressure tanks. The Designer should also consider the impacts of changes in pressure on the operation of the fire pump(s).

Hydropneumatic tanks should meet applicable American Society of Mechanical Engineers (ASME) code requirements. The maximum allowable working pressure should be marked on each tank.

21.11 Electrical

All new electrical installations should be inspected and approved by the local Electrical Inspector. Reference should be made to Chapter 19 – Electrical. Each electrical system should have:

.1 A kilowatt-hour meter owned by the electric utility;
.2 A service switch (circuit breaker type) that allows the whole of the electrical system to be disconnected from the supply;
.3 A surge protector on the main service;
.4 Power distribution and control equipment for the pumps;
.5 Adequate lighting for safe access and maintenance;
.6 Adequate heat and ventilation;
.7 Control system for monitoring and operation of equipment;
.8 A Supervisory Control and Data Acquisition System (SCADA) for larger or more sophisticated water systems (multiple reservoirs and/or multiple pump stations); and
.9 A standby generator if utility power in the area is determined to be unreliable or at the least, provision for a portable standby power generator connection.

21.11.1 Pumped System Electrical Considerations

The electrical system for pumps, either raw or treated, should have the following controls:

.1 Adjustable motor circuit interrupter for short circuit protection;
.2 Magnetic contactor which incorporates an adjustable, manually re-settable, overload protection relay to monitor the motor current and shut down the pump if the current exceeds the motor manufacturer's recommended values;
.3 Hands-off automatic control selector switch;
.4 Elapsed time meter to total the hours of operation of the pump;
.5 Green indicator light which turns on when the pump is running;
.6 Control power-on light to allow the operator to determine if power is available;
.7 Red alarm indicator light which turns on to indicate pump trouble;
.8 Single phase protection for three phase systems;
.9 Amp meter and phase switch (optional); and
.10 Manual control/override for testing purposes and to allow for equipment to run in case of failure of automatic control systems.

Single phasing, which can cause motor burnout, often results when one of the electric utility's distribution lines are broken and the other phases remain energized. A motor might continue to run when this occurs, although it cannot be started. Higher-than-normal current and overheating of the motor can result. Overload protectors are generally designed to provide single phase protection. The Designer should confirm that the protector selected is adequate or should provide a separate voltage-sensing type of relay to detect loss of one or more phases and shut down the motors.

A "lead-lag" pump-sequence manual selector switch or an automatic control alternator should be installed to even out the wear of pumps of similar size in a multiple-pump installation, instead of leaving a particular pump in the leading (first started) control position.

Multiple pump systems should have controls designed for time-delayed automatic restarting of the pumps which ensures staggered starting of the pumps after a power outage. This will avoid low voltage which could result in motor overheating, or magnetic controllers and relays dropping out (i.e. failing to maintain their contacts closed).

To reduce inrush currents during pump starts, pumps/motors of 7.5 kW or 10 hp or more should be controlled through a soft starter or a variable frequency drive (VFD). Soft starters should not be used to slowly ramp down pump motors during pump stops (soft stops). For water hammer mitigation during pump stops, VFDs should be used.

A well pump should be provided with a protection device that will shut it off in the event that the well water level drops below a level that will adversely affect the pump operation. A number of methods are available to perform this protective function. A red alarm light requiring manual resetting should be provided to draw attention to the problem if it occurs. All other pumps should be provided with protective devices that will shut them off if there is a loss of water supply to the pump.

For booster pumping systems that do not include balancing storage, pumps should be controlled in a manner that does not adversely affect pump operation pump life and that does not consume excessive electrical energy.

21.11.2 Standby Power

The frequency and length of power outages and the treated water storage capacity and drawdown rate of reservoirs are factors determining the need for standby electric generators (diesel or gas engine driven). A standby system should meet all codes and standards as specified in Chapter 19 – Electrical.

If standby power is required, it should be provided by means of an emergency standby generator set. The Designer should refer to the *AWWA Emergency Power Source Planning for Water and Wastewater* publication.

21.11.3 Reservoir Control

Reservoir level control systems should use either loop-powered pressure transmitters or loop-powered ultrasonic transmitters. These devices can provide a remote level indication at the pump station and can provide operating levels for several pumps as well as high and low reservoir alarms. Any changes to operating levels can be made at the pump house. The high-level alarm should override individual pump controls to shut off all pumps. Each level transmitter in any reservoir, holding tank or wet well that receives pumped flows should be backed up by a mechanical float switch set at a High High Level just before the overflow level. This float switch should override any pump controls, shut off all pumps and trigger an alarm.

21.12 Monitoring

A Water Supplier must monitor its drinking water source, the water in its system and the water it provides for the parameters, and at the frequency, established by the Drinking Water Protection

Regulation (see DWPR Schedules A and B) and by its Operating Permit. In addition to these parameters, there are also recommended monitoring criteria for pathogen log reduction credit assignment based on the type of treatment processes used; refer to the *Guidelines for Pathogen Log Reduction Credit Assignment* for more details.

Refer to Chapter 22 – Water Quality Monitoring for further guidance on the water quality monitoring that should be undertaken by a Water Supplier to confirm the continued supply of potable water and that treatment units are performing as designed.

21.13 Distribution System Water Quality

Distribution system water quality can pose particular challenges for small water systems. Proper planning during design is integral, otherwise infrastructure upgrades are often required to mitigate water quality issues. The following Table 21-6 provides an overview of common water quality issues noted in distribution systems, possible causes and possible remediation actions.

Table 21-6 Adverse Water Quality Causes and Actions (sourced from Small System Operation and Maintenance Practices, FCM 2005)

Adverse Water Quality Result	Possible Causes	Possible Course of Action
Disinfection by-products (THMs or HAAs)	• Inadequate water treatment (organic matter). • Excessive detention time. • Excessive chlorine use. • High pH. • Inappropriate chlorine injection location.	• Remove naturally occurring organic matter through enhanced treatment. • Use an alternative primary disinfectant or add ammonia after sufficient contact time to create chloramines. • Optimize pH adjustment for balance of corrosion control and DBP production. • Obtain assistance from a water quality expert. • Properly operate storage facilities to ensure adequate turnover of water. • Properly operate distribution systems (e.g. routinely flush mains). • Consider design changes to system (e.g. loop mains).
Low disinfectant (Cl_2) residual	• Inadequate disinfection dosage/residual. • Poor source water quality (high DOC—dissolved organic carbon). • Inadequate water treatment. • Excessive detention time. • Contaminant intrusion. • Poor maintenance and repair practices.	• Check dosing system for leaks, pump problems, or other issues. • Check concentration of raw chemical for degradation. • Increase chlorine dosage. • Flush/swab distribution system. • Implement biofilm control program. • Properly operate storage facilities to ensure adequate turnover of water. • Properly operate and repair distribution systems.

Adverse Water Quality Result	Possible Causes	Possible Course of Action
	• Poor distribution system design. • Aging distribution system. • Pipe contamination due to poor transportation, handling, storage, and installation practices. • Degraded chemical from excessive storage times.	• Rehabilitate/replace watermains. • Use appropriate disinfection procedures for new mains and repairs. • Install chlorine booster stations or add ammonia to create chloramines (which are weaker oxidants but last longer in the distribution system). • Deliver pipes with end caps to reduce contamination during installation. • Consider design changes.
Lead and copper	• Internal corrosion. • Unstable water. • Low pH in water.	• Implement corrosion control treatment. • Raise treated water pH. • Raise treated water alkalinity (e.g. use a limestone contactor or add soda ash). • Consider alternate corrosion inhibitors (i.e. phosphates). • Flush distribution system regularly. • Educate public. • Rehabilitate/replace water services. • Use approved materials.
pH instability and scale formation	• Inadequate water treatment. • Excessive detention time in cement pipes. • Unstable water.	• Take daily water samples and test pH. • Control blending of water sources. • Properly operate distribution systems. • Consider design changes (i.e. pH adjustment, ion exchange). • Obtain expert assistance if the problem cannot be readily resolved.
By-products of linings and coatings	• Leaching of chemicals. • Unstable water.	• Use approved materials. • Properly cure linings and coatings.
***E. coli* or total coliform detection in treated water**	• Chlorination/disinfection system failure. • Wellhead contamination. • Distribution system contamination/backflow. • False positive sample.	• Perform all regulatory notifications/actions. • Check disinfection system. • Increase chlorine residual. • Flush system. • Retest using approved testing procedures. • Ensure water samplers are properly trained on collection methods. • Eliminate source of contamination. • Shut down source and use alternate/backup supply.

Adverse Water Quality Result	Possible Causes	Possible Course of Action
		• Ensure positive pressure in distribution system. • Identify and eliminate any potential back pressure sources. • Clean storage tanks at least every other year; more frequent cleaning may be required depending on water source and level of treatment.
Waterborne disease outbreak	• Inadequate water treatment. • Inadequate primary disinfection. • Contaminant intrusion. • Backflow from non-potable sources. • Poor maintenance and repair practices. • Main breaks. • Inadequate disinfection of new mains/equipment. • Terrorism or vandalism.	• Maintain adequate disinfectant residual. • Maintain positive water pressure in distribution systems (try to maintain above minimum 140 kPa). • Implement backflow prevention program. • Control valve and hydrant operations. • Properly operate storage facilities. • Properly operate and repair distribution systems. • Use appropriate disinfection procedures for new mains and repairs. • Provide security. • Consider design changes.
Worms/insects	• Inadequate water treatment. • Poor design/construction/ maintenance of storage facilities. • Inadequate flushing/ swabbing program. • Problems with water intake in unfiltered systems.	• Properly operate storage facilities to ensure adequate sealing at all times. • Regularly monitor, inspect, and maintain storage facilities. • Check water intake for holes through or around screens. • Consider design changes.
Taste and odour	• Poor raw water quality. • Inadequate water treatment. • High disinfectant concentrations. • Excessive detention time. • Blending of chlorinated and chloraminated water. • Stratification during ammonia addition for chloramination. • Internal corrosion of unlined mains.	• Upgrade treatment—select optimal process. • Maintain adequate disinfectant residual. • Flush/swab watermains. • Properly operate storage facilities. • Properly design and operate distribution systems. • Implement corrosion control treatment. • Rehabilitate/replace watermains. • Use approved materials that are suitable for Canadian climate (e.g. paint). • For chloramination, ensure ratio of chlorine to ammonia is maintained.

Adverse Water Quality Result	Possible Causes	Possible Course of Action
	• Leaching chemicals from watermain linings.	• Ensure linings are cured properly in new watermain construction. • Consider design changes. • Consider treatment changes (e.g. GAC).
Colour and appearance	• Inadequate water treatment. • Excessive detention time. • Internal corrosion of unlined mains. • Sediment in watermains.	• Control blending of water sources (i.e. conduct testing before mixing water from different sources). • Implement corrosion control treatment. • Rehabilitate/replace watermains. • Eliminate dead ends. • Flush/swab watermains.

22 Water Quality Monitoring

22.1 General

This chapter describes water quality monitoring that should be considered as part of water system design to confirm the continued supply of potable water and that treatment units are performing as designed, and provides design considerations to facilitate water quality monitoring.

Minimum monitoring requirements are prescribed in the *Drinking Water Protection Act* and the Drinking Water Protection Regulation. The Designer should be familiar with the operational requirements of the DWPA and DWPR. The water system design should enable the Water Supplier to effectively demonstrate compliance and meet good industry practice. Consideration should also be given to on-site record keeping (paper and/or digital).

The DWPA, Section 11, sets out the following monitoring requirements:

(1) In the case of a prescribed water supply system, the water supplier must:
  a. monitor its drinking water source, the water in its system and the water it provides for the parameters, and at the frequency, established by the regulations and by its operating permit,
  b. have the sampling required for that monitoring carried out in accordance with the regulations and the directions of the drinking water officer, and
  c. have the analyses required for that monitoring carried out in accordance with the regulations, through laboratories that meet the requirements established by the regulations and by individuals who are qualified in accordance with the regulations.

(2) The laboratory conducting monitoring analyses under this section must report the results in accordance with the regulations to the drinking water officer and, subject to the regulations, to the water supplier.

(3) A water supplier must ensure that a laboratory conducting monitoring analyses under this section is aware of the applicable standards and requirements established by the regulations and the operating permit for the water supply system.

Similarly, Section 8.0 of the DWPR sets out the following monitoring analysis requirements:

(1) A water supplier must transport water samples to a laboratory in accordance with the procedures established by a drinking water officer.

(2) For the purpose of section 11 (1) of the Act, a water supplier must monitor for total coliform bacteria and, effective April 1, 2006, *Escherichia coli*, at the frequencies set out in Schedule B of this regulation.

(3) Despite subsection (2), a drinking water officer may establish different sampling frequencies for a water supplier.

(4) A laboratory carrying out monitoring analyses for the parameters referred to in subsection (2) must be approved in writing by the Provincial Health Officer.

(5) If requested to do so by a drinking water officer, a laboratory must provide to the drinking water officer, the water supplier, or both, a report.
  a. listing all water samples sent by the water supplier to the laboratory, and
  b. describing, for all samples analyzed, the results of any monitoring analyses for total coliform bacteria and *Escherichia coli*.

Schedule B
Frequency of Monitoring Samples for Prescribed Water Supply Systems

Population Served by the Prescribed Water Supply System:	Number of Samples Per Month:
less than 5,000	4
5,000 to 90,000	1 per 1,000 of population
more than 90,000	90 plus 1 per 10,000 of population in excess of 90,000

On-going source water monitoring plays an important role in the multi-barrier approach to safe drinking water. Monitoring at the intake or raw water source allows plant operators to modify treatment if water quality fluctuates due to seasonal or unexpected changes, and to ensure that raw water remains within the design range for the treatment system. It also allows Water Suppliers to monitor their source water quality to assess if existing source water quality issues change or if new hazards emerge, and respond accordingly.

In addition to the bacteriological water quality monitoring requirements specified under Schedules A and B of the DWPR, additional monitoring or testing of source water may be required, as determined on a case-by-case basis. For example, depending on the source water and treatment, source water monitoring may be required for systems with filtration exemption or pathogen log reduction credits assigned for subsurface filtration. Refer to the following Ministry of Health guidance documents for additional information:

.1 *Drinking Water Treatment Objectives (Microbiological) for Surface Water Supplies in British Columbia*;
.2 *Drinking Water Treatment Objectives (Microbiological) for Ground Water Supplies in British Columbia*; and
.3 *Guidance Document for Determining Groundwater at Risk of Containing Pathogens (GARP)*.

22.2 Analytical Recommendations

All samples should be collected, preserved, stored, handled and analyzed in accordance with:

.1 The *Standard Methods for the Examination of Water and Wastewater*, published by the American Public Health Association, the American Waterworks Association and the Water Environment Federation (APHA/AWWA/WEF), as amended or replaced from time to time; or
.2 A method authorized in writing by the Drinking Water Officer.

Where on-line instruments are specified or allowed, such instruments should be kept maintained and calibrated in accordance with the manufacturer's recommendations.

22.2.1 Turbidity Analysis

The turbidity of filtered water is usually measured online or through grab samples in the field using the nephelometric method. Nephelometry determines turbidity using the intensity of scattered light measured by a detector that is at 90° to the incident light source. Table 22-1 lists seven nephelometric methods for the measurement of turbidity in drinking water that have been developed by consensus standards organizations or are approved by recognized organizations. Designers should specify turbidimeters that conform to one of the methods discussed below when monitoring drinking water, selecting an option which is appropriate to the range of turbidity expected in source and treated water.

Table 22-1 Recognized Analytical Methods for Measuring Turbidity in Drinking Water (sourced from Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Turbidity)

Method	Reference	Description
APHA/AWWA/WEF Standard Method 2130B	APHA et al. (2012)	Tungsten lamp at 2200-3000 K and one or more perpendicular detectors (and filters) with spectral response peak of 400-600 nm; light path less than or equal to 10 cm. Applicable measurement range of 0 to greater than 1000 NTU.
USEPA Method 180.1 Rev. 2.0	USEPA (1993)	Tungsten lamp at 2200-3000 K and one or more perpendicular detectors (and filters) with spectral response peak of 400-600 nm; light path less than or equal to 10 cm. Applicable measurement range of 0-40 NTU.
ISO 7027	ISO (1999)	Tungsten lamp (and filters), diode or laser as radiation source at 860 nm (or 550 nm if sample is colourless) with a perpendicular detector and aperture angle of 20-30°. Two applicable measurement ranges are available, depending on the method selected. The diffuse radiation method has a range of 0-40 FNU. The attenuation of radiant flux has a range of 40-4000 FAU.
GLI Method 2	GLI International Inc. (1992)	Two perpendicular 860 nm light sources alternately pulse each 0.5 seconds, and two perpendicular detectors alternately measure "reference" and "active" signals. Applicable measurement range of 0-40 NTU. The method allows dilution for measurement of samples above 40 NTU.
Hach FilterTrak Method 10133 Rev. 2.0	Hach Company (2000)	Laser diode at 660 nm at 90° to detector/receiver (light path less than or equal to 10 cm), which may use photomultiplier tube and fibre optic cable. Applicable measurement range of 0-5000 mNTUs (0-5.0 NTU).

Method	Reference	Description
ASTM D6698-07	ASTM International (2007)	This method is for the online measurement of turbidity below 5 NTU in water. A variety of instrument technologies may be used in this method, including the design features listed in the methods above. Applicable measurement range of less than or equal to 0.02-5.0 NTU.
ASTM D6855-10	ASTM International (2010)	This method is for the static measurement of turbidity below 5 NTU in water. A variety of instrument technologies may be used in this method, including the design features listed in the methods above. Applicable measurement range of less than or equal to 0.02-5.0 NTU or FNU.

As the turbidity of a sample can change due to changes in temperature, particle flocculation and precipitation, samples should be analyzed immediately. It is recommended that samples be analyzed using on-site turbidimeters in the treatment plant or portable turbidimeters when conducting sampling in the field. It is not recommended to measure turbidity in an offsite laboratory.

22.3 Laboratory Testing Equipment

For facilities that have on-site laboratories, the following should be considered depending on the water quality parameters that are being treated at the water treatment plant:

- .1 General considerations for the design of laboratory facilities are listed in Section 5.4 – Monitoring Equipment and Laboratory Facilities;
- .2 Public water supplies which chlorinate should have test equipment for determining both free and total chlorine residual by methods in *Standard Methods for the Examination of Water and Wastewater;*
    - Chlorine residual test equipment should be provided and should be capable of measuring residuals to the nearest 0.1 mg/L. All systems should use the DPD colourimetric method or amperometric titration. It is recommended that systems using the DPD method have a digital readout and self-contained light source;
- .3 Surface water supplies should provide equipment/facilities for microbiological testing of water from both the treatment plant and the distribution system; however, these samples are for operational monitoring, not to meet regulatory monitoring requirements. Depending on the regulatory sampling schedule, deviations from this recommendation may be allowed;
- .4 Surface water and GARP supplies, as well any source water with a filtration exemption, should have a nephelometric turbidimeter meeting the requirements of Table 22-1;
- .5 Each surface water treatment plant using flocculation and sedimentation, including those with lime softening, should have a pH meter, jar testing equipment, and titration equipment for both hardness and alkalinity;
- .6 Each ion exchange softening plant and lime softening plant treating only groundwater should have a pH meter and titration equipment for both hardness and alkalinity;

.7 Each iron and/or manganese removal plant should have test equipment capable of accurately measuring iron to a minimum of 0.1 mg/L, and/or test equipment capable of accurately measuring manganese to a minimum of 0.05 mg/L;
.8 If fluoridation or fluoride removal treatment is implemented, equipment should be provided for measuring the quantity of fluoride in the water;
.9 WTPs which feed polyphosphates and/or orthophosphates should have test equipment capable of accurately measuring phosphates from 0.1 to 20 mg/L;
.10 Where the process treatment involves reduction of raw water colour, equipment should be provided to determine both true and apparent colour in the raw water and treated water quality ranges;
.11 Where UV treatment is used, a UVT spectrophotometer (capable of measuring transmission of 254 nm wavelength light through a path length of 1 cm of water) with an accuracy within +/- 2% should be provided. Refer to the Ministry of Health's *Guidelines for Ultraviolet Disinfection of Drinking Water* for more detailed information; and
.12 Jar testing equipment should be provided to evaluate modifications to coagulation/flocculation/clarification treatment processes and chemical dosages at the bench scale. If DAF is used at the WTP, specialized jar testing equipment for bench-scale DAF should be obtained. The Designer should provide the initial jar test settings that reflect plant operations as part of the design process. This should include the mixing speed, mixing times, and chemical injection sequences.

Additionally, the following general equipment should be considered for the laboratory:

.1 Spectrophotometer;
.2 Glassware appropriate for preparing reagents and analysis (e.g. pipettes, beakers, volumetric flasks graduated cylinders, Erlenmeyer flasks);
.3 Deionized water source;
.4 Thermometer;
.5 Fume hood if required for specific reagents or water quality testing specific to the facility; and
.6 Analytical balance to 0.1 mg accuracy.

22.4 Treatment System Monitoring

Water treatment facilities should be designed to provide equipment for monitoring, notification and recording that demonstrates the treatment processes are operating reliably, meeting performance objectives, and comply with the treatment requirements set out in the drinking water system's Operating Permit. Treatment system monitoring may consist of a combination of grab sampling, online analyzers, and local and remote condition alarming/notification. Equipment and system monitoring are a key component of the multi-barrier approach to ensure the supply of clean, safe and reliable drinking water and provide an effective tool for early identification of potential treatment process or equipment performance issues.

The scope of the monitoring should be developed based on recommendations from the Drinking Water Officer, the size and complexity of the treatment processes, remoteness and operational response times, skill level of operations staff, level of equipment and system redundancy, and the Water Supplier's standard practice. Consideration should also be given to meeting warranty requirements and monitoring the performance of new equipment.

For source/raw water quality monitoring, additional discussion can be found in Section 6.1.3 – Source Water Quality.

Refer to Chapter 20 – Instrumentation and Controls for details on the requirements of specific monitoring equipment, especially to Section 20.3 – Instrumentation for instrumentation selection and design.

22.4.1 Water Quality Parameters

Generally, any parameters that are targeted in the treatment process should be monitored. Table 22-2 identifies recommended water quality monitoring parameters for source water/raw water and various treatment processes.

Table 22-2 Monitoring Parameter for Specific Treatment Systems

Process	Recommended Water Quality Monitoring Parameters
Source Water/Raw Water	• The specific parameters to test and frequency of sampling should be selected on a source-by-source basis and should consider the source water type, proximity to potential contaminant sources, current and anticipated land use in the source area, and effects of changing climate conditions. Table 6-1 (see Section 6.1.3 – Source Water Quality) lists recommended parameters for raw water assessment which may be carried through to regular monitoring.
Coagulation/Flocculation	• pH • Streaming current • Zeta potential • Alkalinity
Sedimentation	• Effluent turbidity
Solids Contact Clarifiers	• Turbidity • pH following clarification
Proprietary Clarifiers	• Instrumentation for proprietary clarifiers including ballasted flocculation and dissolved air flotation should be provided per manufacturer recommendations and should include effluent turbidity
pH Adjustment	• pH
Rapid Media Filtration	• Filter effluent particle counts • pH • Turbidity of the influent, effluent and filter-to-waste per filter
Membrane Filtration	• Instrumentation should be provided per manufacturer recommendations. • Turbidity, integrity test (and optionally, particle count) on each individual filter train effluent

Process	Recommended Water Quality Monitoring Parameters
Slow Sand Filtration	• Turbidity
Cartridge Filtration	• Turbidity
Clearwell	• Free chlorine residual • Fluoride residual (if fluoridation is practiced) • pH • Turbidity
Contact Time	At locations where contact time needs to be calculated: • Free chlorine residual • pH • Turbidity • Water temperature
Treated Water	• Free chlorine residual • Colour • Fluoride residual (if system fluoridates) • Monochloramine (if system uses chloramination) • pH • Water temperature • Turbidity
UV Systems	Refer to the *Guidelines for Ultraviolet Disinfection of Drinking Water* • UVT (if required for dosing strategy) • Water temperature (inside vessel)
Residuals Treatment	• Turbidity • TSS • pH
Filter Backwash Recycled Water	• pH • Turbidity

22.4.2 Sample Taps

Designers should provide sample taps before treatment to assess the source water quality, and after treatment but before entering the distribution system. Designers should provide additional sample taps at intermittent points in more complex treatment plants to help in process control, verify on-line analyzers, and assess specific treatment processes.

Designers should locate source sample taps upstream far enough to avoid influence from downstream chemical injection. Designers should locate sample taps for treated and partially treated water after added chemicals mix completely. Because turbulent flow conditions can dislodge pipe scale or entrain air, avoid sample taps in turbulent flow locations, such as near valves, elbows, tees and flanges. Also, avoid tapping the bottom or top of the pipe, which can introduce sediment or air. Sample probes or quills are recommended to collect samples from the centre of the pipe.

Sample taps should be smooth nosed without any internal or external threads to reduce the risk of microbial contamination or aeration of the sample. Aeration can change the pH or result in loss of chlorine residual so that the sample is not representative of the water in the pipe.

22.5 Distribution System Water Quality Monitoring

Water Suppliers should monitor and report on distribution water quality and designs should incorporate means to readily monitor water quality. The DWO should be consulted to confirm the location, frequency, and parameters that need to be sampled.

The key parameters that are commonly considered to be indicators of water quality in terms of public health are:

.1 Chlorine residual (free and total);
.2 *E. coli* (as an indicator of fecal contamination);
.3 Total coliform; and
.4 Disinfection by-products (such as THMs, HAAs, etc.).

Useful parameters from an operational perspective include:

.1 Ammonia, nitrate, nitrite (if chloramination is used);
.2 Turbidity;
.3 Flow; and
.4 Pressure.

For monitoring of lead, refer to the *Guidelines on Evaluating and Mitigating Lead in Drinking Water Supplies, Schools, Daycares and Other Buildings,* by Ministry of Health for guidance on sampling objectives and protocols and Chapter 12 – Internal Corrosion Control. Other routine sampling and monitoring parameters can include the following:

.1 pH;
.2 Temperature;
.3 Alkalinity;
.4 Conductivity;
.5 Colour;
.6 Taste and odour parameters as required;
.7 Iron and manganese, as required;
.8 Soluble metal stemming from pipe material (e.g. lead, iron, copper);
.9 Corrosion inhibitors (if used); and
.10 Fluoride (if used).

23 References

10 State Standards (Water Supply Committee of the Great Lakes). 2006. Recommended Standards for Water Works.

10 State Standards. 2018. Recommended Standards for Water Works

Aboriginal Affairs and Northern Development Canada (now Indigenous Services Canada, ISC). 2014. First Nations On-reserve Source Water Protection Plan.

ACI 350.3/350R. Seismic Design of Liquid Containing Concrete Structures, and Commentary.

ACI 350/350R. Code Requirements for Environmental Engineering Concrete Structures.

ACWWA. 2020. Water Supply Guidelines, Draft 2.

Agriculture and Agri-Foods Canada. 2006. Diversion of Water from Surface-Water Sources Through Infiltration Galleries.

Allwood J.M. et al. 2014. Glossary. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

ANSI Z358.1. 2014. Emergency Eyewash and Shower Equipment.

APHA et al. 2012. Standard methods 2130: Turbidity. In: Standard Methods for the Examination of Water and Wastewater. 22nd edition.

Assembly of First Nations (AFN), 2008. Climate Change and Water: Impacts and Adaptations for First Nation Communities.

ASTM. 2010. Standard Test Method for Determination of Turbidity Below 5 NTU in Static Mode.

ASTM. 2007. Standard Test Method for On-line Measurement of Turbidity Below 5 NTU in Water.

Atlantic Canada Water Works Association. 2004. Atlantic Canada Guidelines for the Supply, Treatment, Storage, Distribution, and Operation of Drinking Water Supply Systems.

Atlantic Canada Water Works Association. 2012. Atlantic Canada Guidelines for the Supply, Treatment, Storage, Distribution, and Operation of Drinking Water Supply Systems.

Atlantic Canada Water Works Association. 2020. Atlantic Canada Water Supply Guidelines, Draft 2, March 2020.

AWWA. 2015. A100 Water wells.

AWWA. 2010. B102 Manganese Greensand for Filters.

AWWA. 1998. B112 Microfiltration and Ultrafiltration Membrane Systems.

AWWA. 2016. B600 Standard for Powdered Activated Carbon.

AWWA. 1997. C116 Protective Fusion-Bonded Coatings for the Interior and Exterior Surfaces of Ductile-Iron and Gray-Iron Fittings.

AWWA. 1997. C200 Steel Water Pipe, 6 In. (150 mm) and Larger.

AWWA. 1997. C210 Liquid-Epoxy Coatings and Linings for Steel Water Pipe and Fittings.

AWWA. 1996. C213 Fusion-Bonded Epoxy Coatings and Linings for Steel Water Pipe and Fittings.

AWWA. 1997. C300 Reinforced Concrete Pressure Pipe, Steel-Cylinder Type.

AWWA. 2018. C502 Dry Barrel Fire Hydrants.

AWWA. 1994. C509 Resilient-Seater Gate Valves for Water Supply Service.

AWWA. 1997. C510 Double Check-Valve Backflow Prevention Assembly.

AWWA. 1997. C511 Reduced Pressure Principle Backflow Prevention Assembly.

AWWA. 1999. C512 Air-Release, Air/Vacuum, and Combination Air Valves for Water and Wastewater Service.

AWWA. 2014. C651 Disinfecting Water Mains.

AWWA. 2002. C652 Disinfection of Water-Storage Facilities.

AWWA. 2003. C653 Disinfection of Water Treatment Plants.

AWWA. 2003. C654 Disinfection of wells.

AWWA. 2018. C655 Field Dechlorination.

AWWA. C670 Online Chlorine Analyzer Operation and Maintenance.

AWWA. C671 Online Turbidimeter Operation and Maintenance.

AWWA. 2012. C800 Underground Service Line Valves and Fittings.

AWWA. 2016. C900 Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 4 In. Through 60 In. (100 mm Through 1,500 mm).

AWWA. 1996. C901 Polyethylene (PE) Pressure Pipe and Tubing, ¾ In. (19 mm) Through 3 In. (76 mm), for Water Service.

AWWA. C904 Crosslinked Polyethylene (PEX) Pressure Tubing, ½ In. (13 mm) Through 3 In. (76 mm), for Water Service.

AWWA. 1999. C906 Polyethylene (PE) Pressure Pipe and Fittings, 4 In. Through 65 In. (100 mm Through 1,650 mm), for Waterworks.

AWWA. 1996. D100 Welded Carbon Steel Tanks for Water Storage.

AWWA. 1997. D102 Coating Steel-Water Storage Tanks.

AWWA. 1997. D103 Factory-Coated Bolted Caron Steel Tanks for Water Storage.

AWWA. D107 Composite Elevated Tanks for Water Storage.

AWWA. D108 Aluminum Dome Roofs for Water Storage Facilities.

AWWA. 1995. D110 Wire- and Strand-Wound, Circular, Prestressed Concrete Water Tanks.

AWWA. 1995. D115 Tendon-Prestressed Concrete Water Tanks.

AWWA. 1984. D120 Thermosetting Fiberglass-Reinforced Plastic Tanks.

AWWA. 1996. D130 Geomembrane Materials for Potable Water Applications.

AWWA. E102 Submersible Vertical Turbine Pumps.

AWWA. E103 Horizontal and Vertical Line-Shaft Pumps.

AWWA. F110 Ultraviolet Disinfection Systems for Drinking Water.

AWWA. G100 Water Treatment Plant Operation and Management.

AWWA. 1999. Iron and Manganese Removal Handbook.

AWWA, 2004. M7 Problem Organisms in Water: Identification and Treatment.

AWWA. M14 Recommended Practice for Backflow Prevention and Cross-Connection Control.

AWWA. M21 Groundwater.

AWWA. 2014. M22 Sizing Water Service Lines and Meters.

AWWA. M23 PVC Pipe Design and Installation.

AWWA. 2011. M37 Operational Control of Coagulation and Filtration Processes.

AWWA. 1999. M38 Electrodialysis and Electrodialysis Reversal.

AWWA. 2013. M42 Steel Water-Storage Tanks.

AWWA. 2006. M44 Distribution Valves: Selection, Installation, Field Testing & Maintenance.

AWWA. 2016. M51 Air Valves: Air Release, Air/Vacuum, and Combination.

AWWA. M53 Microfiltration and Ultrafiltration Membranes for Drinking Water.

AWWA. 2010. M57 Algae: Source to Treatment

AWWA. 2017. M58 Internal Corrosion Control Manual.

AWWA. 2015. M65 On-Site Generation of Hypochlorite.

AWWA. 2021 M71 Manual: Climate Action Plans – Adaptive Management Strategies for Utilities.

AWWA/WRF.2016. Managing Cyanotoxins in Drinking Water: A Technical Guidance Manual for Drinking Water Professionals.

AWWA. 2010. Manganese Greensand for Filters.

AWWA. 2015. Manganese Greensand for Filters.

AWWA. 2005. Ozone in Drinking Water Treatment: Process, Design, Operation, and Optimization.

AWWA. 2020. Per- and Polyfluoroalkyl Substances (PFAS).

AWWA and James Edzwald. 2000. Water Quality and Treatment.

BC Ground Water Association (BCGWA). 2017. Groundwater Protection Regulation Handbook, Version 1.

BC Ministry of Environment. 2016. Best Practices for Prevention of Saltwater Intrusion.

BC Ministry of Environment. 2016. Indicators of Climate Change for British Columbia 2016 Update.

BC Ministry of Environment. 2008. Living Water Smart.

BC Ministry of Environment. 2011. Water Applicant’s Agency Resource Guide.

BC Ministry of Environment & Climate Change Strategy and BC Ministry of Forests, Lands, Natural Resource Operations & Rural Development. 2020. Guidance for Technical Assessments in Support of an Application for Groundwater Use in British Columbia. ISBN 978-0-7726-7950-5.

BC Ministry of Environment & Climate Change Strategy and BC Ministry of Forests, Lands, Natural Resource Operations & Rural Development. 2019. Groundwater Protection Regulation: Guidance Manual.

BC Ministry of Environment, Lands and Parks; Ministry of Health and Ministry of Municipal Affairs. 2004. Well Protection Toolkit. ISBN 0-7726-5566-9.

BC Ministry of Environment & Climate Change Strategy. 2020. Source Drinking Water Quality Guidelines.

BC Ministry of Environment & Climate Change Strategy Protection & Sustainability Branch. 2017. Source Drinking Water Quality Guidelines.

BC Ministry of Health. 2007. Application of POE and POU Water Treatment Technologies in BC.

BC Ministry of Health. 2016. British Columbia Guidelines (Microbiological) on Maintaining Water Quality in Distribution Systems.

BC Ministry of Health. 2018. Decision Protocols for Cyanobacterial Toxins in B.C. Drinking Water and Recreational Water.

BC Ministry of Health. 2017. Drinking Water Officers' Guide.

BC Ministry of Health. 2001. Drinking Water Protection Act.

BC Ministry of Health. 2018. Drinking Water Protection Regulation.

BC Ministry of Health. 2015. Drinking Water Treatment Objectives (Microbiological) for Ground Water Supplies in British Columbia.

BC Ministry of Health. 2012. Drinking Water Treatment Objectives (Microbiological) for Surface Water Supplies in British Columbia.

BC Ministry of Health. 2017. Guidance Document for Determining Ground Water at Risk of Containing Pathogens.

BC Ministry of Health. 2020. Guidance for Treatment of Rainwater Harvested for Potable Use.

BC Ministry of Health. 2022. Guidelines for Pathogen Log Reduction Credit Assignment.

BC Ministry of Health. 2022. Guidelines for UV Disinfection of Drinking Water.

BC Ministry of Health. 2019. Guidelines on Evaluating and Mitigating Lead in Drinking Water Supplies, Schools, Daycares, and Other Buildings.

BC Ministry of Health. 2007. Planning and Implementation of POE and POU in Water Treatment Systems in BC.

BC Ministry of Health. 2017. Small Water System Guidebook.

BC Ministry of Health. Stop the Spread of Invasive Mussels.

BC Ministry of Health. 2014. Water Sustainability Act.

BC Ministry of Forests, Lands, Natural Resource Operations & Rural Development (FLNRORD). 2012. Design Guidelines for Rural Residential Community Water Systems.

BC Ministry of Forests, Lands, Natural Resource Operations & Rural Development. 2003. Dike Design and Construction Guide - Best Management Practices for British Columbia.

BC Ministry of Forests, Lands, Natural Resource Operations & Rural Development CPCN Application. 2020. Guide to Applying for a Certificate of Public Convenience and Necessity (CPCN).

BC Ministry of Transportation and Highways. 1995. Utility Policy Manual.

BC Ministry of Transportation and Infrastructure. Subdivision Approval & Servicing Bylaws.

BC Ministry of Water, Land and Air Protection Ecosystem Standards and Planning Biodiversity Branch. 2004. Standards and Best Management Practices for Instream Works.

BC Ministry of Water, Land and Air Protection Ecosystem Standards and Planning Biodiversity Branch. Change Approval for Work In and About a Stream.

BC Office of the Provincial Health Officer. 2019. Clean, Safe, and Reliable Drinking Water.

Boyle, J. et al. 2013. Climate Change Adaptation and Canadian Infrastructure, A review of the literature, The International Institute for Sustainable Development.

British Columbia Plumbing Code. 2018

Bush, E. et al. 2019. Canada's Changing Climate Report.

Canadian General Standards Board (CGSB). Standard CAN/CGSB 24.3-92 Identification of Piping System

Canadian Mortgage and Housing Corporation (CMHC). 2012. Guidelines for Residential Rainwater Harvesting Systems Handbook.

Compendium of Forest Hydrology and Geomorphology in British Columbia. 2010. BC Land Management Handbook 66, Chapter: 19.

CSA Group. 2011. Backflow Preventers and Vacuum Breakers.

CSA Group. 2012. Rainwater Harvesting Systems.

CSA Group. 2017. Selection and Installation of Backflow Preventers / Maintenance and Field Testing of Backflow Preventers

CSA Group. 2011. Water Cisterns.

Driscoll, F.G. 1986. Groundwater and Wells.

EGBC. 2020. Professional Practice Guidelines Developing Climate Change-Resilient Designs for Highway Infrastructure in British Columbia, Version 2.0.

EGBC. 2021. Code of Ethics.

Engineers Canada. 2018. Public Guideline: Principles of Climate Adaptation and Mitigation for Engineers.

EGBC. 2020. Practice Advisory – Flowing Artesian Wells and Excavation. Version 1.0.

Environmental Operators Certification Program. 2018. Program Guide

Environmental Protection Agency. 2020. 17th Annual Drinking Water Workshop: Small Systems Challenges and Solutions.

Environmental Protection Agency. 2016. Climate Change Adaptation and Saltwater Intrusion.

Environmental Protection Agency. 2019. Climate Change and Harmful Algal Blooms.

Environmental Protection Agency. 1999. Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual.

Famiglietti, J.S. 2014. The global groundwater crisis. Nature Climate Change. 4: 945-948.

Federation of Canadian Municipalities. 2004. Monitoring Water Quality in the Distribution System. A best practice by the National Guide to Sustainable Municipal Infrastructure.

Fire Underwriters Survey. 1999. Water Supply for Public Fire Protection.

GLI International Inc. 1992. Analytical Method for Turbidity Measurement.

Government of Alberta. 2011. Application Form and Guide for a New or Renewed Approval of a Municipal Waterworks System.

Government of Alberta. 2012. Guidelines for Municipal Waterworks.

Government of Alberta. 2011. Standards for Municipal Waterworks.

Government of British Columbia. Agricultural Waste Management

Government of British Columbia. Waste Discharge Authorizations

Hach Company. 2000. Hach Method 10133: Determination of Turbidity by Laser Nephelometry.

HDR Engineering, Inc. 2001. Handbook of Public Water Supplies, 2nd Edition, Chapter 14. Iron and Manganese Removal.

Health Canada. 2016. Cyanobacterial Toxins in Drinking Water.

Health Canada. 2019. Draft Aluminum in Drinking Water.

Health Canada. 2017. Draft Barium in Drinking Water.

Health Canada. 2019. Draft Escherichia Coli in Drinking Water.

Health Canada. 2018. Draft Guidance on the use of Enterococci bacteria as indicators in Canadian Drinking water supplies.

Health Canada. 2002. From Source to Tap - The multi-barrier approach to safe drinking water.

Health Canada. 2013. Guidance for Providing Safe Drinking Water in Areas of Federal Jurisdiction.

Health Canada. 2009. Guidance on Controlling Corrosion in Drinking Water Distribution Systems.

Health Canada. 2012. Guidance on the Use of Heterotrophic Plate Counts Supplies.

Health Canada. 2019. Guidance on the Use of Quantitative Microbial Risk Assessment in Drinking Water.

Health Canada. 2013. Guidance on Waterborne Bacterial Pathogens.

Health Canada. 2010. Guideline Technical Document - Fluoride.

Health Canada. 1992. Guideline Technical Document - Lead.

Health Canada. 1995. Guideline Technical Document – Odour.

Health Canada. 2005. Guideline Technical Document - Taste.

Health Canada. 2020. Guidelines for Canadian Drinking Water.

Health Canada. 2014. Guidelines for Canadian Drinking Water Guidelines Summary Table.

Health Canada. 2019. Guidelines for Canadian Drinking Water Guidelines Summary Table.

Health Canada. 2016. Guidelines for Canadian Drinking Water Quality - Bromate.

Health Canada. 2020. Guidelines for Canadian Drinking Water Quality - Chloramines.

Health Canada. 2009. Guidelines for Canadian Drinking Water Quality - Chlorine.

Health Canada. 2008. Guidelines for Canadian Drinking Water Quality - Chlorite and Chlorate.

Health Canada. 2019. Guidelines for Canadian Drinking Water Quality - Copper.

Health Canada. 2012. Guidelines for Canadian Drinking Water Quality - Enteric Protozoa (*Giardia* and *Cryptosporidium*.

Health Canada. 2019. Guidelines for Canadian Drinking Water Quality - Enteric Protozoa (*Giardia* and *Cryptosporidium*).

Health Canada. 2019. Guidelines for Canadian Drinking Water Quality - Enteric Viruses.

Health Canada. 2012. Guidelines for Canadian Drinking Water Quality - Escherichia coli.

Health Canada. 2019. Guidelines for Canadian Drinking Water Quality - Lead.

Health Canada. 2019. Guidelines for Canadian Drinking Water Quality - Manganese.

Health Canada. 2011. Guidelines for Canadian Drinking Water Quality - NDMA.

Health Canada. 2018. Guidelines for Canadian Drinking Water Quality - Perfluorooctane Acid.

Health Canada. 2018. Guidelines for Canadian Drinking Water Quality - Perfluorooctane Sulfonate.

Health Canada. 2015. Guidelines for Canadian Drinking Water Quality - pH.

Health Canada. 2019. Guidelines for Canadian Drinking Water Quality - Strontium.

Health Canada. 2011. Guidelines for Canadian Drinking Water Quality - THMs and Other Disinfection-by-products.

Health Canada. 2012. Guidelines for Canadian Drinking Water Quality - Total Coliforms.

Health Canada. 2003. Guidelines for Canadian Drinking Water Quality - Turbidity.

Health Canada. 2012. Guidelines for Canadian Drinking Water Quality - Turbidity.

Health Canada. 2019. Guidelines for Canadian Drinking Water Quality - Uranium.

Health Canada. 2011. Guidelines for Canadian Drinking Water Quality -Enteric Viruses.

Health Canada. 2013. Guidelines for the Management of Naturally Occurring Radioactive Materials (NORM).

Health Canada. 2019. Guidelines on Evaluating and Mitigating Lead in Drinking Water Supplies, Schools, Daycares and Other Buildings.

Health Canada. 2016. Radionuclides in groundwater: federal contaminated sites advisory bulletin.

HealthLinkBC. 2018. Wildfire: Its Effect on Drinking Water Quality

Indian & Northern Affairs Canada (now Indigenous Services Canada, ISC). 2006. Design Guidelines for First Nations Water Works.

Indian & Northern Affairs Canada (now ISC). 2010. Protocol for Centralized Drinking Water Systems in First Nations Communities.

Indian & Northern Affairs Canada (now ISC). 2010. Protocol for Decentralized Water and Wastewater Systems in First Nations Communities.

Indian & Northern Affairs Canada (now ISC). 2016. Protocol for INAC Funded Infrastructure.

Indian & Northern Affairs Canada (now ISC). 2006. Protocol for Safe Drinking Water in First Nations Communities.

Indian & Northern Affairs Canada (now ISC). 2010. Technical Guidance Document for Water Quality Parameters.

Indigenous Services Canada. 2018. ISC Design Guidelines for Water Works Check List.

Infrastructure Canada. 2019. Climate Lens Guidelines

Institute for Catastrophic Loss Reduction. 2014. Canadian Climate Change Risk Assessment Guide. A strategic Overview of Climate Risks and Their Impact on Organizations.

Insurance Advisory Organization. 1999. Water Supply for Public Fire Protection.

Insurance Bureau of Canada & Federation of Canadian Municipalities. 2020. Investing in Canada's Future: The Cost of Climate Adaptation at the Local Level.

Intergovernmental Panel on Climate Change (IPCC). 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change.

Intergovernmental Panel on Climate Change (IPCC). 2014. Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.

International Organization for Standardization. 1999. Water Quality -- Determination of Turbidity.

Irish Environmental Protection Agency. Water Treatment Manual: Disinfection.

Lemmen, D.S. et al. 2016. Canada's Marine Coasts in a Changing Climate.

Journal AWWA, Ford et al. 2001. Pilot-testing with the End in Mind.

Journal AWWA. Cummings and Summers. 1994. Using RSSCTs to Predict Field-Scale GAC Control of DBP Formation.

Journal AWWA. Westerhoff et al. 2003. Rapid Small Scale Column Tests for Arsenate Removal in Iron Oxide Packed Bed Columns.

Journal AWWA, Clifford and Liu. 1993. Ion Exchange for Nitrate Removal.

Journal AWWA, Liang et al. 1999. Nitrate Removal from Contaminated Groundwater.

Proceedings Annual AWWA Conference. Gehling et al. 2003. Removal of Arsenic by Ferric Chloride Addition and Filtration.

Journal AWWA. Kumar and Pearce. 2006. Developing a Protocol to Evaluate New-Generation Membranes for Desalting Brackish Groundwater.

Kawamura. 2000. Integrated Design and Operation of Water Treatment Facilities, 2nd edition

Master Municipal Construction Documents Association. 2014. Design Guidelines

MWH. 2005. Water Treatment Principles and Design

MWH. 2012. Water Treatment: Principles and Design, 2nd edition

National Guide to Sustainable Municipal Infrastructure. 2003. Water Quality in Distribution Systems.

NSF International. 2018. NSF/ANSI 14 Plastic Piping System Components and Related Materials.

NSF International. 2016. NSF/ANSI 372 Drinking Water System Components - Lead Content.

NSF International. 2018. NSF/ANSI 401 Drinking Water Treatment Units Emerging Compounds and Incidental Contaminant.

NSF International. 2018. NSF/ANSI 42 Drinking Water Treatment Units - Aesthetic Effects.

NSF International. 2018. NSF/ANSI 53 Drinking Water Treatment Units - Health Effects.

NSF International. 2018. NSF/ANSI 55 UV Microbiological Water Treatment Systems.

NSF International. 2018. NSF/ANSI 58 Reverse Osmosis Drinking Water Treatment Systems.

NSF International. 2018. NSF/ANSI 60 Drinking Water Treatment Chemicals - Health Effects.

NSF International. 2018. NSF/ANSI 61 Drinking Water System Components - Health Effects.

NSF International. 2018. NSF/ANSI 62 Drinking Water Distillation Systems.

NSF International. 2018. NSF/ANSI 600 Health Effect Evaluation and Criteria for Chemicals in Drinking Water.

Pang et al. 2010. Removal of DDT in drinking water using nanofiltration process, Desalination, 250:2, 553-556

PCA. 1992, Circular Concrete Tanks Without Prestressing

Proceedings Annual AWWA Conference. Gehling et al. 2003. Removal of Arsenic by Ferric Chloride Addition and Filtration.

Province of Manitoba. 2012. Best Practices Manual for Small Drinking Water Systems.

Province of Manitoba. 2017. Chlorine and Alternative Disinfectants Guidance Manual.

Province of Manitoba. 2005. Filtration and Disinfection Log Reduction Credits.

Province of Nova Scotia. 2012. Nova Scotia Treatment Standards for Municipal Drinking Water Systems.

Province of Ontario. 2008. Design Guidelines for Drinking Water Systems.

Province of Ontario. Procedure for Disinfection of Drinking Water in Ontario.

Province of Quebec. 2015. Design Guidelines for Drinking Water Production Facilities (Volume 1).

Province of Quebec. 2017. Design Guidelines for Drinking Water Production Facilities (Volume 2).

Public Infrastructure Engineering Vulnerability Committee (PIEVC). 2020. Engineering Protocol for Infrastructure Vulnerability Assessment and Adaptation to a Changing Climate.

Rahman et al. 2010. Advanced Oxidation Treatment of Drinking Water: Part I. Occurrence and Removal of Pharmaceuticals and Endocrine-Disrupting Compounds from Lake Huron Water, Ozone: Science & Engineering, 32: 4, 217 — 229

Rodriguez-Narvaez et al. 2017. Treatment technologies for emerging contaminants in water: A review, Chemical Engineering Journal, Volume 323, 361-380

Rossman, L. A., and Grayman, W. M. (1999). Scale-model studies of mixing in drinking water storage tanks. Journal of Environmental Engineering, ASCE, 125(8), 755-76.

S.Y. Jasim. et al. 2020. Removal of Cyanotoxins in Detroit River Water Using Ozone-Based Advanced Oxidation Processes

S. Schalk et al. 2005. UV-Lamps for Disinfection and Advanced Oxidation - Lamp Types, Technologies and Applications.

San Francisco Public Utilities Commission. 2016. San Francisco Rainwater Harvesting Manual

Schneider, M., Bláha, L. 2020. Advanced oxidation processes for the removal of cyanobacterial toxins from drinking water. Environ Sci Eur 32, 94.

Schock et al. 1996. The Corrosion and Solubility of Lead in Drinking Water.

Simon, G.P. 1991. Tables and Conversion Factors - Chemical Equivalent Weights and Conversion Factors.

State of California. 2018. Alternative Filtration Technology - Membrane Filtration.

State of California. 2018. Alternative Filtration Technology Summary - CCF, Pressure Filters, Bag and Cartridge Filters.

State of California. 2003. Guidance Criteria for the Separation of Water Mains and Non-Potable Pipelines.

State of Colorado. 2014. Baffling Factor Guidance Manual - Determining Disinfection Capability and Baffling Factors for Various Types of Tanks at Small Public Water Systems.

State of Colorado. 2014. Summary of Accepted Bag and Cartridge Alternative Filtration Technologies.

Statistics Canada, 1996, Quarterly Estimates of the Population of Canada, the Provinces and the Territories, 11-3, Catalogue no. 91-001, Ottawa.

Texas Commission on Environmental Quality. 2004. Selection of Baffling Factors and Operating Conditions for T10 Calculations.

United States. Department of Agriculture. (2008). *Climate Change and Water Perspectives from the Forest Service*, Sustaining Healthy Watersheds, FS 908.

United States Environmental Protection Agency. 2003. Final Revised Guidance Manual for Detecting Lead and Copper Control Strategies.

United States Environmental Protection Agency. 1992a. Lead and Copper Rule Guidance Manual, Vol. II: Corrosion Control Treatment.

United States Environmental Protection Agency. 2005. A Regulator's Guide to the Management of Radioactive Residuals from Drinking Water Treatment Technologies.

United States Environmental Protection Agency. 2005. A Regulators' Guide to the Management of Radioactive Residuals from Drinking Water Treatment Technologies.

United States Environmental Protection Agency. 2009. CFR Part 141 - National Primary Drinking Water Regulations.

United States Environmental Protection Agency. 2014. Climate Change Adaptation Implementation Plan.

United States Environmental Protection Agency. 2015. Climate Ready Water Utilities Adaptation Strategies Guide for Water Utilities.

United States Environmental Protection Agency. 2014. Cyanobacteria and Cyanotoxins: Information for Drinking Water Systems.

United States Environmental Protection Agency. 1993. Determination of Turbidity by Nephelometry.

United States Environmental Protection Agency. Drinking Water Treatment Residuals.

United States Environmental Protection Agency. 2010. Emerging Contaminants - Nanomaterials.

United States Environmental Protection Agency. 1999. Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual

United States Environmental Protection Agency. 2001. Filter Backwash Recycle Rule.

United States Environmental Protection Agency. 2010. Long Term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual.

United States Environmental Protection Agency. 2005. Membrane Filtration Guidance Manual.

United States Environmental Protection Agency. 2016. Optimal Corrosion Control Treatment Evaluation Technical Recommendations for Primacy Agencies and Public Water Systems.

United States Environmental Protection Agency. 2014. Design Manual - Removal of Fluoride from Drinking Water Supplies by Activated Alumina.

United States Environmental Protection Agency. 2012. Sanitary Protection of Reservoirs (Tanks) - Vents, Drains and Overflows.

United States Environmental Protection Agency. 2006. Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule.

Virginia Department of Health. 2016. Virginia Rainwater Harvesting & Use Guidelines.

Wachinski, A.M. 2016. Tables and Conversion Factors - Common Water Treatment Chemicals.

Washington State. 2011. Chlorine Contact Time for Small Water Systems.

Washington State. 2018. Group B Drinking Water Design Guidelines.

Washington State. 2006. Pipeline Separation Design and Installation Reference Guide.

Washington State. 2017. Sanitary Protection of Reservoirs - Hatches.

Washington State. 2016. Sanitary Protection of Reservoirs - Vents.

Washington State. 2019. Water System Design Manual.

WorkSafe BC. 2019. Safe Work Practices for Chlorine.

World Health Organization. 2019. Microplastics in Drinking Water.