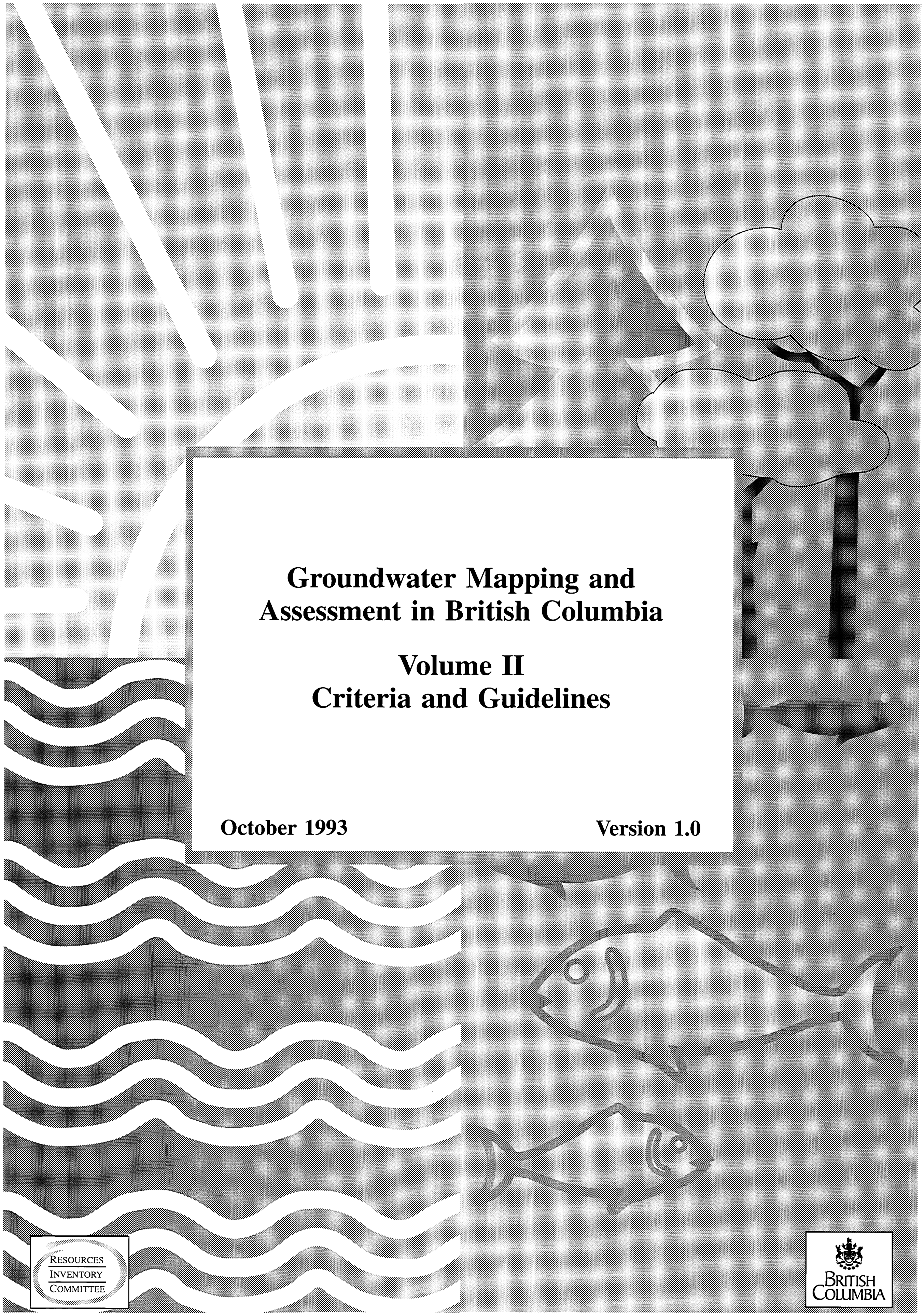

Groundwater Mapping and Assessment in British Columbia

Volume II
Criteria and Guidelines

October 1993

Version 1.0

Resources Inventory Committee

British Columbia

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Groundwater Mapping and Assessment in British Columbia

Volume II – Criteria and Guidelines

Developed by
Piteau Associates Engineering Ltd.,
Turner Groundwater Consultants
for the Earth Sciences Task Force,
Resources Inventory Committee

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EXECUTIVE SUMMARY

Piteau Associates Engineering Ltd. and Turner Groundwater Consultants were retained by the Resource Inventory Committee, Earth Science Task Force to review groundwater mapping and assessment in British Columbia. The study team have reviewed existing methods for the acquisition, processing, and dissemination of groundwater information in British Columbia and other jurisdictions. The results of this review and assessment are presented in a two-volume report: Volume I, entitled Review and Recommendations offers suggestions to facilitate the collection, management, and dissemination of groundwater information; Volume II, entitled Criteria and Guidelines has been prepared to encourage a consistent approach to groundwater mapping and assessment in British Columbia.

This project included surveying a broad group of individuals to obtain comments on groundwater mapping and assessment as well as holding a stakeholder workshop which provided a forum for discussion on this important issue.

The review of existing hydrogeological assessment methods and comments received from those concerned with the development, use, management and protection of groundwater resources resulted in the following consensus:-

- The **establishment of a centralized core of high quality, up-to-date, and readily accessible groundwater information** is essential. This will be achieved by consolidating and automating water-well reports and collecting and sharing groundwater data. Only when this has been completed can detailed mapping and the characterization of aquifers proceed.
- The **establishment of a minimum set of data elements** to foster the sharing of information between interested agencies is fundamental to the overall strategy for organizing and managing groundwater data.

In terms of improved access to groundwater information, this report provides recommendations for the establishment of a central groundwater information source and allowing for access to this information by computer. Other recommendations to provide greater access to groundwater information and to increase public awareness on groundwater issues include publishing a groundwater data source book, releasing selected groundwater information and reports for public circulation, and the publication of brief fact sheets on groundwater and related issues in British Columbia.

It is also recommended that the Provincial Government set standards for groundwater mapping and data collection with support from the Federal Government. Local governments should accept a significant role in the management and protection of groundwater resources.

ACKNOWLEDGEMENTS

Funding of the Resources Inventory Committee work, including the preparation of this document, is provided by the Corporate Resource Inventory Initiative (CRII) and by Forest Renewal BC (FRBC). Preliminary work of the Resources Inventory Committee was funded by the Canada-British Columbia Partnership Agreement of Forest Resource Development FRDA II.

The Resources Inventory Committee consists of representatives from various ministries and agencies of the Canadian and the British Columbia governments as well as from First Nations peoples. RIC objectives are to develop a common set of standards and procedures for the provincial resources inventories, as recommended by the Forest Resources Commission in its report "The Future of our Forests".

Earth Sciences Task Force

This report has been prepared with assistance and suggestions provided by several knowledgeable individuals including Rod Zimmerman and other members of the Groundwater Section of the Ministry of Environment, Lands and Parks and Hugh Liebscher, Senior Hydrogeologist with Environment Canada. Paul Matysek and members of the RIC Earth Sciences Task Force planned and directed the project.

Dr. Allan Freeze, of R. Allan Freeze Engineering Inc. of White Rock, B.C., moderated a workshop on groundwater mapping and assessment, and reviewed the summary report. Dr. Robert Palmquist, of Applied Geotechnology Inc. of Bellevue, Washington, assisted with planning of the workshop and provided much of the USA based resource material.

The authors wish to acknowledge contributions from John Gilliland of Environment Canada, Dr. John Vaccaro, US Geological Survey in Tacoma, Washington, and Marilyn Blair, Washington State Department of Ecology, in Olympia, Washington.

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1. INTRODUCTION

This report presents a recommended approach and criteria for groundwater mapping and assessment in British Columbia. Information presented in this report is the result of a project funded by the Resources Inventory Committee to develop criteria and a general approach for groundwater mapping and assessment in British Columbia. The criteria were developed through the cooperative efforts of staff from Environment Canada, the provincial Ministry of Environment, Lands and Parks, the Ministry of Energy, Mines and Petroleum Resources, Piteau Associates Engineering Ltd. and Turner Groundwater Consultants. Representatives of these organizations utilized previous work of their agencies as well as personal experience in groundwater sciences to develop the criteria and approach. In addition, comments were solicited from a broad group of individuals concerned with the development, use, management and protection of the groundwater resource of British Columbia. Federal input to the project is administered under the auspices of the Fraser River Action Plan (FRAP) which calls for the reduction in contaminant loading to groundwater through identification of contaminant sources and the development and implementation of suitable control measures.

The criteria, general approach and guidelines for application were developed to encourage a consistent approach to groundwater mapping and assessment in British Columbia. Potential users of this report include provincial and federal agencies, local governments and geological and engineering consultants.

These criteria for assessing groundwater conditions allow for the preparation of maps. However, the prepared maps are interpretations of known or estimated subsurface conditions. They are intended for use as screening tools and guides to indicate where additional information or other special requirements might be desirable to support land use or resource protection decisions.

2. BASIC GROUNDWATER CONCEPTS AND TERMINOLOGY

The concept of a groundwater regime is based on the fact that the occurrence and distribution of groundwater is not merely a product of chance, but the consequence of a finite combination of climatic, hydrologic, geologic, topographic, ecologic and soil-forming factors that together form an integrated dynamic system. These factors are interrelated in such a way that each provides some insight into the functioning of the total system and thus serves as an indicator of local conditions of groundwater occurrence. It is possible, therefore, to evaluate the general potential of an area for groundwater development by appraising as many of the factors listed above as practical and then by interpreting the local regime on the basis of known relationships among the factors and their effect on the groundwater regime.

Most important among the preceding relationships are the physical characteristics of the framework in which the groundwater system occurs, the balance between groundwater recharge and discharge and the consequent hydrologic and lithologic implications that may be drawn, and the relationship among the factors affecting the movement of groundwater from the point of recharge to the point of discharge.

Obviously the groundwater regime must be viewed as a dynamic system in which water is absorbed at the land surface and eventually recycled back to that surface. Groundwater may be visualized as occurring in a subsurface reservoir, the boundaries of which are formed by adjacent less permeable or impermeable geological materials. The reservoir may be open everywhere to the land surface (unconfined), or it may be capped in large part by impermeable or relatively impermeable geological materials (confined).

The hydrologic equation, which is basically a statement of the law of conservation of matter as applied to the hydrologic cycle, defines the water balance. It states that in a specified period of time all water entering a specified area must either go into storage within its boundaries, be consumed therein, be exported from, or flow out either on the surface or underground.

In developing an estimate of balance between recharge to, and discharge from, a groundwater regime the general manner in which that regime functions must be identified. The potential for recharge to the groundwater regime in an area depends on the amount and pattern of annual precipitation in relation to the potential for evaporation and to the occurrence of any surface or subsurface inflow from adjacent areas. Most of this potential recharge is commonly intercepted by the soil veneer and eventually returned to the atmosphere through processes of evapotranspiration or dissipated as surface runoff.

Water below the surface of the earth is referred to as underground water and occurs in two distinct zones. The uppermost zone, which occurs immediately below the land surface, contains both water and air and is referred to as the unsaturated zone. Below the unsaturated zone is a zone in which all interconnected openings contain only water and which is referred to as the saturated zone. The water table is the level near the upper part of the saturated zone at which water occurs under a pressure equal to the atmospheric pressure. Water in the saturated zone is the only underground water that is available to supply wells and springs and is the only water to which the name groundwater is correctly applied.

Hydrologic Cycle

The term hydrologic cycle is used to refer to the constant movement of water above, on, and below the surface of the earth. The concept of the hydrologic cycle is central to an understanding of the occurrence of water and the development, management and protection of the groundwater resource.

Although the hydrologic cycle has neither a beginning or an end, it is convenient to discuss its principal features by starting with evaporation from vegetation, from exposed surfaces including the land surface, and from the ocean. This moisture forms clouds which, under favourable conditions, returns the water to the land surface or oceans in the form of precipitation.

Precipitation occurs in several forms, including rain, snow, and hail, but we will consider only rain in this discussion. The first rain wets vegetation and other surfaces and then begins to infiltrate into the ground. Infiltration rates vary widely, depending on land use, from possibly as much as 25 mm per hour in mature forests to a few millimetres per hour in silty soils under cultivation. When and if the rate of precipitation exceeds the rate of infiltration, overland flow occurs.

The first infiltration replaces soil moisture and thereafter the excess percolates slowly downward to the zone of saturation. The water in the zone of saturation moves downward and laterally to areas of groundwater discharge such as springs on hillsides or seeps in the bottom of streams and lakes or beneath the ocean.

Water reaching streams, both by overland flow and from groundwater discharge, moves to the sea where it is again evaporated to perpetuate the cycle.

Aquifers and Confining Beds

From the standpoint of groundwater occurrence, all rocks underlying the surface of the earth are classified as aquifers or confining beds. An aquifer is a saturated permeable unit that will yield water in a usable quantity to a well or spring.

A confining bed is a geological unit that restricts the movement of groundwater either into or out of adjacent aquifers.

Groundwater occurs in aquifers under two different conditions. Where water only partly fills an aquifer, the upper surface of the saturated zone is free to rise and decline. The water in such aquifers is said to be unconfined and the aquifers are referred to as unconfined aquifers.

Where water completely fills an aquifer that is overlain by a confining bed, the water in the aquifer is said to be confined. Such aquifers are referred to as confined aquifers.

Water wells open to unconfined aquifers are referred to as water-table wells. The water level in these wells indicates the position of the water table in the surrounding aquifer.

Wells drilled into confined aquifers are referred to as artesian wells. The water level in artesian wells stands at some height above the top of the aquifer but not necessarily above the land surface. The static water level in wells completed in confined aquifers stands at the level of the potentiometric surface of the aquifer.

2.1 Groundwater Flow Systems

The aquifers and confining beds underlying a study area comprise the groundwater system of the area. Hydraulically, the system serves two functions:

- stores water to the extent of its porosity; and
- transmits water from recharge areas to discharge areas.

Thus, a groundwater system serves as both a reservoir and as a transmitting medium. Water enters the groundwater system in recharge areas and moves through them, as dictated by hydraulic gradients and hydraulic conductivities, to discharge areas. The rate of movement of groundwater from recharge areas to discharge areas depends on the hydraulic conductivities of the aquifers and confining beds through which the water moves and on the hydraulic gradients. Before a governing equation for groundwater flow can be derived, a conceptual model of the flow system must be developed. There are two conceptual views of groundwater systems - the aquifer system model and the flow system model.

The Aquifer System Model

The aquifer system model is used to simulate two-dimensional horizontal flow in confined and unconfined aquifers. This model is based on the concept of confined and unconfined aquifers and is especially suited to analysis of flow to pumping wells. This type of model is the basis for many analytical solutions including those of Theis (1935) and Cooper (1946). In the aquifer system model, groundwater flow is assumed to be strictly horizontal through aquifers and strictly vertical through confining beds. The ability of an aquifer to transmit water is described by its **hydraulic conductivity**. In the aquifer system model the hydraulic conductivity is integrated in the vertical dimension to give an average transmission characteristic known as **transmissivity** such that:

$$T = Km \tag{2.1}$$

where: T = transmissivity, m2/day

K = hydraulic conductivity, m/day

m = aquifer thickness, m

The transmissivity of a confined aquifer is constant if the aquifer is homogeneous and of uniform thickness. However, the transmissivity of an unconfined aquifer always varies spatially because the saturated thickness depends on the elevation of the water table. Although assumed to be constants in the analytical solutions used in well hydraulics, hydraulic conductivity and transmissivity vary spatially in field situations because aquifers are always heterogeneous.

Flow System Model

In the flow system model, one is not concerned with identifying aquifers and confining beds as such, but in constructing the three-dimensional distribution of heads, hydraulic conductivities, and storage properties everywhere in the system. The flow system model allows for both vertical and horizontal components of flow throughout the system and thereby allows treatment of flow in two-dimensional profile or in three dimensions.

2.2 An Overview of Groundwater Mapping Methods

A groundwater map is a graphical representation of the occurrence and distribution of groundwater within a geographical relationship. The purpose of groundwater mapping is twofold:

- to provide information on the occurrence and distribution of groundwater; and
- to provide the basis for understanding the relationship between groundwater and geological and hydrological environment.

Groundwater maps, in contrast to most other maps, deal with transient, rather than essentially constant phenomena. Transient data can be shown on maps in two very different ways. One shows essentially static conditions on the basis of totals or averages for specific time spans; the other shows conditions at a particular moment or during a short interval of time. The primary objective of groundwater mapping is to define the physical characteristics of the groundwater system. In order to accomplished this, the hydrogeologist must have capabilities in:

- data access;
- data retrieval; and
- data analysis.

Data can be used to illustrate surface and subsurface features and to describe the flow characteristics of groundwater. The first step to understanding the hydrogeology of an area is having an idea of the groundwater flow patterns and the material water must travel through.

Perhaps the preeminent publication dealing with the explanation and preparation of groundwater maps is entitled Hydrogeological Maps (UNESCO, 1977) wherein groundwater maps are divided into four broad categories depending on their basic content and/or principal purpose as follows:-

Geological Groundwater Map

The distribution of rock types, and or geological formations, dominates and the groundwater conditions are implied from the geological framework. The geology may be supplemented, either directly on the map or in the explanatory notes, by information such as areas of recharge and discharge, the configuration of the water table or the piezometric surface, the thickness of the zone of aeration and distribution of water quality characteristics. The principal advantage of this type of map is that it shows the extent to which the geology of an area may provide clues to the occurrence, distribution, and movement of groundwater. The principal shortcoming of this type of map is that it presents an essentially static picture of what in nature are essentially dynamic phenomena. Moreover, it implies a closer relationship between geological formations and groundwater occurrence than actually exists.

Hydraulic Groundwater Map

The hydraulic type of map is one in which the elements on the map are based on the classification of rocks and formations according to the conditions under which water occurs within them. The geological formations are shown as such but are described in terms of their hydraulic and closely related characteristics, such as porosity, permeability, degree of fracturing, and shape of aquifer. Hydraulic groundwater maps show limits of artesian and water-table conditions, groundwater divides, distribution of hydraulic characteristics. and the elements of geological structure which influence groundwater occurrence. Hydraulic maps may be supplemented with information about the groundwater situation indicated by isolines or other symbols.

Groundwater Resource Map

The resource type of map is widely utilized to indicate groundwater yield and characteristics of water quality affecting use. The most common factor shown is availability, usually by scales dividing the range of yield into arbitrary units. Resource maps may also show yields of water of quality suitable for specific purposes, such as domestic, municipal, agricultural and industrial use. As a rule groundwater resource maps do not show groundwater hydraulics and dynamics.

Hydrostratigraphic Map

This approach to groundwater mapping and assessment, utilizing modern concepts of groundwater hydrology, differs from the others in that it is based on the mapping of hydrological properties and the classical geological framework supplements and supports the hydrological information. The information presented on the map is in terms of the ability of the subsurface rocks to transmit and store water, including their permeabilities, transmissivities, storage coefficients, hydrochemical characteristics and the characteristics of the water table or the piezometric surface. The principal difference between this type of map and the hydraulic groundwater map is that the hydrostratigraphic map shows aquifers as units, whereas the hydraulic map relates the water-bearing characteristics to specific geological units.

The important differences between this type of map and earlier maps is that aquifers and confining beds are mapped as distinctive, independent units whereas earlier groundwater maps related the water-bearing characteristics to specific geologic units. This new concept in mapping has many practical and utilitarian purposes, particularly in modelling efforts. In summary, a hydrostratigraphic unit defines, as well as maps, a hydrogeologic unit as a quantity of geological material distinguished and characterized by its porosity and permeability.

3. GROUNDWATER MAPPING AND ASSESSMENT

Groundwater mapping is a method of assessing and recording the results of subsurface hydrological investigations. The first step in developing a groundwater mapping protocol is to establish the purpose of the assessment followed by the formulation of a conceptual model of the groundwater flow system. A conceptual model is a pictorial representation of the groundwater flow system. The purpose of developing a conceptual model is to simplify the field problem and organize the associated field data so that the groundwater system can be analyzed more readily. Simplification is necessary because a complete reconstruction of the field system is not feasible. The data requirements for the conceptual groundwater flow model are listed in Table 3.1. These data should be assembled prior to formulating the conceptual model. There are three steps in developing the conceptual groundwater model: 1) defining the hydrogeologic setting; 2) preparing a water budget; and 3) defining the flow system.

Defining The Hydrogeologic Setting

Geologic information, including geologic maps, cross sections and well logs, are combined with information on hydrologic properties to define the hydrogeologic setting for the conceptual model. A hydrogeologic setting is a composite description of all the major geologic and hydrologic factors which affect and control the movement of groundwater into, through and out of an area. It is defined as a mappable unit with common hydrogeologic characteristics. Several geologic formations may be combined into a single hydrogeologic unit or a geologic formation may be subdivided into aquifers and confining beds.

In order to assist users of this manual, the criteria and guidelines presented herein have been developed within the framework of existing classification systems. Heath (1984) divided the United States into fifteen groundwater regions. based on the features in a groundwater system which affect the occurrence and distribution of groundwater. Since it is difficult to determine the occurrence and distribution of groundwater on a regional scale, smaller "hydrogeologic settings" have been developed by Aller, et al (1987) within each of the regions described by Heath. These hydrogeologic settings create units which are mappable and, at the same time, permit further delineation of the factors affecting the occurrence and distribution of groundwater. Although these hydrologic settings were developed for typical regions within the United States, experience has shown that they are applicable to most areas within British Columbia. Descriptions of these hydrogeologic settings is beyond the scope of this manual, however, the user is referred to Aller, et al (1987) for a detailed description and written narrative for each of the hydrogeologic settings used in the preliminary mapping method.

Preparing the Water Budget

The sources of water to the system as well as the expected flow directions and exit points should be part of the groundwater map. The field-estimated inflows may include groundwater recharge from precipitation, overland flow, or recharge from surface water bodies. Outflows may include springflow, baseflow to streams, evapotranspiration and pumping. A water budget should be prepared from the field data to summarize the magnitudes of these flows and changes in storage.

Defining the Flow System

The hydrostratigraphy forms the framework of the groundwater map. Hydrologic information is used to conceptualize the movement of groundwater through the system. Hydrologic information of precipitation, evaporation, and surface water runoff, as well as head data and geochemical information are used in this analysis. Water level measurements are used to estimate the general direction of groundwater flow, the location of recharge and discharge areas, and the connection between aquifers and surface water systems. Definition of the flow system may be based solely on physical hydrologic data, but it is advisable to use geochemical data whenever possible to strengthen the conceptual model. Water chemistry data can be used to infer flow directions, identify sources and amounts of recharge, estimate groundwater flow rates, and define local, intermediate, and regional flow systems.

3.1 Data Requirements

Data needed for groundwater mapping are summarized in Table 3.1. The data can be grouped into two general categories; physical characteristics and hydrogeologic characteristics. Data included under physical characteristics defines the geometry of the groundwater system including the thickness and aerial extent of each hydrostratigraphic unit. Hydrogeologic characteristics include information on the heads and fluxes.

Obtaining the information necessary for mapping is not an easy task. Some data may be obtained from existing reports, but in most cases additional on-site field work will be required.

Transmissivity and storage coefficient are typically obtained from pumping test results. For mapping at a large scale, values of hydraulic conductivity can be determined by pumping tests if volume-averaged values are desired or by "slug tests" if point values are required. For unconsolidated sediments, hydraulic conductivity may also be obtained from laboratory grain size analyses. In the absence of site-specific field or laboratory measurements, initial estimates for aquifer properties may be taken from tables (Freeze and Cherry, 1979).

Hydrologic stresses include pumping, recharge, and evapotranspiration. Of these, pumping rates may be the easiest to estimate. Recharge is one of the most difficult parameters to estimate. Likewise, field information for estimating evapotranspiration is likely to be sparse.

Table 3.1 Data Requirements for Groundwater Mapping

Physical Characteristics	
1.	Geologic map and cross sections showing the areal and vertical extent and boundaries of the system.
2.	Topographic map showing surface water bodies and divides.
3.	Contour maps showing the elevation of the base of the aquifers and confining beds.
4.	Isopach maps showing the thickness of aquifers and confining beds.
Hydrogeologic Characteristics	
1.	Water table and potentiometric maps for all aquifers.
2.	Hygrographs of groundwater and surface water levels and discharge rates.
3.	Maps and cross sections showing hydraulic conductivity and/or transmissivity distribution.
4.	Maps and cross sections showing the storage properties of the aquifers and confining beds.
5.	Spatial and temporal distribution of rates of evapotranspiration, groundwater recharge; surface water-groundwater interaction, groundwater pumping and natural groundwater discharge.

4. APPLICATION OF GROUNDWATER MAPPING CRITERIA

Since groundwater is a hidden resource not amenable to direct observation, some level of assessment is necessary to determine the occurrence and distribution of groundwater within a given study area.

The scope and detail of the assessment depends upon both the objectives and size of the study area. In the case of an already developed groundwater basin, the assessment may consist simply of assembling information derived from nearby wells. Large assessment programs where data are sparse may require the use of a number of diverse and sometimes complex procedures to evaluate the occurrence and distribution of groundwater Regardless of complexity, any thorough assessment study must answer four basic questions:

- Where does the water come from?
- Where does it go?
- Is it potable?
- What is the nature of its geologic container?

Prior to beginning a groundwater assessment, the project objectives must be clearly defined. Project boundaries must be delineated. And finally, any constraints on the project must be identified and understood. These constraints may be physical, legal and/or economic. In order to provide the optimum, in technical and economic assessment of existing groundwater conditions, it is suggested that the work be carried out in two separate phases as follows:-

- A Level 1 Preliminary Groundwater Assessment wherein available information is collected and analyzed to provide a qualitative assessment of existing groundwater conditions in the study area.
- A Level 2 Detailed Groundwater Assessment directed towards the collection and analysis of quantitative hydrogeological information in those areas requiring further assessment for the purpose of groundwater development and/or protection.

Such a phased approach affords the implementing agency financial control and allows for decision making at critical intervals throughout the assessment process.

5. LEVEL 1 GROUNDWATER ASSESSMENT – PRELIMINARY

5.1 Introduction

A Level 1 Groundwater Assessment describes the occurrence and distribution of groundwater based on an evaluation of readily-available information. No new data are collected and no new geologic interpretations are necessary. The preliminary assessment is a first approximation of the groundwater regime and can quickly and inexpensively provide a qualitative overview of groundwater conditions.

The mapping technique described in this chapter is a qualitative method of describing the occurrence and distribution of groundwater. The assessment criteria and guidelines are based on the US Environmental Protection Agency's DRASTIC model (Aller, et al., 1985). Although originally developed as a means of evaluating groundwater pollution potential, the DRASTIC model also provides a qualitative assessment with respect to groundwater availability.

5.2 DRASTIC

The methodology used in evaluating groundwater pollution potential is comprised of two major components:

- the designation of mappable units, termed hydrogeologic settings; and
- the superposition of a comparative rating system called DRASTIC.

Hydrogeologic settings form the basis of the DRASTIC system of evaluating groundwater pollution potential. A hydrogeologic setting is a composite representation of all the major geologic and hydrologic factors which affect and control the movement of groundwater into, through, and out of an area. It is defined as a specific area with common hydrogeologic characteristics, and as a consequence, common vulnerability to pollution by induced contaminants. Utilizing these factors it is possible to make generalizations about both groundwater availability and groundwater pollution potential.

Inherent in each study area are the physical characteristics which affect the occurrence and distribution of groundwater. In developing the DRASTIC system, Aller, et al. determined the most important mappable characteristics that control groundwater pollution potential to be:

D	**D**epth to water
R	Net **R**echarge
A	**A**quifer media
S	**S**oil media
T	**T**opography, or slope
I	**I**mpact of vadose zone media
C	Hydraulic **C**onductivity of the aquifer

These factors, which have been arranged to form the acronym DRASTIC, include the basic requirements needed to evaluate the hydrogeologic characteristics of a study area.

The DRASTIC factors represent measurable parameters for which data are generally available from a variety of sources without detailed reconnaissance.

A numerical ranking system has been devised using the DRASTIC factors. The system contains three significant parts: weights, ranges and ratings.

Weights

Each DRASTIC factor has been evaluated with respect to the others to determine the relative importance of each factor. Each DRASTIC factor has been assigned a relative weight ranging from 1 to 5 as shown in Table 5-1 where the most significant factors have weights of 5, and the least significant, a weight of 1.

Table 5-1 Assigned Weights for Drastic Features

Feature	Weight
Depth to Water	5
Net Recharge	4
Aquifer Media	3
Soil Media	2
Topography	1
Impact of the Vadose Zone Media	5
Hydraulic Conductivity of the Aquifer	3

Ranges

Each DRASTIC factor has been divided into either ranges or significant media types which have an impact on pollution potential (Tables 5-2 to 5-8).

Ratings

Each range for each DRASTIC factor has been evaluated with respect to the others to determine the relative significance of each range with respect to pollution potential. Based on the graphs, the range of each DRASTIC factor has been assigned a rating which varies between 1 and 10 as shown in Tables 5-2 through 5-8. The factors D, R, S, T, and C have been assigned one value per range. A and I have been assigned a "typical" rating and a variable rating. The variable rating allows the user to choose either a typical value or to adjust the value based on more specific knowledge.

This system allows the user to determine a numerical value for any hydrogeologic setting by using an additive model. The equation for determining the DRASTIC Index is:

DRDW + RRRW + ARAW + SRSW + TRTW + IRIW + CRCW = DRASTIC Index

where R = rating

W = weight

Once the DRASTIC Index has been computed, it is possible to identify areas which are more likely to be susceptible to groundwater contamination relative to one another. The higher the DRASTIC Index, the greater the groundwater pollution potential.

5.3 Data Sources

Before an area can be evaluated using the DRASTIC system, the basic information on each parameter must be collected. DRASTIC has been designed to use information which is available from a variety of sources. The most common source of each parameter is listed below:

Depth to Water	Well logs and or hydrogeologic reports;
Net Recharge	Water resource reports combined with data on precipitation and temperature from Environment Canada, Atmospheric Environment Service;
Aquifer Media	Published geologic and hydrogeologic maps and reports;
Soil Media	Published soil survey reports and terrain maps prepared by the B.C. Ministry of Environment, Lands and Parks;
Topography	Published NTS topographic maps (various scales) and terrain maps a scale of 1:50,000;
Impact of the Vadose Zone	Published geologic reports; and
Hydraulic Conductivity	Published hydrogeologic reports or estimated.

The more accurate the data used to complete the DRASTIC Index, the better the preliminary assessment. There may be gaps in the data, however these gaps can be filled with careful interpolation.

5.4 Drastic Parameters

Depth to Water

Depth to water is important because it determines the thickness of material through which infiltrating water must travel before reaching the aquifer.

Groundwater occurs in aquifers under two different conditions. Where water only partly fills an aquifer, the upper surface of the saturated zone is free to rise and decline. The water in such aquifers is said to be **unconfined** and the aquifers are referred to as **unconfined aquifers**.

The methodology can be used to evaluate either confined or unconfined aquifers. In an unconfined aquifer, the user chooses depth to water as the depth from the ground surface to the water table.

The **water table** is the expression of the surface below the ground level where all the pore spaces are filled with water. Water level data may be obtained from well logs and published water-level maps.

Special definitions must be assumed when evaluating depth to water for a confined aquifer. In the methodology, when an aquifer is confined, depth to water should be redefined as the depth to the top of the aquifer. This depth also corresponds to the base of the confining layer. When evaluating the depth to the top of the aquifer, the user does not refer to water-level maps. The necessary information may be obtained from geologic reports containing cross sections or maps of the elevations of the bedrock surface. Well logs may also be a source of information.

Table 5-2 Ranges and Ratings for Depth to Water

Depth to Water (metres)	
Range	**Rating**
0-2	10

2-3	9
3-9	7
9-15	5
15-23	3
23-30	2
>30	1
Weight: 5	

In all cases, the user should gather as much information as possible about an aquifer in order to make an accurate and valid selection of the depth-to-water rating.

Net Recharge

The primary source of groundwater is typically precipitation which infiltrates through the surface of the ground and percolates to the water table. Net recharge represents the total quantity of water which is applied to the ground surface and infiltrates to reach the aquifer. Net recharge includes the average annual amount of infiltration and does not take into consideration distribution, intensity or duration of recharge events.

Values for net recharge are often available for watershed or specific study areas. These values typically are found in published water resource or hydrologic reports and may need to be extrapolated to obtain representative recharge values for areas situated outside the study area of the published report.

Because net recharge values are less precise and less easily obtained than values for other DRASTIC parameters, the ranges for net recharge are intentionally broad. These broad ranges afford the user "leeway" in choosing a range which is representative of the amount of recharge for the area. Net recharge values can be chosen to evaluate either unconfined or confined aquifers. In areas where the aquifer is unconfined, recharge to the aquifer usually occurs more readily that in areas with confined aquifers. In unconfined conditions, net recharge values reflect typical water balance calculations.

Table 5-3 Ranges and Ratings for Net Recharge

Net Recharge (millimetres/year)	
Range	**Rating**
0-50	1
50-100	3
100-175	6
175-250	8
>250	9
Weight: 4	

The principal recharge area for a confined aquifer is often many kilometres away. However, many confined aquifers are not truly confined and are partially recharged by migration of water through the confining layers. Values for net recharge can be chosen to reflect the amount of water which may actually recharge the aquifer. Special consideration may need to be given to known recharge-discharge areas. A recharge area occurs where there is a downward component of movement to the direction of groundwater flow. And conversely, discharge areas have an upward component of flow near the surface. Discharge areas commonly form springs, rivers or other surface water expressions. Recharge and discharge areas may be influenced by changes in groundwater gradients.

Aquifer Media

Aquifer media refers to the consolidated or unconsolidated geological material which serves as an aquifer. For the purpose of these guidelines, aquifer media have been designated by descriptive names as follows:-

Massive Shale – thick bedded shales, claystone or clays which typically yield only small quantities of water from fractures.

Metamorphic/Igneous Rock – consolidated bedrock of metamorphic or igneous origin which contains little or no primary porosity and which yields water only from fractures within the rock. Typically well yields are low and are a function of the degree of fracturing.

Weathered Metamorphic/Igneous Rock – unconsolidated material which contains primary porosity and is derived by weathering of the underlying bedrock.

Glacial Till – unconsolidated to semi-consolidated mixtures of gravel, sand, silt and clay which is poorly sorted and stratified. The low hydraulic conductivity of the till produces low yields to wells.

Bedded Sandstone, Limestone and Shale – typically thin-bedded sequences of sedimentary rocks which contain primary porosity.

Massive Sandstone – consolidated sandstone bedrock which contains both primary and secondary porosity and is typified by thicker deposits than the bedded sandstone, limestone and shale sequences.

Massive Limestone – consolidated limestone or dolomite which is characterized by thicker deposits than the bedded sandstone, limestone and shale sequences.

Sand and Gravel – unconsolidated mixtures of sand to gravel-size particles which contain varying amounts of fine materials. Sands and/or gravels which have only small amounts of fine material are termed "clean."

Basalt – consolidated extrusive igneous bedrock which contains bedding planes, fractures and vesicular porosity. The term is used herein in a generic sense, even though it is actually a rock type.

Table 5-4 Ranges and Ratings for Aquifer Media

Aquifier Media		
Range	**Rating**	**Typical Rating**
Massive Shale	1-3	2
Metamorphic/Igneous	2-5	3
Weathered Metamorphic/Igneous	3-5	4
Glacial Till	5-6	5
Bedded Sandstone, Limestone, and Shale	5-9	6
Massive Sandstone	4-9	6
Massive Limestone	4-9	8
Sand and Gravel	4-9	8
Basalt	2-10	9
Weight: 3		

Because this DRASTIC parameter is less quantifiable than numerical parameters, the user should use an aquifer media type and rating based on the foregoing discussion and available information on the geology of the area. The user may choose to evaluate any aquifer within an area, however, only one aquifer may be evaluated at a time. In a multi-layer system, the user must decide which aquifer to choose as the appropriate media. Information on aquifers is typically available in published geologic or hydrologic reports, thesis, well logs or other exploratory boring.

Soil Media

Soil media refers to that uppermost portion of the vadose zone characterized by significant biological activity. For purposes of these guidelines, soil is considered to be the upper weathered zone of the earth with a depth of two metres or less from the ground surface. Soil has a significant impact on the amount of recharge which can infiltrate into the ground. Soil media are best described by referring to the basic soil types as classified by the Soil Conservation Service (1951) as follows:-

Nonshrinking and Non-aggregated Clay – ilitic or kaolinitic clays which do not expand and contract with the addition of water.

Clay Loam – a soil textural classification which is characterized by 15-55% silt, 27-40% clay and 20-45% sand.

Muck – a soil consisting of fine, dark-coloured, well decomposed organic material that typically contains a higher mineral or ash content than peat.

Silt Loam – a soil textural classification characterized by 50-80% silt, 12-27% clay and 0-50% sand.

Loam – a soil textural classification characterized by 25-50% silt, 7-27% clay and 0-50% sand.

Sandy Loam – a soil textural classification characterized by 0-50% silt, 0-20% clay and 15-50% sand.

Shrinking and/or Aggregated Clay – characterized by montmorillonitic clays that swell and contract with alternating wetting and drying.

Peat – a soil consisting of undecomposed to partially decomposed plant material that is fresh enough to be identified.

Sand – a size-based delineation of angular or rounded particles ranging in size from 0.25 mm to 2 mm.

Gravel – a particle-based size classification typified by particles larger than 2 mm in size. Gravels commonly include a mixture of sand, silt clay and gravel particles, with a preponderance of large-size particles.

Thin or Absent – if a soil layer is not present, or if the layer is so thin as to be considered ineffective, the infiltration potential is very high. Thin or absent should generally be chosen when the soil profile is less than 250 mm.

Table 5-5 Ranges and Ratings for Soil Media

Soil Media	
Range	Rating
Thin or Absent	10
Gravel	10
Sand	9

Peat	8
Shrinking and/or Aggreated Clay	7
Sandy Loam	6
Loam	5
Silty Loam	4
Clay Loam	3
Muck	2
Nonshrinking and Nonaggreated Clay	1
Weight: 2	

The selection of an appropriate soil requires the user consider the characteristics of the soils which influence groundwater recharge. This is accomplished by identifying the most significant soil textural layer which influences water movement. The user may take several approaches in this evaluation, however, the following approach is recommended:

- look at the general soil association map for the study area;
- read the soil-association descriptions in the text to identify major soil types;
- read the individual soil series descriptions for the major soil series in each soil association;
- review the depth and thickness of each soil texture in the soil profile by referring to the USDA texture category in the table of engineering properties: and
- evaluate all soil horizons in the profile of a soil series and choose the most significant textural layers that will affect infiltration based on consideration of the thickness and texture of the layers. Compare the chosen texture with the surface texture described in the general soil association description and map legend to determine what portions, if any, of the general soil association map may be used.

Topography

As used in these guidelines, "topography" refers to the slope and slope variability of the land surface. Topography helps control the likelihood that precipitation will runoff or remain on the surface in one area long enough to infiltrate. Topography is also significant because gradient and direction of flow often can be inferred for water-table conditions from the general slope of the land.

Table 5-6 Ranges and Ratings for Topography

Topography	
Range, %	**Rating**
0-2	10
2-6	9
6-12	5
12-18	3
>18	1
Weight: 1	

Percent slopes for topography may be determined from published terrain maps and NTS topographic maps. Recently published soil and terrain maps have designations on the maps which represent percent slope ranges.

Percent slope may also be calculated directly from topographic maps. Percent slope is equal to the vertical "rise" divided by the horizontal "run". The user must measure the change in elevation over a measured distance on the topographic map. Change in elevation is calculated by counting the number of contour lines crossed within the measured length, multiplied by the contour interval of the map.

Impact of the Vadose Zone Media

The vadose zone is defined as that zone above the water table which is unsaturated. The type of vadose zone media determines the recharge characteristics of the material below the soil profile and above the water table. Vadose zone media have been designated by descriptive names. Each medium, listed in order of increasing recharge capability, is discussed as follows:-

Confining layer – this media is chosen when evaluating a confined aquifer. A confining layer represents an impermeable layer which restricts the movement of water into an aquifer.

Silt/Clay – a deposit of silt and clay-sized particles which serves as a barrier to the movement of water.

Metamorphic/Igneous Rock – consolidated rock of metamorphic or igneous origin which contain no significant primary porosity and which permit movement of water through fractures.

Shale – a consolidated thick-bedded clay rock which may be fractured. Infiltration capacity is low but increases with the degree of fracturing.

Limestone – consolidated massive limestone or dolomite which typically contains fewer bedding planes than bedded limestone, sandstone and shale sequences. Infiltration capacity is low but increases with the degree of fracturing.

Sandstone – a consolidated sand rock which contains both primary and secondary porosity and is typified by thicker bedding as opposed to bedded limestone, sandstone and shale sequences. Infiltration capacity is largely controlled by the degree of fracturing and the primary porosity of the sandstone.

Bedded Limestone, Sandstone and Shale – typically thin-bedded sequences of sedimentary rocks which contain primary porosity, but where the controlling factor in determining infiltration capacity is the degree of fracturing.

Sand and gravel with Significant Silt and Clay – unconsolidated mixtures of sand and gravel which contain an appreciable amount of fine material. These materials have a high concentration of clay, thereby reducing the permeability of the deposits. These deposits are commonly referred to as "dirty" and have a lower infiltration capacity than "clean" sands and gravels.

Sand and Gravel – unconsolidated mixtures of sand to gravel-sized particles which contain only small amounts of fine materials. The range in ratings shown in Table 5-7 reflects principally a grain-size distribution where unsorted fine-grained deposits have a lower infiltration capacity and coarser-grained well-sorted deposits have a higher infiltration capacity.

Basalt – consolidated extrusive igneous bedrock which contains bedding planes, fractures and vesicular porosity. This is a special case of metamorphic/igneous. The term is used herein in a generic sense, even though it is actually a rock type.

Karst Limestone – consolidated limestone bedrock which has been dissolved to the point where large open interconnected cavities and fractures are present. This is a special case of limestone where infiltration capacity is high based on the amount of open area in the rock.

Table 5-7 Ranges and Ratings for Impact of the Vadose Zone Media

Impact of the Vadose Zone Media		
Range	Rating	Typical Rating
Confining Layer	1	1
Silt/Clay	2-6	3
Shale	2-5	3
Limestone	2-7	6
Sandstone	4-8	6
Bedded Limestone, Sandstone and Shale	4-8	6
Sand and Gravel with significant Silt and Clay	4-8	6
Metamorphic/Igneous	2-8	4
Sand and Gravel	6-9	8
Basalt	2-10	9
Karst Limestone	8-10	10
Weight:5		

The selection of the vadose zone media depends on whether the aquifer to be evaluated is unconfined or confined. In the case of an unconfined aquifer, the user must select the most significant media which influences infiltration capacity. By definition, the vadose zone will include all the unsaturated material below the soil and above the water table.

Where an aquifer is confined, the impact of the vadose zone includes all material below the soil and above the top of the aquifer. In many situations, the vadose zone will not be a true vadose zone, because part of the saturated zone may be treated as the vadose zone. When evaluating a confined aquifer, the user must choose "confining layer" as the vadose zone media.

Since the confining layer is the media which most significantly impacts infiltration capacity, the user is choosing the true impact of the vadose zone. Confining layer is used regardless of the other media composition of the area.

For example, where a sandstone aquifer is overlain by a confining shale layer which is in turn overlain by a sand and gravel deposit of sufficient thickness, the impact of the vadose zone media is chosen as "confining layer" even though the shale and sand and gravel would be listed in Table 5-7.

Although no specific designation for glacial till is listed in Table 5-7, glacial tills can be evaluated using the following criteria:

- Depending on the characteristics of the till, the user may choose either **silt/clay** or **sand and gravel with significant silt and clay** as the appropriate media and adjust the ratings accordingly.
- For example, a sandy till may be called a sand and gravel with significant silt and clay and assigned a rating of 6. Conversely, a dense, unfractured clayey till would be called silt/clay and assigned a rating of 3.

Information on the vadose zone media is typically available in published geologic or hydrologic reports, well logs or other exploratory boring.

Hydraulic Conductivity of the Aquifer

Hydraulic conductivity refers to the ability of the aquifer materials to transmit water, which in turn, controls the rate at which groundwater will flow under a given hydraulic gradient. Hydraulic conductivity is controlled by the amount and interconnection of void spaces within the aquifer which may occur as a consequence of intergranular porosity, fracturing and bedding planes.

Values for hydraulic conductivity are calculated from aquifer pumping tests. Information on hydraulic conductivity is typically available in published hydogeologic reports. If this information is not available from published reports, values of hydraulic conductivity may be estimated as follows:-

For **unconsolidated deposits with interstices**, the hydraulic conductivity depends on the size of the grains, as in the following table.

Medium (Unified Soil Classification)	K (m/day)
Sandy silt	0.5-2
Silty sand	2-4
Very fine sand	4-20
Fine sand	20-40
Fine sand	40-80
Fine to medium sand	80-130
Medium to coarse gravel	130-180
Coarse sand and gravel	180-400

For **hard rocks**, hydraulic conductivity depends on the permeability of the matrix and that of the fractures. The following table of ranges is given for unfractured rocks.

Medium	K (m/day)
Limestone	10^{-3}-10^{-7}
Sandstone	10^{-2}-10^{-8}
Metamorphic/Igneous	10^{-7}-10^{-11}

The broad ranges for hydraulic conductivity provided in Table 5-8 were designed to provide flexibility in selecting appropriate values.

Table 5-8 Ranges and Ratings for Hydraulic Conductivity

Hydraulic Conductivity (metres/day)	
Range	**Rating**
<4	1
4-12	2
12-28	4
28-40	6
40-80	8
>80	10

Weight: 3

From the above discussion and in the application of the DRASTIC Index, it will be recognized that there is redundance between some of the parameters. Net recharge determines, on an annual basis, the quantity of water from precipitation that is available for infiltration. Topography and soil media also influence net recharge. Topography has site-specific influence which determines whether the capacity for recharge is high or low. The permeability of the surface soils has a similar impact. In addition to its direct influence upon recharge, topography exerts a significant influence upon soil thickness, drainage characteristics, and development of the soil profile. These factors, in turn, influence soil media as well as previously-mentioned factors. In addition, topography usually bears a predictable relationship to hydraulic gradient and direction of groundwater flow under water-table conditions.

It is evident that all of the DRASTIC parameters are interacting, dependent variables. There selection is based on available data quantitatively developed and rigorously applied, but on a subjective understanding of "real world" conditions in a given area. The value of the DRASTIC parameters is in the fact that they are based on information that is readily available for most areas of British Columbia, and which can be obtained and meaningfully mapped in a minimum of time and at minimum cost.

5.5 USING THE DRASTIC SYSTEM

This section provides a step-by-step discussion of the methods used to evaluate a study area using DRASTIC. Although each user who uses the method will personalize the approach, the following discussion will provide a starting point for the user.

Step 1. Gather all published information available for the study area for each DRASTIC parameter.

Step 2. Read and evaluate available data. Start to make preliminary choices about which aquifer, or aquifers, should be evaluated. DRASTIC permits the user to choose either a confined or unconfined aquifer for evaluation. This choice will determine the type of data needed for other key DRASTIC parameters. Depth to water and the impact of the vadose zone media are most significantly affected. Remember, if an aquifer is evaluated as confined, the depth to water is chosen as the depth to the top of the aquifer and the impact of the vadose zone is chosen as a confining layer.

The user may also choose to evaluate different aquifers on the same map. This may be necessary where the aquifer is not continuous across the study area. Evaluation of different aquifers may be desirable where one aquifer does not have the same importance, either economically or usage-wise in the area. Care should be taken to document which aquifer is being evaluated so that users of the final map can understand the evaluations. DRASTIC does not permit the evaluation of two separate aquifers at the same location on the same map; two separate maps must be produced.

Step 3. Identify the pertinent hydrogeologic region and begin to formulate ideas about the appropriate hydrogeologic setting.

Step 4. Begin the mapping procedure by selecting a 1:20,000 scale topographic map. It is recommended that mapping proceed to the adjacent maps to maintain continuity.

Step 5. Mapping is carried out by creating a series of overlays to represent the DRASTIC parameters. Theoretically an overlay is necessary for each parameter, however DRASTIC parameters are frequently closely associated. In some areas the vadose zone and aquifer media are the same. In other areas, soil and topography are intimately related. In these instances, it is not necessary to create seven separate overlays.

Step 6. After the 1:20,000 topographic map is selected, the first overlay can be constructed by placing a piece of matte acetate over the map and taping it down. Choose a DRASTIC parameter to begin the map. It is typically easier to choose the aquifer media as the starting parameter because the values chosen for other parameters may depend on the choice of aquifer for mapping. So that consistency in creating the maps is maintained, a specified colour should be assigned to each DRASTIC parameter.

Step 7. Referring to available information, draw boundary lines for the chosen DRASTIC parameter using the categories provided in Tables 5.2 through 5.8. Try to keep in mind that DRASTIC is best applied by recognizing the generalities and combining the unimportant specifics. This is best done by remembering that drastic areas should represent areas that are 40 hectares or larger in size. It is important to "lump" generalities and not to "split" unnecessarily.

It is during the mapping exercise that the user may become acutely aware of data gaps or data deficiencies. It is often times necessary to supplement the printed information with professional expertise. It is also during the mapping exercise that the user will realize that the data used to generate the DRASTIC map is produced at a variety of scales. For example, soils are commonly mapped at a level of detail representing 85% accuracy in a 0.5 or 1 ha area. Whereas, values for hydraulic conductivity are frequently extrapolated from only a few points of reference or simply estimated from aquifer media. When creating the map it is therefore important to attempt to "justify" the scales by either making generalizations or finding the most detailed information available. This process of trying to evaluate data at relatively equal scales produces a better map.

Step 8. Label the enclosed areas with the appropriate category. Record the corresponding weight and rating for the area and multiply the two numbers. Circle the number for easy reference.

Step 9. Select the next parameter to evaluate. Tape down an additional acetate sheet or use the same sheet as before. Select a different coloured pencil. Draw in the appropriate boundaries, label and circle the computed number.

Step 10. Continue to map all seven DRASTIC parameters with a different coloured pencil using as many sheets of acetate as necessary. By the time this portion of the exercise is complete, the user will have identified areas where additional information is needed.

Step 11. Overlay and align all the sheets of acetate. Add an additional clean acetate sheet to the top. Select a black, or other appropriate, pencil and retrace all the boundaries that are seen through the overlain sheets. Remember that the final map should have no areas smaller than 40 hectares. This may mean that the user may not be able to trace all the lines. In this instance, the user needs to employ the technique of "lumping." This is best done by reviewing the parameters that create this line. The user should carefully look at boundaries which coincide between parameters. Where one or more parameter lines coincide the importance of keeping that line is enhanced. The reliability of the data which made the line should also be evaluated. For example, it is frequently very easy to make a detailed map using topography alone. However, since topography has only a weigh of 1 in DRASTIC, it may be possible to re-evaluate those boundaries with respect to soil, vadose zone and aquifer boundaries. By reasoning processes similar to this, the user is able to create a valid map delineating realistic areas.

Step 12. At this point, the user needs to evaluate the hydrologic settings which are present on the map. This is done by reviewing the descriptions in the appropriate hydrogeologic region as described by Aller, et al (1987). The descriptions and block diagrams provide generalized information about important hydrogeologic parameters with respect to the occurrence and distribution of groundwater. The block diagrams provide a "typical" range of values which might be present somewhere in the study area. It is unlikely that the map which has been generated will duplicate the type descriptions presented in Aller, et al.

Step 13. Next label the areas on the final map with the appropriate hydrogeologic setting and sum the DRASTIC numbers for a selected area. This number is the DRASTIC Index for the mapped unit and a measure of relative pollution potential.

The user should note that the map produced using these steps is a map which outlines areas of hydrogeologic settings and variable DRASTIC Indices. However, the user should also note that the numbers are not contoured. Contour lines imply a sequential progression between each line. The DRASTIC numbers are comparative and not sequential. This means that each individual index value is not related to the adjacent value but only serves as a means of comparison.

It is possible to construct a DRASTIC map using a Geographic Information System (GIS). A Geographic Information System (GIS) is designed to combine and display many layers of spatial data into differing formats so results may be more easily interpreted by the user. Geographic Information systems is a broad term for a variety of software packages capable of manipulating spatial-oriented data. The capabilities and output of the GIS varies with the software package.

6. LEVEL 2 GROUNDWATER ASSESSMENT – DETAILED

6.1 Introduction

A Level 2 Groundwater Assessment provides a quantitative description with respect to the occurrence and distribution of groundwater within a study area. The objectives of the Level 2 assessment are summarized as follows:-

- define the hydrogeologic setting of the study area;
- estimate the annual groundwater recharge to the area;
- evaluate potential yield and water-quality problems.

Activities carried out during the detailed groundwater assessment always include an information search and field reconnaissance survey. Upon completion, a forecast of the scope and budget for the remainder of the assessment can be made. The Level 2 Groundwater Assessment consists primarily of the following tasks:

- The collection, synthesis and analysis of all available pertinent information including hydrogeological reports, geological maps and reports, topographic and terrain maps, aerial photographs, water quality and climatological information and water well and spring records on file with the Ministry of Environment, Lands and Parks.
- A field reconnaissance survey of the various factors which affect the occurrence and distribution of groundwater including an inventory of existing water wells and springs to determine their yield characteristics and chemical quality-of-water.
- Preparation of a groundwater map and assessment report which outlines existing hydrogeological conditions and provides recommendations, specifications and cost estimates for detailed groundwater studies in those areas requiring further assessment.

6.2 Information Search

Assemble and evaluate all pertinent data available for the study area, including such possible sources as geologic maps, topographic maps, aerial photographs, geologic reports, water well records, water-quality information and climatological records.

6.3 Hydrogeologic Setting

This report has been prepared using the concept of hydrogeologic settings. A hydrogeologic setting is a composite description of all the major geologic and hydrologic factors which affect and control the movement of groundwater into, through and out of an area. It is defined as a mappable unit with common hydrogeologic characteristics.

Regional Hydrogeologic Setting

Initially, a review of a regional groundwater conditions is carried out. The Groundwater Section of the Ministry of Environment, Lands and Parks has historically taken the lead in defining regional groundwater systems in British Columbia, and continually updates this work. The latest edition of Groundwater Resources of British Columbia, Draft No. 2, September, 1991 uses the following criteria to define regional hydrologic settings:-

- Number and type of aquifers and confining bed relationships;

- Type of porosity in dominant aquifer;
- Storativity and transmissivity of dominant aquifer; and
- Recharge and discharge mechanisms of dominant aquifer.

B.C. Environment has divided the province into nine geographic groundwater regions and twenty-five sub-regions. Within a regional groundwater system lie many local aquifers that may provide significant amounts of groundwater. These may include alluvial river deposits, glacial moraines and outwash deposits, and fractured bedrock.

Local Hydrogeologic Setting

Any study area is actually a three-dimensional volume consisting of one or more aquifers separated or bounded by confining beds. Its depth may be defined as that below which no significant groundwater occurs or the quality of the groundwater is unsuitable.

Within a local hydrogeologic setting a convenient unit of study is the drainage basin in which the surface-water divides and groundwater divides coincide, and for which there are no external inflows or outflows of groundwater (Freeze and Cherry, 1979). On a suitable sized topographic map, the boundary is the line that is perpendicular to each maximum topographic contour that it crosses. The surface area of the basin may be calculated using a planimeter or by direct measurement using the map scale.

The basin boundary may be considered no-flow boundary because no flow crosses it. All precipitation falling within the boundary flows toward the centre of the basin, whereas precipitation falling outside the boundary flows into another basin. The geologic lower boundary of the study area, sometimes referred to as a hydrologic basement, may also be considered no flow boundary because no significant groundwater flow crosses it.

A system of branching streams collects drainage and carries it out of the basins. Stream courses are marked on topographic maps. Depending upon the size of the drainage basin and the map scale, positions of surface-water bodies, such as ponds and reservoirs, and gauging stations are shown on the map.

Aquifer-Confining Bed Systems

The study area may include a multiaquifer system composed of two or more aquifers separated and bounded by confining beds. If there is little or no pumping within the area, it may be considered to be in a steady-state or equilibrium condition (heads within the aquifer do not change appreciably over time). With groundwater pumping, leakance may allow confining beds to release significant amounts of water from storage into adjoining aquifers.

Geologic maps indicate the aerial extent of potential alluvial aquifer materials and their contact with bedrock and structures that control the movement of groundwater. These unconsolidated surficial deposits are usually designated on standard geologic maps . The extent of such deposits can also be revealed on aerial photographs and, more precisely, by field mapping. Major structural controls over groundwater flow such as faults may also be shown on geologic maps. The study of aerial photographs sometimes reveals structural patterns that control groundwater movement in fractured crystalline rocks. These are indicated as lineaments caused by soil or vegetation change too subtle to be seen at the surface. Vertical cross sections may be shown on geologic maps. These are prepared using surface data such as geological structures formed by tectonic and erosional processes, and from borehole and geophysical data. Often it is possible to improve the accuracy of these cross-sections with information gathered during the information search and reconnaissance phase of the study.

When the basin is large in relation to the study area it is practical to isolate a portion of it for more detailed work. Boundaries should be established around the desired area parallel and perpendicular to the direction of inferred groundwater flow.

Direction of Groundwater Movement and Hydraulic Gradient

A well inventory is prepared during the preliminary phase of the assessment. Essential data included are the surface elevation of all boreholes, their total depths, water levels (which may be obtained by sounding) and screen or perforation schedules.

If no direct or indirect observation of the groundwater elevation is available, the surface topography is assumed to reflect the direction of groundwater flow. In areas of relatively low topographic relief, the surface elevation gradient may also be assumed to be the hydraulic gradient.

When water level data are available, they are plotted and contoured on the base map, usually topographic. The groundwater flow lines are drawn at right angles to the water-level elevation contours in the direction of decreasing elevation. After the elevation contours have been drawn, the hydraulic gradient expressed as the decrease in water level elevation per unit of horizontal distance can be calculated at several different point on the map.

This procedure, though simple, can lead to erroneous conclusions because the potentiometric surface is neither static nor a simple plane. It moves and changes its profile in response to varying patterns of recharge, discharge, and pumping. Unless all water levels are measured over a short period of time, the contour map may be incorrect.

When more than one aquifer exists in the hydrogeologic environment, each has its own potentiometric surface, direction of groundwater flow, and hydraulic gradient. A potentiometric map prepared from measured water levels in more than one aquifer will usually reveal a complex surface, which should alert the investigator that a multiaquifer system exists. Sometimes the contouring of a potentiometric surface permits subdividing a groundwater basin into several subbasins.

Some error is inherent in mapping a continuous surface from a fixed number of data points. In drawing water level contours, interpolation must be performed between the points. When data points are few and unequally spaced, only limited confidence can be placed in the resulting map. Extrapolation by contouring beyond the control points, as may occur with the use of computer-contouring programs, should therefore be interpreted with caution.

It should be noted that a groundwater contour map may be used to construct a flow net and, as such, can be used to estimate the magnitude of groundwater flow. A flow net is a graphical illustration of groundwater flow represented by two sets of lines. One set, referred to as equipotential lines, connect points of equal head and thus represents the elevation of the water table or potentiometric surface. The second set, referred to as flow lines, indicates the path followed by a particle of water as it moves through the aquifer in the direction of decreasing head. Flow nets not only show the direction of groundwater flow, but can be used to estimate the quantity of groundwater flowing through the aquifer.

By rewriting Darcy's law as a finite difference equation, the total flow (Q) becomes

$$Q = T(N_f / N_d)h \tag{6.1}$$

where T = transmissivity (L^2T^{-1})
N_f = number of flow channels
N_d = number of potential drops
$h = (N_d)\Delta h$
Δh = difference in head between equipotential lines

The Darcy equation shows that for constant flow, the hydraulic gradient bears an inverse relationship to the hydraulic conductivity. This suggests that areas where the hydraulic gradient is relatively low should be favourable for groundwater development (wider spacing of water-table contours infers areas of higher hydraulic conductivity).

The direction of movement of groundwater may indicate the location of recharge and discharge areas. Groundwater contour maps reveal concealed barriers to groundwater flow, such as faults or shallow bedrock ridges by abrupt changes in water level. These linear features are indicated by zones of relatively large water level difference.

6.4 The Hydrologic Budget

If the information search justifies further study, the next step is to construct a simple hydrologic budget, using easily accessible rainfall data, a topographic map, and a generalized geologic map. It quickly can be determined if the objectives in terms of the hydrogeologic setting are reasonable. If so, a field reconnaissance visit is conducted.. This will improve the hydrogeologic perspective and provide the bulk of the conceptual solution to the problem.

Quantification of the flow system concept with respect to the occurrence and distribution of groundwater requires the introduction of a hydrologic budget equation, or water balance, that describes the hydrologic regime in a drainage basin (Freeze and Cherry, 1979). However, the application of steady-state hydrologic budget equations provides only a crude approximation of the hydrologic regime in a drainage basin.

If we limit ourselves to drainage basins in which the surface water divides and groundwater divides coincide, and for which there are no external inflows or outflows of groundwater, the water-balance equation for an annual period would take the form

$$P = Q + E + \Delta S_S + \Delta S_G \tag{6.2}$$

where P = precipitation
Q = runoff
E = evapotranspiration
ΔS_S = change in surface-water storage
ΔS_G = change in groundwater storage

Averaged over many years of record, $\Delta S_S = \Delta S_G = 0$, and Eq. (6.2) becomes

$$P = Q + E \tag{6.3}$$

where P = average annual precipitation
Q = average annual runoff
E = average annual evapotranspiration

Considering an ideal drainage basin, wherein the discharge area constitutes a very small percentage of the total basin area, then

$$Q = Q_S + Q_G \quad (6.4)$$

where QS is the surface water component of average annual runoff and QG is the groundwater component, or average annual baseflow, of average annual runoff. Equation (6.4) suggests that it might be possible to separate streamflow hygrographs into their surface-water and groundwater components.

Calculation of a Hydrologic Budget

The calculation of a hydrologic budget is relatively simple, involving only the subtraction of total outflow from total inflow, plus or minus the change in storage within the study region. However, the application of the steady-state hydrologic-budget equation provides only a crude approximation of the hydrologic regime in a drainage basin and estimation of values for the individual variables within the equation may be difficult.

Of all these variables, it is the evapotranspiration estimates that pose the greatest problem since it includes water evaporated from water surfaces, soils, and other surfaces, as well as that transpired by vegetation. The most widely used methods of calculation utilize the concept of potential evapotranspiration (PE), which is defined as the amount of water that would be removed from the land surface by evaporation and transpiration processes if sufficient water were available in the soil to meet the demand.

In a discharge area where upward rising groundwater provides a continuous moisture supply, actual evapotranspiration (AE) may closely approach potential evapotranspiration. In a recharge area, actual evapotranspiration is always considerably less than potential evapotranspiration.

Numerous empirical methods of calculating evapotranspiration have been developed. The most common is that of Thornthwaite and Mather (1957) where potential evapotranspiration (PE) is estimated solely from climatological measurements. The potential evapotranspiration (PE) per month is given by

$$PE = U \times F(\lambda) \quad (6.5)$$

where U = unadjusted potential evapotranspiration equal to $16(10t/TE)^a$

$a = 0.000000675(TE)^3 - 0.0000771(TE)^2 + 0.01792(TE) + 0.49239$

TE =*temperature-efficiency index*, being equal to the sum of twelve monthly values of heat index $i = (t/5)^{1.514}$, where t is the mean monthly temperature in °C

$F(\lambda)$ =correction coefficient, function of the latitude and month as given in Table 6-1.

Equation (6.5) provides an estimate of monthly "potential" evapotranspiration (PE) that represents the evaporating power of the atmosphere observed on the ground in a plant-covered area where there is at all times sufficient water in the soil for the needs of the vegetation. If there were a shortage of water, the actual evapotranspiration (AE) would be a function of the PE and the quantity of available water.

Table 6-1 Correction Coeffiecient F(λ) Depending on Month and Latitude

Lat N	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
48	0.76	0.80	1.02	1.14	1.31	1.33	1.34	1.23	1.05	0.93	0.77	0.72
49	0.75	0.79	1.02	1.14	1.32	1.34	1.35	1.24	1.05	0.93	0.76	0.71
50	0.74	0.78	1.02	1.15	1.33	1.36	1.37	1.25	1.06	0.92	0.76	0.70

As a first approximation, one imagines that the upper layer of the soil constitutes a reservoir, the maximum capacity of which is estimated (St). In this reservoir, evapotranspiration may occur freely at the potential evapotranspiration (PE) rate. When it is empty, the evapotranspiration can only feed on the precipitation of the given month. When it is full, the excess moisture generates infiltration towards the aquifer. During a given month, one calculates the balance of the rainfall, the PE and the soil moisture storage (St), which makes it possible to compute the AE and the moisture surplus (N), that water available for runoff and/or groundwater recharge.

Table 6-2 gives an example for the climatological station located at the Vancouver International Airport using the Thornthwaite formula to calculate PE. Thus we can estimate, as a first approximation, that the moisture surplus in 611 mm/year and the actual evapotranspiration 502 mm/year.

Table 6-2 Estimation of Evapotranspiration and Moisture Surplus

Thornthwaite Water Balance (mm)													**49° 11′N**
													123° 10′W
STATION:	**VANCOUVER INT'L A**												**Elev: 3m**
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temp	2.5	4.6	5.8	8.8	12.2	15.1	17.3	17.1	14.2	10.0	5.9	3.9	9.8
I	0.35	0.88	1.25	2.35	3.86	5.33	6.55	6.43	4.86	2.86	1.28	0.69	36.69
U	10.6	20.4	26.2	41.1	58.5	73.6	85.2	84.2	68.9	47.2	26.7	17.1	
F(λ)	0.75	0.79	1.02	1.14	1.32	1.34	1.35	1.24	1.05	0.93	0.76	0.71	
PE	8	16	27	47	77	99	115	104	72	44	20	12	642
P (mm)	154	115	101	60	52	45	32	41	67	114	150	182	1113
P-PE	146	99	74	13	-26	-53	-83	-63	-5	70	130	170	471
PWL_{cum}					-26	-79	-162	-225	-230				
St	100	100	100	100	77	44	19	10	9	79	100	100	
StCh	0	0	0	0	-23	-33	-25	-9	-1	70	21	0	
AE	8	16	27	47	75	78	57	50	68	44	20	12	502
Def.	0	0	0	0	3	20	58	54	4	0	0	0	140
N	146	99	74	13	0	0	0	0	0	0	109	170	611

PE = potential evapotranspiration
P = precipitation
P-PE = precipitation minus potential evapotranspiration
PWL_{cum} = accumulated potential water loss
St = soil moisture storage
StCh = water added to (+) or withdrawn from (-) soil moisture storage
AE = actual evapotranspiration
Def = moisture deficit, (PE-AE)
N = moisture surplus, (P-AE)-StCh

Groundwater in Storage

Although the total amount of groundwater stored within an aquifer is not an element of the hydrologic budget, it is essential in that it represents water available for use. However, often only a portion of the groundwater in storage may be exploited without creating undesirable effects.

The **sustainable yield** of a groundwater basin can be defined as the annual extraction of water that does not exceed the average annual groundwater recharge.

This concept is not quite correct, major groundwater development may significantly change the recharge-discharge regime as a function of time. Basin yield depends on both the manner in which the effects of withdrawal are transmitted through the aquifers, and on the changes in the rates of groundwater recharge and discharge induced by the withdrawals. In the form of a transient hydrologic budget, the flow equation may be written

$$Q_t = R_t - D_t + \Delta S/\Delta t \qquad (6.6)$$

where Q_t = total rate of groundwater withdrawal
R_t = total rate of groundwater recharge to the basin
D_t = total rate of groundwater discharge from the basin
$\Delta S/\Delta t$ = rate of change of storage in the saturated zone

Referring to Eq. (6.6), withdrawals from a groundwater basin which increase with time result in a steady-state flow system in which recharge equals discharge. Each increase is initially balanced by a change in storage, which in an unconfined aquifer takes the form of an immediate decline in the water table. At the same time, the basin strives to set up a new equilibrium under conditions of increased recharge.

If pumping rates are allowed to increase indefinitely, an unstable situation arises where the declining water table reaches a depth below which the maximum rate of groundwater recharge can no longer be sustained.

After this point in time, the same annual precipitation rate no longer provides the same percentage of infiltration to the water table. Evapotranspiration during soil-moisture-redistribution periods now takes more of the infiltrated rainfall before it has a chance to percolate down to the groundwater zone.

At some point in time with increasing pumping rates, the water table reaches a depth below which no stable recharge rate can be maintained. Once the maximum available rate of induced recharge is attained, it is impossible for the basin to supply increased rates of withdrawal.

The only source lies in an increased rate of change of storage that manifests itself in rapidly declining water tables and pumping rates can no longer be maintained at their original levels. At this point "mining" of the aquifer begins.

To derive an estimate for groundwater in storage within a basin, it is necessary to multiply the volume of saturated materials by their specific yield (S_y). To obtain aquifer volume, it is necessary to know the basin boundary, the shape and thickness of the geological container, and the nature of to aquifer materials. Usually only a very rough estimate can be made during the preliminary phase of a groundwater study.

6.5 Hydrogeologic Reconnaissance

The field reconnaissance survey is carried out to observe and note those characteristics which affect the occurrence and distribution of groundwater and may include:-

- the location of existing water wells and springs, their elevation, water levels and yield characteristics;
- chemical quality-of-water; and

- mapping those parameters which may affect the occurrence and distribution of groundwater.

Data collected during the field reconnaissance survey are primarily areal in character. Observation details recorded in a field notebook are referenced to specific map locations. One major task is the mapping of the surficial extent of aquifer materials. Surface observations coupled with standard geologic mapping techniques such as delineation and evaluation of outcrops, formation contacts, fractures, and measurements of strike and dip are useful.

Better understanding of the hydrogeologic environment is aided by preparation of vertical cross sections from these data in conjunction with lithologic logs of existing boreholes. Lithological samples may be gathered and preserved for later, more detailed examination.

A well inventory is usually made during the reconnaissance survey. The location and surface elevation of each well, together with any other relevant information such as owner, total depth, and current status - abandoned, inactive, or active - is recorded. Hydrogeologic tasks such as water level, field water-quality measurements (temperature, conductivity, pH, etc.), and collection of water samples for laboratory analyses may be accomplished. Frequently, however, wells are sealed for protection and special arrangements for access must be made. It may be worthwhile to repeat water-level measurements during subsequent field visits to check for seasonal variations.

Stream courses should also be located on the field map, and an estimate of their flows made. This may be done by timing a float along a measured reach at a point where an approximation of cross-sectional area of the flow channel can be made. Mapping of natural surface-water bodies, as well as associated seepage areas, may help to define a discharge zone or the location of barriers acting as natural dams to groundwater flow.

Springs represent groundwater discharge zones. They should be mapped, flows estimated, and samples taken for water-quality tests.

When the reconnaissance is completed, the data are compiled, analyzed, and collated with the data collected from the information search. The preliminary hydrologic budget is revised, allowing for a more reliable opinion whether or not objectives can be reached. If the opinion is marginal or clearly positive, the investigator will design a phased program of investigation proceeding from the general to the specific.

6.6 Chemical Quality-of-Water

The chemical quality of groundwater is determined by the kind and amount of chemical matter dissolved in the water. A knowledge of the chemical quality of groundwater and its areal distribution is important from both the point of view of its suitability for human consumption and for the information it can supply about the direction and extent of groundwater flow.

Chemical analyses for the major constituents of groundwater may be carried out in the field, but detailed investigation usually requires submitting the water sample to a water-quality laboratory. The following constituents should be either determined or calculated: HCO_3^- + CO_3^{--}, Cl^-, SO_4^{--}, Ca^{++}, Mg^{++}, Na^+ + K^+, Fe^{++} and total dissolved solids. Methods of analysis and interpretation have been described by Toth (1966).

The degree of mineralization of groundwater is proportional to the time the water spends in the ground. At recharge areas bicarbonate is the dominant anion, whereas chloride and sulphate become more important as the water moves toward discharge area. The ratio of Ca^{++} to Mg^{++} decrease generally toward discharge areas because of the higher solubility of magnesium compounds than that of calcium compounds.

Since some dissolved constituents (Ca^{++}, Mg^{++}, Fe^{++}, Fe^{+++}) may precipitate from a water sample during storage under laboratory conditions the analyses should be completed as soon as possible after the samples have been collected.

The preliminary examination of chemical quality-of-water data is aimed at classifying the chemical analyses of groundwater, identifying hydrochemical types and describing changes in the chemical composition in time and space. The regional distribution of the six principal components (HCO_3^-, Cl^-, SO_4^{--}, Ca^{++}, Mg^{++}, $Na^+ + K^+$) should be determined first and the analytical results plotted on the classification diagram shown in Figure 6.1 in which the concentration ions determined in each analysis is designated by a symbol which is entered in the appropriate square of the graph. Grouping of the analyses shown on the classification diagram is made after taking into consideration the geological and hydrological situation.

		HCO_3		SO_4		Cl	
		Cl	SO_4	HCO_3	Cl	SO_4	HCO_3
Ca	Mg						
	Na						
Na	Ca						
	Mg						
Mg	Ca						
	Na						

Figure 6-1 Classification Diagram Illustrating Chemical Composition of Groundwater

Compilation of hydrochemical maps showing the aerial distribution of total dissolved solids, relative amounts of $HCO_3^- + CO_3^{--}$, and the ratio of Ca^{++} to Mg^{++} may provide an insight to the distribution of groundwater flow within the drainage basin.

6.7 Synthesis of Data

After all the information has been gathered and analyzed, a conceptual hydrogeologic model that best fits the observed data must be developed. From the well records and static water-level measurements, conclusions can be drawn about the number and types of aquifers present in the study area. From the position of the static water level and the depths to various boundaries, estimates of aquifer thickness can be made. Estimates of hydraulic conductivity and aquifer thicknesses are used to predict aquifer transmissivities and potential aquifer yields. Aquifer thicknesses may also be used in conjunction with predicted zones of greater hydraulic conductivity to make site selections for exploratory drilling. The information search, field reconnaissance, and hydrologic budget analysis complete the preliminary phase of the groundwater assessment, and those elements needing additional detailed study are usually identified. These activities may include:

- The initiation of geophysical surveys utilizing electro-magnetic and/or resistivity methods to determine subsurface conditions and optimize locations for exploratory drilling and testing;
- The drilling and testing of exploratory wells at locations recommended for groundwater development and/or monitoring. Information obtained from these exploratory wells will be used to calculate aquifer characteristics as well as to provide optimum well design for long-term aquifer development, monitoring and protection; and
- The preparation of a detailed groundwater report and maps describing the existing groundwater regime with particular reference to groundwater potential, long-term safe yield and aquifer protection.

7. WORKING WITH MAPS

Hydrogeological maps are commonly constructed to organize significant amounts of information about the groundwater regime in both its spatial relationship and in relationship to the configuration of the land surface itself. The ability of hydrogeological maps to show this spatial relationship carries a corollary benefit, that of providing crucial tests for the validity and usefulness of the data being shown.

Classification of hydrogeological maps according to scale is easily done, but it is significant only in terms of the purpose of the map. Basically, the scale of a map is a reflection of its purpose and the reliability of the data shown, and the scale should be so determined. UNESCO (1977) has prepared the chart shown in Table 7-1 which relates map scale to data complexity and reliability. The Table also provides a guide as to the most appropriate scale to use given the number of hydrogeological elements to be shown and the density and distribution of reliable data in the area to be mapped.

Table 7-1 Map Scale Related to Aerial Coverage

Scale	Rankings Related to Aerial Coverage		
	Continental	Regional	Global
1:25,000,000	A-1	A-1	Not suitable
1:10,000,000	B-1	B-1	Not suitable
1:5,000,000	B-1	B-1	Not suitable
1:1,000,000	Not suitable	C-2	Not suitable
1:500,000	Not suitable	C-3	Not suitable
1:250,000	Not suitable	C-4	Not suitable
1:100,000	Not suitable	D-4	D-2
1:50,000	Not suitable	D-5	D-3
1:20,000	Not suitable	D-6	D-4
1:10,000	Not suitable	Not suitable	C-5
1:1,000	Not suitable	Not suitable	B-6
1:200	Not suitable	Not suitable	A-7

The system sets up arbitrary rankings of increasing complexibility and reliability, and assigns the combinations of the rankings and specific scales. In each instance the key letter-figure (A-1, etc.) suggests a lower limit of complexibility and reliability for a particular scale as follows:

Ranking by Complexity

Rank	Explanation
A	Display one element only (e.g., water table)
B	Display two elements (e.g., geology and water table
C	Display three elements (e.g., geology, water table and aquifer thickness
D	Display more than three elements

Ranking by Reliability

Rank	Explanation
1	Based entirely on estimates and generalizations

2	Data 10% reliable; 90% estimated, generalized or unknown
3	Data 25% reliable: 75% approximated
4	Data 50% reliable; 50% approximated
5	Data 75% reliable; 25% approximated
6	Data 90% reliable; 10% approximated
7	Data 100% reliable

For example, to determine the limits of usefulness of a map on a 1:250,000 scale, refer to Table 7-1 and read across on line under Scale marked 1:250,000. For continental purposes, it is not suitable. For regional purposes, it should be preferably show no more than three elements (not counting base map information such as contours, streams, roads, etc.) for which there are reliable data sufficient to cover 50% or more of the area. Obviously small-scale maps should not be used as a basis for local studies, and large-scale maps should not be used as a basis for regional interpretations. Moreover, there is a need to balance the scale of the map with the amount and reliability of information shown. A large-scale map should not be used to show limited amounts of data simply because showing them on a large-scale map makes the data appear more reliable than they really are. Similarly, the presentation of large amounts of reliable information on a small-scale map results in overloading that distracts from usefulness.

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GLOSSARY

Absorption: Refers to the trapping of molecules or ions within the internal structure of the solid.

Adsorption: The attraction and adhesion of layer of ions from an aqueous solution to the solid mineral surfaces with which it is in contact.

Advection: The transport of a non-reactive, conservative contaminant, or tracer, in a porous medium at an velocity equal to the average groundwater velocity.

Acid: Any substance which reacts with other substances and generates hydrogen ions in solution (H+), or which neutralizes bases yielding water. Is a molecule with a positive field which is capable of neutralizing a basic molecule having a "free" electron pair.

Acidity: Of a water; is the capacity of the water to donate protons (i.e. includes the un-ionized protons of weakly ionizing acids such as H2CO3 and tannic acid, as well as hydrolysing salts such as ferrous and/or aluminum sulphate). Normally expressed as mg/L CaCO3.

Acute: A stimulus severe enough to induce an immediate response.

Alkalinity: The capacity of water to accept protons (usually interpreted by the HCO31 , CO3+2, OH- components), normally expressed as CacO3.

Aquiclude: A geologic formation which has an extremely low permeability when compared to an adjacent aquifer.

Aquifer: A geologic formation, group of formations or part of a formation, that contains sufficient saturated permeable material to yield significant quantities of water to wells, boreholes and springs. Several types of aquifers can exist.

i) Confined aquifer (artesian) – contains water under sufficient pressure that water levels in wells tapping it rise above the bottom of the confining bed.

ii) Unconfined aquifer – the water table is located within the formation.

Aquitard: A geologic formation which has appreciably greater permeability than an aquiclude, but considerably lower permeability than an aquifer.

Artesian: Refers to groundwater under sufficient hydrostatic head to rise above the aquifer containing it.

Attenuation: The decreased of the maximum concentration of a given constituent in a solution as a function of time or distance travelled along a flow path. It is related to a pulse of solute injected into a flowing solution. Attenuation is, therefore, caused by both adsorption and by dispersion.

B-horizon: The lower soil zone which is enriched by the deposition or precipitation of material from the overlying A-horizon.

Bacteria: Single-cell or non-cellular microorganisms that lack chlorophyll. Some cause diseases, but others aid in pollution control by breaking down organic matter in air and water.

Baseflow: That part of stream discharge derived from groundwater seeping into the stream with respect to time.

Baseflow Recession: The declining rate of discharge of a stream fed only by baseflow for an extended period. Typically, a baseflow recession will be exponential.

Bioaccumulate: General term describing a process by which chemical substances are accumulated by aquatic organisms from water directly or through consumption of food containing the chemicals.

Bioaccumulation: The process by which a contaminant accumulates in the tissues of an organism. For example, certain chemicals in food eaten by a fish tend to accumulate in its liver and other tissues.

Bioassays : A procedure that measures the response of living plants, animals, or tissues to a test sample.

Bioavailable: The fraction of the total chemical in the surrounding environment which can be taken up by organisms. The environment may include water, sediment, suspended particles, and food items.

Biota: The animals and plants that live in a water body.

BOD: Biochemical Oxygen Demand; is a measure of the oxygen required to biochemically degrade organic, nitrogenous and inorganic materials (Unit is mg/L).

Biochemical Oxygen Demand is the quantity of materials present in a sample that need oxygen to decay, as measured by a specific test. A major objective of wastewater treatment is to reduce its biochemical oxygen demand so that the oxygen content of the water body will not be significantly reduced. Although BOD is not a specific compound, it is defined as a conventional contaminant.

Bog: An ombrotrophic peatland, which is extremely nutrient-poor, with acidic water and with a dominant Sphagnum moss vegetation.

Buffer: A mixture of a weak acid and conjugate base (e.g. H2CO3 and HCO3) which provide pH stability.

Capillary: An interstice capable of holding water above the water table by a combination of adhesive and cohesive forces.

Carcinogen: A substance which induces cancer in a living organism.

Cation Exchange Capacity (CEC): Ability of a geologic material to exchange cations adsorbed onto mineral surfaces (exchange sites) with cations in the groundwater. Expressed as the number of millequivalents of cations that can exchange in a material with a dry mass of 100g (meq/100g).

Chlorinity: Of sea water; the mass of pure silver (in grams) necessary to precipitate the halogens in 328.5233 g of sea water.

Chlorophenol: Products of the reaction between phenolic compounds and chlorine. The largest use of chlorophenols within the region is in the wood treating industry. Chlorophenols may be produced inadvertently by reactions which take place during chlorination of wastewater effluent.

Chronic: Involving a stimulus that is lingering or continues for a long time; often signifies periods from several weeks to years, depending on the reproductive life cycle of the aquatic species. Can be used to define either the exposure or the response to an exposure (effect). Chronic exposure typically induces a biological response of relatively slow progress and long continuance.

Clastic: Rock composed of broken pieces of older rocks.

COD: Chemical Oxygen Demand - a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant (Unit is mg/L).

Coefficient of Permeability (k): Ratio of flow velocity to driving force (hydraulic gradient) or viscous flow under saturated conditions of a specified liquid in a porous medium (m/s).

Cohesion: Cohesion in water refers to the attraction of water molecules to each other.

Colloidal: Size of particulate matter: Lies between lower limit of suspended matter and upper limit of dissolved solids.

Colluvial: A sedimentary deposit consisting of alluvium (river deposits) in part and also containing angular fragments of the original rocks (e.g. talus, cliff debris, rock slides, avalanche material).

Common Ion Effect: Of a solution; repression of solubility in the presence of an excess of one of the ions concerned in the solubility excess of one of the ions concerned in the solubility expression.

Consumptive Use: Of a plant; water used by plants for transpiration and growth, water vapour loss from adjacent soil/snow and intercepted precipitation (units: equiv. depth of water per unit time).

Contaminant: Any solute that enters the hydrologic cycle through human action. A substance that is not naturally present in the environment or is present in elevated concentrations or amounts, and which can, in sufficient concentration, adversely affect an environment.

Contemporaneous: Of erosion; erosion accomplished during a short cessation in the upbuilding of deposits, e.g., flood plains, deltas, etc.

Contiguous: Two adjoining bodies, e.g. laterally contiguous.

Conventional Contaminant: Conventional contaminants include suspended solids, faecal coliform bacteria, biochemical oxygen demand (BOD), nutrients, pH, and oil and grease.

Cupola: Dome shaped portion of an ambrophilous bog dominated by sphagnum and flanked on the fringe by a lagg.

Darcy's Law: The law governing laminar water flow through soils may be expressed as: $Q = KiA$ Where:

> Q = rate of flow (m3/s)
> K = the hydraulic conductivity (m/s)
> i = hydraulic gradient or head loss per unit distance travelled (dimensionless)
> A = the cross-sectional area through which the flow occurs (m2)

Darcy Velocity: Rate flow (Q) divided by the cross-sectional area (A) through which flow occurs. $VD = Q/A = nV$

Where: V = velocity of flow through interstices (m/s) and
n = porosity

Deflation: Of a geologic process: The removal of material from a beach or other land surface by wind action.

Dendritic: Of shape: Leaf like appearance, commonly refers to a drainage pattern.

Depressurization: A reduction of hydrostatic pressure.

Depocentre: Of a depositional environment: An area of maximum deposition.

Designated Water Use: A water use that is protected at a specific location, and that is one of the following:

- drinking, public water supply, and food processing
- aquatic life and wildlife
- agriculture (livestock watering and/or irrigation)
- recreation and aesthetics
- industrial water supply

Desorption: Ion exchange process whereby ions attached to geologic materials by ionic attraction or adsorption are released into solution in groundwater. Also see adsorption.

Desiccate: Of a process: Substance remaining after removal of moisture.

Detrital: Decomposed rock material consisting of mechanically derived clastic products.

Deuterium: Stable isotope of hydrogen 2H having one neutron and an atomic weight of 2.

Dewatering: Process of lowering the water table or piezometric surface by removing water from storage.

Diamicton: Of a material; a nonsorted sediment containing a wide range of particle sizes, regardless of genesis.

Diffusion: Tendency for solutes to spread out in a porous medium due to the thermal-kinetic energy of solute particles on a molecular scale. Is an important dispersive mechanism of contaminants in very low velocity groundwaters.

Diffusivity (D): See hydraulic diffusivity.

Diluvium: Of a sedimentary deposit; coarse superficial deposits of glacial and fluvio-glacial origin laid down during the ice age.

Discharge Area: An area in which there are upward components of hydraulic head in the aquifer. Groundwater is flowing toward the surface in a discharge area and may escape as a spring, seep, river baseflow, or by evaporating and transpiration.

Dispersed: Of a soil; commonly clay which readily forms colloidal particles (characteristics - low permeability, will shrink, crack and become hard on drying and slake and become plastic on wetting).

Dispersion: Tendency for solutes to spread out from a flow line along the flow path, as a result of mechanical mixing and diffusion.

Dissolved Oxygen: Oxygen which is present (dissolved) in water and therefore available for fish and other aquatic organisms to use. If the amount of the dissolved oxygen in the water is too low, aquatic organisms may be adversely affected. Wastewaters often contain oxygen demanding substances which can consume dissolved oxygen if discharged into the environment.

Distal: Sediment consisting of fine clastic formed furthest from the source area. Also refers to distant.

Dip: Of geological features; the angle at which a stratum or any planar feature is inclined from the horizontal.

DNAPL: Dense Non Aqueous Phase Liquid. These are family of organic compounds which are only slightly soluble in water and which are denser than water. These liquids include a number of chlorinated organic compounds.

Drawdown: The difference in evaluation between the static water level (before pumping or dewatering) and the water level measured in a well or piezometer after commencement of pumping or dewatering (m).

Drift: Of a glacial deposit; any rock material, such as boulders, till, gravel, sand or clay, transported by a glacier and deposited by or from the ice on land or in water derived from the melting of the ice.

DO: Dissolved Oxygen; (Unit: mg/L).

Dy: Subaqueous, muddy, acid humus horizon on top of parent material; consists of amorphous precipitation of humus gels (has a high C/N ratio).

EC: Electric conductivity of fluid measured in units of millisiemens per metre (mS/m), microsiemens per centimetre (uS/cm) or micromhos per centimetre (umho/cm). Note: 1 umho/cm = 1 uS/cm = 0.1 mS/m.

Echelon Faults: Geologic structure in rock consisting of separate faults having parallel but step-line trends.

Effective Size: Particle size of a soil: The size which 10% of the material is smaller than (i.e., 90% is retained).

Effluent: The liquid flowing out of a facility or household into a sewer system or water body.

Effluent Stream: Groundwater term used to describe a stream that is gaining groundwater along a given reach. (Note: A better term would be a gaining stream.)

Eh: A measure of the oxidizing or reducing tendency of a solution. It is measured in volts and is commonly called the redox potential and is defined as the energy gained in the transfer of 1 mole of electrons from an oxidant to H2. It is related to the pE.

Elevation Head: The portion of fluid potential of hydraulic head attributable to the elevation above a datum of the point of measurement.

Environmental Isotopes: Naturally occurring isotopes existing in water in the hydrological cycle including the stable isotopes:

oxygen-18 (18_O)
deuterium (2_H)
carbon-13 (13_C)
sulphur-34(^{34}S)

and the radioactive isotopes:

tritium (^{3}H)
carbon-14(^{14}C)

Ephemeral: Of a stream; flow occurs only in response to precipitation (i.e., no snow melt or groundwater seepage).

Equipotential Line: Two-dimensional representation of an equipotential surface (i.e., equal energy surface) in a specified hydrogeologic unit.

Equipotential Surface: Surface in a three-dimensional hydrogeological systemrepresenting locus of points of equal hydraulic head.

Equivalents per Litre (eq/L): Number of moles of solute multiplied by the valance of the solute species in one litre of solution. Reflects charge concentration rather than solute concentration.

Equivalents per Million (epm): Number of moles of solute multiplied by the valence of the solute species in one kilogram of water.

Erratic: Of a rock particle; is a clast that differs in lithology from the underlying bedrock. Generally applies to ice rafted rocks.

Evapotranspiration: The combined loss of water from soil and plant surfaces (equals: evaporation plus transpiration).

Exchange Complex: In a soil; the surface active constituents of soils (both organic and inorganic) that are capable of cation exchange.

Facies: A stratigraphic unit distinguished from other units by different appearance or composition.

Falling Head Permeability Tests: Method of determining hydraulic conductivity of the porous medium or geologic formation in the vicinity of a piezometric tip. Based on the time required for the water level in the piezometer to return to static following an artificial increase in head (tests monitoring an artificial increase in head are rising head tests).

Fecal Coliform: Those coliform bacteria which are found in the intestinal tract of mammals. The presence of high numbers of fecal coliform bacteria in a water body can indicate the release of untreated wastewater and may indicate the presence of pathogens.

Fen: Meadow like, sedge-rich peatland on minerotrophic sites, better nutritionally and less acidic than a bog. Sphagnum species are subordinate or absent.

Fibric: Refers to a peat material with a low degree of decomposition or organic matter; H1 to H3.

Field Capacity: Of a soil; the moisture content of soil in the field 2 to 3 days after a thorough wetting of the soil profile by precipitation or irrigation. (Units: % moisture on a dry weight basis).

Fixation: Process in a soil: Where certain chemical elements are retained in the soil on a semi-permanent basis.

Flowing Artesian: Groundwater under sufficient hydrostatic head to rise above ground level, and flow from a well or piezometer.

Flow Line: A line, perpendicular to equipotential lines or surfaces, which represents the direction or groundwater flow in a porous medium.

Flow Net: The set of intersecting equipotential lines and flowlines representing two-dimensional steady flow through porous media.

Flux: The fluid flow across a unit surface area of a porous medium (see Darcy Velocity). (m3/s/m2 = m/s).

Groundwater: Subsurface water occurring below the water table in fully saturated geologic materials and formations.

Gyttja: Subaqueous humus form, muddy grey-brown to blackish sediment, rich in organisms occurring in waters sufficiently rich in nutrients and oxygen.

Hardness: Of water: a measure of the amount of calcium, magnesium, and iron dissolved in the water (mg/L).

Hazardous Waste: Any solid, liquid or gaseous substance which, because of its source or measurable characteristics, is classified under the Provincial Waste Management Act, Special Waste Regulations (April 1988) as hazardous and subject to special handling, shipping, storage and disposal requirements.

Heavy Metals: Those metals which have densities greater than 5.0. These include: antimony, arsenic, beryllium, cadmium, chromium, copper, lead, manganese, mercury, nickel, selenium, silver, thallium, vanadium and zinc. Many of these compounds can damage living organisms at low concentrations and tend to accumulate in the food chain.

Humification: The decomposition of organic matter to form humus.

Humus: The fraction of the soil organic matter that remains after most of the added plant and animal residues have decomposed.

Hydraulic Conductivity (K): Ratio of Darcy velocity to driving hydraulic force (hydraulic gradient) for water, at ambient (i.e., aquifer temperatures under saturated conditions (see also Coefficient of Permeability, m/s).

Hydraulic Diffusivity: Ratio of hydraulic conductivity (K) over the specific storage (Ss) D = K/Ss = T/S, (m2/s).

Hydraulic Gradient: Change in hydraulic head per unit length of flow path (dimensionless).

Hydraulic Head: The sum of the pressure and elevation heads (m), demonstrated by the height to which a column of water in a piezometer will rise.

Hydrogeochemical Facies: Groundwater with separate but distinct chemical compositions contained in a hydrogeologic unit.

Hydrogeologic Unit: A formation, part of formation, or a group of geologic units which there are similar hydrogeologic characteristics allowing for grouping in aquifers or confining layers.

Hydrograph: A graph that shows some property of groundwater, or surface water, as a function of time.

Hydromorphic: Highly organic (bog or marsh) type of soil.

Hydrophobic: Having an adversity for water. In hydrogeochemical usage, this term indicates a relatively low affinity for dissolving in water. Compounds with Kow values greater than 0.1 are said to be hydrophobic. Very hydrophobic compounds have Kow values in ranging from 104 to 107.

Hydrostatic Head: Pressure head of water exerted at any given point in a body of stationary water (m).

Hydrostatic Pressure: Pressure exerted by water at any given point in a body of stationary water (kPa).

Hydrostratigraphic Unit: See Hydrogeologic Unit

Hypolimnion: The lower layer of water in a sea or lake.

Hypsithermal: Postglacial warm interval extending from about 7,000 to Interval 600 B.C., responsible for the last 6-foot eustatic rise of sea level.

Illuvial: Of a soil horizon; the B-horizon of the soil profile or the zone of accumulation.

Imbricate: Of a gravel deposit; the shingling or overlapping affect of stream flow upon flat pebbles in the stream bed. The pebbles are inclined so that the upper edge of each individual is inclined in the current direction.

Impermeable: Surface across which there is little or no groundwater flow, relative boundary to other units.

Infiltration: The flow or movement of water throughout the rock or soil surface into the ground.

Injection Well: A well into which water, gas or liquid waste is injected by gravity flow or under pressure, for the purpose of disposing of waste and/or maintaining formation pressures.

Ion Exchange: A process by which an ion in a mineral lattice is replaced by another ion which was present in an aqueous solution.

Ionic Strength: Constant representing the concentration of ions in solution.
Calculated as $I = ½ Mi^2 Zi^2$

where Mi = molal concentration of i species
Zi = charge of i species
I = summation for all species

Intrinsic Permeability (k*): It is an intrinsic function of the properties of the porous medium (m^2) (see also Coefficient of Permeability).

Irrigation Water Requirement: The amount of irrigation water required by crops to maintain optimum growth throughout the growing season. (unit:mm/year) (symbol = IR; but if LR is included symbol = IR_o; and if LR plus application efficiency is included then symbol = IR_{Tot})

Isopachs: Contour lines, drawn through points of equal thickness of a specified geological unit.

Isopleth: Of a graph or map; a line joining points of equal occurrence or frequency of any phenomenon.

Isostatic: Of a large portion of the earth's crust; subject to equal pressure from every side, being hydrostatic equilibrium.

Isotropy: Occurs when there is no directional variation of a physical property at a point in a porous media.

Karst: Of a limestone area: Refers to a topographic form, typically a plateau, marked by sink holes, (or karst holes), interspersed with abrupt ridges and irregular protuberant rocks. Usually underlain by caverns and underground streams.

Kinematic Viscosity: The ratio of dynamic viscosity to mass density. It is obtained by dividing dynamic viscosity by the fluid density. Units of kinematic viscosity are square metres per second.

K_d: Distribution coefficient for a particular chemical compound in and a water bearing unit. (sometimes indicated as K_p) (Typical units = L/Kg). $K_d = K_{oc} \times f_{oc}$

Kjeldahl Nitrogen: see Nitrogen.

K_{oc}: See organic carbon partitioning coefficient. $K_{oc} = K_d/f_{oc}$ (unit = L/Kg).

K_{ow}: See octanol water partitioning coefficient (dimensionless)

LNAPL: Light **N**on **A**queous **P**hase **L**iquids. Liquids which are only sparingly soluble in water and less dense than water. This includes a family of hydrocarbons commonly found in gasoline and oils which will float on the water surface.

Lagg: Zone where water collects at the margin of a peatland near the mineral ground of the surrounding site. The water in this zone is relatively rich in bases and supports an entrophic type of vegetation.

Laterite: Of a soil; red residual soil developed in humid tropical regions. It is leached of silica and contains concentrations of iron and aluminum.

Leachate: Any fluid percolating through through the various layers of refuse in a landfill, and which is primarily derived from rain or snowmelt.

Leaching Requirement: Of a soil; the amount of water entering the soil that must pass through the root zone in order to prevent the soil salinity from exceeding a specified value. Usually based on steady state or long term conditions.

Leach: To wash or drain by percolation. To dissolve minerals, chlorine solutions, acids or water.

Leakance: The vertical flux (m/s) through a low hydraulic conductivity confining layer such as a silt or clay bed.

Lethal: Causing death by direct action. Death of aquatic organisms is the cessation of all visible signs of biological activity.

Lineament: Of a surficial topographic or geologic feature; these are significant lines of landscapes which reveal hidden structural aspects of the underlying soil or rock. the lineaments are frequently observed in air photographs and are commonly due to topographic, geologic, soil moisture, vegetation, or drainage pattern anomalies.

Lithification: Of a rock forming process; the process which converts a newly deposited sediment into an indurated rock.

Lithology: Of a rock particle or group of rocks; the physical character of a rock generally as described from a magnifying glass inspection.

Lutite: Sediment or sedimentary rock consisting principally of clay and clay-sized particles.

Lysimeter: A field device containing a soil column with vegetation on the surface, which is used for measuring actual evapotranspiration or leachate.

MAH: Monocyclic aromatic hydrocarbons

Marl: Loose earthy deposit of calcium or magnesium carbonate, believed to have accumulated in fresh water basins fed by mineral water springs.

Mesic: Refers to a peat material with a moderate degree of decomposition of organic matter.

Mesotrophic: Of a lake; in its intermediate stage of aging. This comes between oligotrophic and antrophic. The nutrient content is becoming significant.

Meteoric Water Line: Line representing the relationship between 180 and 2H precipitation. On a global scale, this line is represented by the equation 2H = 8 180 + 10, but can vary from location to location.

Milliquivalents Per litre (meq/L): Equivalents per litre (eq/L) multiplied by 1000. More common expression of charge concentration in dilute solutions.

Molality (m): A measure of chemical concentration. A one-molal solution has one mole of solute dissolved in 1-Kg mass of solution, (mol/kg).

Molarity (M): A measure of chemical concentration. Number of moles of solute in 1 m3 of solution (mol/L).

Mole (mol): One mole of a compound is the equivalent of one molecular weight (in grams).

Muskeg Oligotrophic: North American term frequently employed for peatland. Of a lake; a "young" lake in its earliest stage of antrophication. Characterized by low concentrations of plant and nutrients and little biological productivity.

Mutagen: An agent that alters the genetic material of a cell in such a manner that the alteration is transmitted to subsequent generations of cells.

Nitrate/Nitrite: see Nitrogen.

Nitrogen: An essential nutrient that is often present in wastewater as ammonia, nitrate, nitrite and organic nitrogen. The concentrations of each form and the sum, total nitrogen, are usually expressed as mg/L elemental nitrogen. The sum of the ammonia, nitrate and nitrite components is called Kjeldahl nitrogen.

Non-point Sources: Contaminant sources which discharge to the receiving environment diffusely rather than through a pipe.

Nutrients: Essential chemicals needed by plants or animals for growth. Excessive amounts of nutrients can lead to degradation of water quality and the growth of excessive numbers of algae. Some nutrients can be toxic at high concentrations.

Octanol Water Partition Coefficient (K_{ow}): The ratio between: a compound's concentration in the octanol phase to its concentration in the aqueous (water) phase of a two phase system. Values range from 10-3 to 107.

Ombrotrophic(ous): Nourished by rain only; typically a raised bog. Waters are typically acidic with low calcium and almost no magnesium.

Organic Carbon Partitioning Coefficient (K_{oc}): The portion of a specific organic compound in solute that sorbs onto the solid phase organic carbon in a proous medium such as sediments.

Organics: Chemicals containing a carbon complex.

Organotin: Organic compounds such as dibutyl and tributyl tin oxide used in marine paints as antifouling agents.

Orogenic: Of the process of forming mountains, particularly by folding and thrusting.

Orthophosphate: see Phosphorus

Oxidation: Occurs in chemical reaction where electrons are released from an ion or molecule (i.e., oxidation state is increased).

Oxygen-18: Stable isotopes of oxygen (180) which has two additional neutrons and an atomic weight of 18.

PAH: Polycyclic (polynuclear) Aromatic Hydrocarbon. A class of complex organic compounds, some of which are persistent and cancer-causing. These compounds are formed from the combustion of organic material and are ubiquitous in the environment. PAH's are found in fossil fuels such as coal and oil and are formed by incomplete combustion of organic fuels like gasoline, wood, and oil. They are commonly formed by forest fires, wood stoves, and internal combustion engines. They often reach the aquatic environment through atmospheric and highway runoff.

PCB: Polychlorinated biphenyl. These include about 70 different but closely related man-made compounds made up of carbon, hydrogen, and chlorine. They persist in the environment and can biomagnify in food chains because they are not water-soluble. PCB's are suspected to cause cancer in humans. PC's are an example of an organic toxicant.

Pathogen: A disease-causing agent, especially microorganisms such as viruses, bacteria, or fungi which can be present in municipal, industrial, and non-point source discharges.

An organism capable of eliciting disease symptoms in another organism.

Pe: A measure of the oxidizing or reducing tendency of a solution. It is a dimensionless quality that is analogous to the pH expression, but describes relative electron activity instead of hydrogen ion activity. Pe = Log (e)

Both Pe and Eh are used to describe the redox condition and are related by the following equation:

pH = (nF/2.3 RT) Eh

Where F = Faraday constant

R = gas constant

T = absolute temperature

n = number of electrons in the half-reaction.

Peat: Unconsolidated soil material consisting largely of undecomposed, or only slightly decomposed, organic matter.

Perched Water Table: Saturated soil zone existing within unsaturated soils due to a localized underlying low permeability layer (see Unsaturated Zone).

Percolation: The downward movement under hydrostatic pressure of water through soil.

Periglacial: Of a location; refers to areas, conditions, processes and deposits adjacent to the margin of a glacier.

Peristaltic Pump: A variable rate low volume pump for groundwater sampling purposes, which excludes sample contamination.

Permeable: Having a texture that permits easy passage of a fluid through the medium (previous).

Permeability: Ability of a porous medium to transmit a fluid.

Persistent: Not readily degraded by natural, physical, chemical, or biological processes.

Pesticide: A general term used to describe any substance (usually chemical) used to destroy or control organisms; pesticides include herbicides, insecticides, algicides, fungicides, and others. Many of these substances are manufactured and are not naturally found in the environment.

pH: Negative log of the hydrogen ion activity in solution (pH = log (H+)).

Phenols: Organic compounds which are hydroxy derivatives of benzene.

Phosphorus: An essential chemical element and nutrient for all life forms. Occurs in orthophosphate, pyrophosphate, tri-polyphosphate, and organic phosphate forms. Each of these forms and their sum, total phosphorus, is usually expressed as mg/L elemental phosphorus.

Phreatophytic: Surface along which the fluid pressure is atmospheric. Same as water table.

Phreatophytic: Of plants; growing plants that depend on a continuous supply of moisture; normally grow where roots can reach water table.

Phthalate Acid Ester (PAE): Complex organic compounds that are usually colourless, oily and highly stable liquids having very low volatility and solubility in water. PAE's have a large number of commercial uses, the largest being as plasticizers for specific plastics such as polyvinyl chloride.

Piezometer: A device used to measure the pressure or pressure head in a short sealed off length of a drillhole or hydrogeologic unit. The device normally measures a fluid level in a small diameter tube, or a water pressure.

Piezometer Nest: A set of two or more piezometers set close to each other but screened at different depths.

Piezometric Level: The level to which the water rises in an open piezometer. Water level is either measured relative to ground surface, an assumed datum or given as an elevation.

Piezometric Surface: Imaginary surface defined by piezometric levels in a specified hydrogeologic unit.

Porosity (n): Proportion of the total volume of a porous medium occupied by voids (dimensionless fraction).

Pressure Head: Fluid pressure divided by unit weight of water (m).

Primary Sewage Treatment: A wastewater treatment method that uses settling, skimming, and often disinfection to remove solids, floating materials, and pathogens from wastewater.

Priority Pollutants: Substances listed by the United States EPA under the Clean Water Act as toxic and having priority or regulatory controls. The list includes toxic metals, inorganic contaminants such as cyanide and arsenic, and a broad range of both natural and artificial organic compounds.

Raised Bog: Raised muskeg, domed bog, high bog, raised peatland etc., ombrotrophic bog (rain fed).

Recharge Area: An area in which the hydraulic gradient has a downward component. infiltration moves downward in the deeper parts of an aquifer in a recharge area.

Recharge Boundary: Surface across which there is a nearly constant hydraulic head. Rivers, lakes, and other bodies of surface water often form recharge boundaries.

Recharge Well: A well through which good quality water is allowed to flow or is injected under pressure into one or more aquifers for the purpose of supplementing or conserving fresh water supplies, reducing water table decline or reducing potential for salt water intrusion.

Receiving Environment: A body of water which receives treated and untreated wastewater. The receiving environment includes water, sediments and biota.

Redox Potential: Same as Eh.

Redox Process: Every oxidation reaction is accompanied by a reduction reaction and vice versa, so that an electron balance is always maintained.

Reduction: Occurs in a chemical reaction where electrons are gained by an ion or molecule (i.e., oxidation state is decreased).

Regressive: Apposite to transgressive.

Reticulate: Of rocks; having a "honeycomb" appearance.

Return Well: Well through which water from a particular aquifer that has been withdrawn for heating or cooling purposes is returned. Water quality should be essentially unchanged.

Rock Cleat: Vertical fracture planes that are commonly found in coal.

Runoff: The portion of the total precipitation on an area that flows away through stream channels.

Saturated Zone: The zone of a porous medium in which all the voids are completely filled with water.

Secondary Sewage Treatment: A wastewater treatment method that usually involves the addition of biological treatment to the settling, skimming and disinfection provided by primary treatment. Secondary treatment provides higher removals of BOD, metals and toxic organics than primary treatment.

Slickenside: Scratches and grooves produced by movement along fault planes.

Sludge: Precipitated or settled organic and inorganic solid matter produced by treatment processes.

Slum: A fluid mixture of silty sand and water (similar to mine tailings slimes).

SNOW: **S**tandard **M**ean **O**cean **W**ater. The internationally accepted standard for referencing analyzed 180 and 2H isotope contents.

Sodium Adsorption Ratio (SAR): Of a soil; the ratio of soil extracts and irrigation waters. Term used to express the relative activity of Na+ in exchange with soil.

$$SAR = \frac{Na^{+}}{[(Ca^{+2} + Mg^{+2})/2]\ ½} \qquad \text{expressed as meq/L}$$

Soil: That earth material which has been so modified and acted upon by physical, chemical and biological agents that it will support rooted plants (i.e. pedological definition of soil).

Soligenous (ic): (produced from soil), refers to peatland deposit that is nourished by mineral water from higher surroundings.

Soluble Sodium Percentage (SSP): Of a water; indicates the proportion of Na^+ in solution in either irrigation water or soil extract) to total cation concentration.

$$SSP = \frac{[Na+]}{(\text{Total Cations})} \times 100\ (\%)$$

Solum: Of a soil; The upper part of a soil profile consisting of the A and B horizons.

Solute: That constituent of a solution which is considered to be dissolved in the other, the solvent.

Solvent: That constituent of a solution which is present in larger amount (i.e. water).

Sorption: The property of a porous medium: which enables it to remove contaminants from another liquid, such as groundwater. It is accomplished by a combination of adsorption and absorption.

Special Waste: a) All dangerous goods which are no longer used for their original purpose and that are i) recyclable material or ii) intended for treatment or disposal, including storage before treatment or disposal, but does not include dangerous goods that are iii) municipal refuse, iv) sewage v) defective products vi) class 7 of the Federal Regulations.

b) Waste oil, c) waste asbestos d) waste pest control product containers and contents e) leachable waste.

Specific Capacity (Sc): Term describing the productivity of a well. Calculated as the pumping rate divided by drawdown at a selected time after pumping is started (L/s/m).

Specific Surface: Of a soil particle; surface area per unit weight of soil (Unit = m^2/gm).

Specific Storativity (Ss): Volume of water that is released from a unit volume of an elastic hydrogeologic unit, with a compressible fluid, under a unit decline of hydraulic head (L/m).

Specific Yield (Sy): Volume of water that an unconfined aquifer released from storage, per unit surface area of aquifer per unit decline in the water table (dimensionless). Same as storativity for unconfined non-elastic aquifers with incompressible fluid.

Spring: A place where water flows from a rock or soil onto the land or in a body of water, without the agency of man being involved.

Static Water Level: Level at which water stands in a piezometer or well set in an aquifer which is not being pumped.

Steady-State: Fluid movement that is not time dependent.

Stream: Any body of flowing water or other fluid, great or small.

Strike: Of geological features; the course or bearing of the outcrop of an inclined bed or structure on a level surface. It is perpendicular to the dip of the strata.

Sub-lethal: (chronic) Does not kill an organism immediately; instead, has long-term effects such as cancer, mutagenic defects in offspring, or reproductive and feeding failure.

Sump: A hole or pit which serves for the collection of quarry or mine waters.

Suspended Solids: Organic or inorganic particles that are suspended and are carried by the water. The term includes sand, mud, and clay particles as well as organic solids in water.

Synchronal: Occurring at the same time.

Synergistic: Interaction between two entities producing an effect greater than an additive one.

TDS: Total dissolved solids in a solution (mg/L).

Tensionmeter: A device used to measure the soil moisture tension in the unsaturated zone.

Teratogen: An agent that increases the incidence of congenital malformations.

Thermocline: Of a lake; that portion of the water in the lake lying between the epilimnium and the hypolimniun, which has a sharp temperature gradient across the layer when moving vertically across.

Through Flow: Groundwater that flows rapidly through a highly permeable near surface zone during intense rainfall events.

Till: Of a sedimentary deposit: Nonsorted, non stratified sediment carried or deposited by a glacier.

Topogeneous (ic): (produced by relief) Refers to a peatland deposit that started development in a water filled depression (pond, lake etc.).

T.U.: See Tritium Unit

Transgressive: Of a deposited formation overlap; due to an advance of deposition over lower layers. Marine deposition at an advancing coastline is transgressive.

Transient Flow: See Unsteady-State Flow.

Transmissivity (T): Rate of horizontal water flow in cubic metres per second through a vertical strip of aquifer one metre wide, and extending the full saturated thickness of the aquifer, under a hydraulic gradient of one metre per metre at the prevailing water temperature (m^2/s).

Tritium: Radioactive isotope of hydrogen (^1H). Tritium (^3H) has a half life of 12.35 years. Natural levels in the hydrosphere are between 5 and 20 tritium units T.U.

Tritium Unit (T.U.): Unit for expressing Tritium concentrations in water.
1 T.U. = 1 $^3H/1x10^{18}$ 1H.

Uniformity Coefficient: Defines variation in grain size of granular material. Ratio of D_{60}/D_{10} size = (D_{60} = sieve size through which 60% will pass).

Unsaturated Zone: The zone between the land surface and the water table. It includes the root zone, intermediate zone, and capillary fringe. The pore spaces contain water at less than atmospheric pressure, as well as air and other gases. Saturated zones, such as perched groundwater, may exist in the unsaturated zone.

Unsteady-State Flow: Fluid movement that is time dependent (i.e., transient flow).

Valence: The charge, whether positive or negative carried by an ion in an aqueous solution i.e., valence of C1- = 1; Ca2+ = 2.

Vapour Pressure Deficit: The difference between the actual and maximum pressure that water vapour can exert at a given temperature.

Water Quality Criteria: A maximum and/or minimum value for a physical, chemical, or biological characteristic of water, biota, or sediment, applicable Province-wide, which must not be exceeded to prevent specified detrimental effects from occurring to a water use, including aquatic life, under specified environmental conditions.

Water Quality Objective: A criterion adapted to protect the most sensitive designated water use at a specific location with an adequate degree of safety, taking local circumstances into account. (In a given water body, each objective may be based on the protection of a different water use, depending on the water uses that are most sensitive to the characteristics of concern in that water body.)

Water Table: Surface along which the fluid pressure is atmospheric, and below which the fluid pressure is greater than atmospheric (i.e., top of saturated zone).

Watershed: The area drained by a river basin.

Well: Shaft sunk in ground and lined with stone or other protection for obtaining subterranean water, oil, etc.

Whole-effluent Acute Toxicity: The aggregate toxic effect of all the toxic constituents in an effluent, regardless of the dilution of the effluent.

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