WATER QUALITY GUIDELINE SERIES

Microbial Indicators Water Quality Guidelines (Reformatted Guideline from 1988)

Technical Appendix

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The Water Quality Guideline Series is a collection of British Columbia (B.C.) Ministry of Environment and Climate Change Strategy water quality guidelines. Water quality guidelines are developed to protect a variety of water values and uses: aquatic life, drinking water sources, recreation, livestock watering, irrigation, and wildlife. The Water Quality Guideline Series focuses on publishing water quality guideline technical reports and guideline summaries using the best available science to aid in the management of B.C.'s water resources. For additional information on B.C.'s approved water quality parameter specific guidelines, visit:

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Notes on Reformatted Version:
Sections of this report on industrial water use, recreational water use and shellfish harvesting have been removed. B.C. no longer develops or supports guidelines for industrial water use. See the Recreational Water Quality Guidelines: Guideline Summary for the latest B.C. recreational guideline recommendations, including shellfish harvesting.

Cover Photograph:
Location: Lower Myra Falls, Buttle Lake, B.C.

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1. INTRODUCTION

Water has always been an important agent in the spread of human disease. Gastrointestinal diseases of all sorts, amoebic and bacillary dysentries, infectious hepatitis, typhoid fever, cholera and polio are examples of water-borne diseases of man which usually spread via the fecal- water-oral pathway. In Canada the incidence of typhoid and paratyphoid fever has decreased by 98% in the last 50 years. The mortality from typhoid was 7/100 000 in 1921. In the United States mortality from typhoid and paratyphoid fevers declined, between 1900 and 1970 from 37 to <1/100 000. Water and sewage treatment, pasteurization of milk, disinfection and bacteriological surveillance are responsible for most of these improvements. Vaccination also helps control epidemics. The need for constant vigilance and control over water supplies and-effluents is highlighted by the occasional epidemic of a water-borne disease (Health and Welfare Canada, 1979; Frobisher et al., 1974). See Section 5.1 for examples.

The categories of water use for which criteria are being developed in British Columbia are:

- drinking water supplies
- wildlife
- livestock
- irrigation

Criteria of all types, but particularly bacterial criteria, are presently undergoing re-evaluation in much of the world (Dutka, 1973), and the historical dependence on total and fecal coliforms as indicators is being replaced with more specific and epidemiologically-derived indicators. Each use of the water and source of contamination should eventually have a representative specific indicator which is associated with a regression equation so that levels of protection can be rationally chosen by criteria-setting agencies. This process has just begun, so present criteria are a mixture of the new and the old. New identification, sampling, culturing and analytical techniques for bacterial indicators, including automated techniques. are being developed. These are necessary before some species can take their place as routine indicators of the health risk of using water from a given source for a specified use.

This report advocates fecal, as opposed to sewage indicators (Cabelli, 1977b). There are organisms in sewage which are not necessarily of human fecal origin and do not pose a human health hazard. They are not necessarily quantitatively monitored by the fecal indicators proposed and there are better indicators of sewage. Due to the specificity of pathogens, the risk of people getting sick is likely much lower if most of the fecal indicator organisms counted came from homeothermic animals other than man. Criteria may be overprotective or underprotective depending upon the ratio of animal to human indicator organisms counted. The source can not be determined on a routine, economical basis and a certain mix of the two sources is assumed when criteria levels are set.

It is recommended that epidemiological studies and sanitary surveys be carried out in certain critical circumstances to determine the actual health risk. The most urgent need for such studies is the spray irrigation of crops which are eaten raw where the actual source of the indicator organisms may be more important than their quantity, within fairly wide but unknown, limits.

Table 1.1 is a summary of the water quality criteria for microbiological indicators. The justification for these criteria is found in chapters 5 - 11.

Table 1.1 Summary of Water Quality Criteria for Microbiological Indicators

Water Uses	Indicators[1]			
	Escherichia coli	**Enterococci**	***Pseudomonas aeruginosa***	**Fecal Coliforms[2]**
Raw Drinking Water Sources	≤10/100 mL (90th perc.)	≤3/100 mL (90th perc.)	none applicable	none applicable
Wildlife	none applicable			
Livestock				
free-ranging animals	none applicable			
general livestock use	200/100 mL (maximum)	50/100 mL (maximum)	none applicable	200/100 mL (maximum)
closely confined (no treatment)	0/100 mL	0/100 mL	none applicable	0/100 mL
(disinfection only)	≤10/100 mL (90th perc.)	≤3/100 mL (90th perc.)	none applicable	≤10/100 mL (90th perc.)
(partial treatment)	≤100/100 mL (90th perc.)	≤25/100 mL (90th perc.)	none applicable	≤100/100 mL (90th perc.)
(complete treatment)	none applicable			
Irrigation				
crops eaten raw[3]	≤77/100 mL (geom. mean)	≤20/100 mL (geom. mean)	none applicable	≤200/100 mL (geom. mean)
public or livestock access	≤385/100 mL (geom. mean)	100/100 mL (geom. mean)	≤10/100 mL (75th perc.)	none applicable
general irrigation	≤1000/100 mL (geom. mean)	250/100 mL (geom. mean)	none applicable	≤1000/100 mL (geom. mean)

Notes on Table 1:

[2]Fecal coliform criteria which presently exist will apply on an interim basis until use of the other preferred indicators is adopted.

[1]Medians and geometric means are calculated from at least 5 samples is a 30-day period. Ten samples are required for 90th percentiles.

[3]Only a few salad greens which cannot. be adequately washed to remove adhering or trapped pathogens are of concern here. Examples include lettuce, cabbage, broccoli, cauliflower, and similar crops.

2. OCCURRENCE OF PATHOGENIC MICROORGANISMS IN THE ENVIRONMENT

2.1 Naturally Occurring Organisms

Water contains some naturally occurring psychrophilic bacteria. These may multiply in milk which is stored for several days before pasteurization. These organisms can grow, even at nearly 0°C, and may be resistant to iodine and chlorine. They are lipolytic, proteolytic and putrefactive (APHA, 1985; Ontario Ministry of the Environment, 1974).

Giardiasis is an infection of the intestine of man caused by the protozoan *Giardia lamblia*. These organisms can remain viable in clear, cold, mountain streams for some time, and are responsible for disease

outbreaks among wilderness hikers and campers drinking contaminated water. Chlorine, in the levels used to disinfect drinking water, does not always kill these organisms (B.C. Ministry of Health, Division of Epidemiology, 1982). *Giardia* is endemic in native animals and may be a problem even in community water systems if proper treatment does not occur. Another protozoan, *Cryptosporidium*, causes similar problems (B.C. Ministry of Health, Division of Epidemiology, 1988).

In oligotrophic, high-altitude streams the loss of introduced enteric bacteria is directly related to the activity and concentration of the periphyton protozoans, the indigenous bacteria are not significant predators of enteric bacteria. Maximum rates of enteric bacteria loss occur at the highest temperatures (maximum 11°C encountered), since the protozoans multiply most rapidly at these higher temperatures. At low winter temperatures, neither enteric bacteria nor protozoans are active, but the inactive enteric bacteria are still viable and will remain so for a long time (Johnston et al., 1974). Hikers drinking the water in the spring may become infected from water contaminated the previous fall.

Some strains of organisms commonly included under the category 'total coliforms', such as *Klebsiella*, *Enterobacter*, and *Citrobacter*, are found in soils, on vegetation and in industrial wastes. They thus compromise the value of the total coliform criterion as a measure of the risk of contacting a pathogen of sewage origin (Health and Welfare Canada, 1979; IJC, 1980). Some strains of *Klebsiella* can cause urogenital and respiratory tract infections, particularly in hospitals.

They may be health hazards in primary-contact recreation water subject to contamination by wood wastes (Huntley et al., 1976), or to workers in pulp and paper mills, especially where water recycling is carried out (Kanarek and Capelenas, 1981; Caplenas et al., 1981).

2.2 Pathogens from Sewage

Many sewage-transmitted diseases are not of significance in British Columbia since the disease incidence is very low; pathogens which may be present in B.C. sewage include those given in Table 2.1 (USA Federal Water Pollution Control Administration, 1968; McKee and Wolf, 1963; Kott, 1977; Hoadley, 1977; Colwell and Kaper, 1977; Cabelli, 1977a, 1977b; Health and Welfare Canada, 1983;100; Kanarek and Capelenas, 1981; Melnick and Gerba, 1980; Frobisher et al., 1974). See also Chapter 17 (Appendix) for diseases associated with sewage.

Organisms which are pathogenic to· humans and other warm-blooded animals are rarely capable of long term survival as free-living organisms. They may survive in water for a time as spores, resting stages, or even in the active state, but usually disappear shortly if not reintroduced to an appropriate host. Virtually a l of the water-borne diseases affecting man are a result of poor sewage treatment and disposal practices, which contribute to pollution of water supplies thus maintaining the infection cycle (Hoehn et al., 1977; Schaffer et al., 1980; Bates et al., 1979; Dixon, 1986). Breaking the infection cycle, as was done recently for smallpox, can have a very beneficial effect on human health. However, few pathogens are as amenable to treatment as was smallpox, and many have small but significant non-human reservoirs in the environment outside man.

2.2.1 *Bacteria*

An average person may discharge 1.6×10^{11} total coliforms per day or 3.2×10^{10} fecal coliforms per day (Kay et al., 1982). Thus, even if a sewage treatment plant achieves a 99.9% reduction in fecal coliforms, an unlikely high efficiency, there are still 3.2×10^{7} organisms remaining per person, per day. While high reduction efficiencies are significant from a technological point-of-view, they are misleading insofar as providing protection from disease. It is the residual population, and its relationship to the infectious dose that is pertinent (McNeill, 1985). For this reason, chlorination or some other form of disinfection is required. While no practicable large-scale treatment is likely to reduce the bacterial count to zero, one

can achieve a level lower than the minimum infectious dose per person, and thus break the infection cycle.

Table 2.1. Diseases Commonly Associated with Fecal Contamination

Disease	**Vector**
	Worms
Ancylostomiasis (hookworm)	*Necator americanus*
Ancylostomiasis (hookworm)	*Ancylostomia duodenale*
Ascariasis (roundworm)	*Ascaris lumbricoides*
Taeniasis (beef tapeworm)	*Taenia saginata*
Taeniasis/Cysticercosis (pork tapeworm)	*Taenia solium*
Trichuriasis (whipworm)	*Trichuris trichiuris*
Diphyllobothriasis (fish tapeworm)	*Diphyllobothrium*
Enterobiasis/Oxyuriasis (pinworm)	*Enterobius vermicularis*
	Protozoans
Amoebiasis (amoebic dysentry)	*Entamoeba histolytica*
Giardiasis	*Giardia lamblia*
	Viruses
Infectious hepatitis	hepatitis A virus
Poliomyelitis	polio virus
Coxsackie Disease	coxsackie virus
	Bacteria
Typhoid fever	*Salmonella typhi*
Paratyphoid fever	*Salmonella paratyphi*
Gastroenteritis (*Salmonella*)	*Salmonella newport*
Gastroenteritis (*Salmonella*)	*Salmonella typhimurium*
Tuberculosis	*Mycobacterium tuberculosis*
Leptospirosis, Swineherds disease	*Leptospira pomona*
Leptospirosis, Canicola fever	*Leptospira canicola*
Leptospirosis, Weil's disease	*Leptospira interrogans*
Cholera	*Vibrio cholerae*
Bacillary dysentry/Shigellosis	*Shigella sonnei*
Bacillary dysentry/Shigellosis	*Shigella flexneri*
Brucellosis	*Brucella melitensis* (goats)
Brucellosis	*Brucella abortus* (cattle)
Brucellosis	*Brucella suis* (pigs)
Tetanus (lockjaw)	*Clostridium tetani*
Botulism (food poisoning)	*Clostridium botulinum*
Gastroenteritis, diarrhea, gas gangrene	*Clostridium perfringens*
Tularemia	*Francisella tularensis*
Bubonic and pneumonic plague	*Yersinia pestis*
Septicemia, urinary tract infections	*Enterobacter aerogenes*
Upper respiratory tract infection and meningitis	*Branhamella catarrhalis*
	Bacteria
Food poisoning, mastitis, abscesses, boils, carbuncles, infantile impetigo	*Staphylococcus aureus*
Ear and urinary tract infections, ulcers, wound and burn infection, diarrhea	*Pseudomonas aeruginosa*
Dental caries	*Streptococcus salvarius*
Generally a harmless indicator of human fecal contamination	*Streptococcus faecalis*

Disease	Vector
Candidiasis (moniliasis), lung, vaginal and oral infections	Fungus *Candida albicans*

Sources: USA Federal Water Pollution Control Administration, 1968; McKee and Wolf, 1963; Kott, 1977; Hoadley, 1977; Colwell and Kaper, 1977; Cabelli, 1977a, 1977b; Health and Welfare Canada, 1983;100; Kanarek and Capelenas, 1981; Melnick and Gerba, 1980; Frobisher et al., 1974).

In South Africa, drinking water from conventional sources and from reclaimed wastewater was analyzed for standard bacterial plate count, total coliforms, fecal coliforms, confirmed *Escherichia coli* type 1, *Pseudomonas aeruginosa*, fecal streptococci, *Clostridium perfringens*, *Staphylococcus aureus*, enteric viruses, and parasitic ova. Water free of coliforms rarely contained any of the pathogens with the occasional exception of *P. aeruginosa*. Water with no coliforms, no *P. aeruginosa*/100 mL, a standard plate count of less than 100/1 mL, and no enteric viruses/10 L will not transmit disease (Grabow, 1977).

2.2.2 *Ascaris*

Eggs of the round worm *Ascaris lumbricoides* survive many sewage treatment processes in a dormant, unembryonated state and are present in anaerobically digested sludge. Even if this sludge is stored for several years, or dried and sold as a soil conditioner, the eggs remain viable, and upon exposure to air they embryonate and become infective. These eggs are the most resistant organisms in human wastes. A few such resistant viral, bacterial, protozoan, or helminth species cause much of the chronic, low level, diseased state of the people in many underdeveloped countries where wastewater treatment is inadequate, or inadequately treated wastes are used as fertilizer (Fitzgerald, 1981).

2.2.3 *Viruses*

Viruses are obligate parasites, which in their inactive form are very resistant to disinfection agents and may survive a long time in water. They are discharged in feces and urine, but only those found in large numbers are of great concern. Human viruses of concern include enteroviruses (polioviruses, Coxsackieviruses and echoviruses), adenoviruses, reoviruses and infectious hepatitis. The latter is the only one with epidemiological evidence of being transmitted through contaminated water. No tissue cell-culture technique has yet been devised to grow and isolate this virus outside a host, but immunological techniques exist for its detection in water (Tobin, 1987). The infectious dose of viruses is very low and the response in the host may vary considerably. One strain of coxsackie virus may produce meningitis, myocarditis, or diarrhea (Hart, 1974).

Coxsackie A2 virus survived longer in sewage or in distilled water than in polluted river water. Enterovirus may remain infective at 4°C for 12 days but loses most infectivity in 5 days at 25°. Groundwater, known to cause infectious hepatitis, still did so after 10 weeks storage. Mediterranean seawater inactivated Sabin poliovirus-1 in 6 days; this inactivation was not affected by filtering the seawater but using pre-boiled seawater or storage at 25°C for two months did reduce the antiviral activity. Salt solutions at similar concentrations showed no specific antiviral effect (Hart, 1974).

Sabin poliovirus-2 was completely inactivated after 5 days in Vancouver seawater at 25°C, but virulent mahoney poliovirus-1 may survive three months in seawater at 17°C. Sabin poliovirus-2 held in Vancouver sea water for 12 days at 4°C lost infectivity, but if fresh water was used there was no decline in infectivity (McLean and Brown, 1968).

2.3 Pathogen Reservoirs

2.3.1 Bivalves

Epidemiological studies have verified that several outbreaks of infectious hepatitis have been caused by eating raw bivalves. Bacterial pathogens affecting bivalves include: *Salmonella*, including *S*. *typhi*; *Shigella* species, which can cause dysentry; *Clostridium* species, which produce poisonous exotoxins; and *Vibrio parahaemolyticus* which causes food poisoning (B.C. Ministry of Health, Division of Epidemiology, 1986b). Many viral pathogens, including infectious hepatitis, are found in bivalves. Where sewage contains parasitic protozoans and worms, the molluscs may be vectors of cysts and eggs. All these organisms can infect man if bivalves are consumed raw or if they are insufficiently cooked. If bivalves are not stored at cold temperatures while in transit, the bacterium *Vibrio parahaemolyticus* can multiply and cause food poisoning (B.C. Ministry of Health, Division of Epidemiology, 1986b). Heat-preserved bivalves are safe from all pathogens except spore-formers like *Clostridium*, which can form toxins during storage after canning unless very efficient heat processing is carried out. Lightly preserved bivalves may transmit eggs and cysts of worms and protozoans and allow toxin production by *Clostridium botulinum* type E. To avoid these problems, bivalves from polluted areas must be given high temperature cooking long enough to allow the heat to penetrate thoroughly, or else they must be held in clean water long enough to cleanse themselves.

2.3.2 *Sediments*

Adsorption to particles and surfaces by indicator bacteria and pathogens may be important to water pollution investigations. Bacteria adsorbed to particles sediment faster than those freely suspended in the water and are found at higher densities on particles than free in the water. This sedimentation may be an important mechanism for the purification of the water column (Gannon et al., 1983). High levels of bacteria in sediments are often documented and this habitat may well be more favorable to their growth and survival than the open water. Adsorption on sediment particles affords the bacteria some protection from ultraviolet light due to the sun or to UV disinfection procedures. Both *E. coli* and *Salmonella* have been shown to have enhanced survival in the sediments Verstraete and Voets, 1976; Gerba and McLeod, 1976; LaLiberte and Grimes, 1982; Van Donsel and Geldreich, 1971; Belton et al., 1972; Qualls et al., 1972; Roper and Marshall, 1974, 1978).

There are several health hazards associated with these bottom reservoirs of bacteria. Dredging will greatly increase the water column concentration of pathogens and indicators by resuspending the particles and their bacteria (Grimes, 1975). Resuspension can also occur by wind and wave action, boats, and most importantly by waders and swimmers (Schillinger and Gannon, 1985).

The settled bacteria may be useful ·as indicators of pollution events after the water no longer tests positive (Matson et al., 1978). In coastal canal waters, fecal coliforms in the water column did not correlate with enterovirus isolations, but coliforms in bottom sediments did show a correlation (Labelle et al., 1980). There may be a 10- to 1000- fold increase in fecal coliform density at the sediment-water interface over that in the overlying water (Van Donsel and Geldreich, 1971; Seyfried et al., 1985a).

2.4 Antibiotic Resistance

Hospital, and to a lesser extent city and other human sewage, contains many coliforms carrying genes for resistance to antimicrobial drugs. The genes are transferable, by transformation, transduction or conjugation, to other bacteria of different species. These organisms may survive sewage treatment and may transfer their resistance to other organisms either during passage through the treatment system or afterwards. Organisms that survive the final treatment and eventually appear in water supplies are a very serious potential health hazard, since in time they could lead to current antibiotics becoming obsolete.

For example, one outbreak of typhoid fever was found to be caused by *Salmonella typhi* resistant to chloramphenicol and ampicillin (U.S. EPA, 1976).

When penicillin was first introduced in 1944, virtually all strains of *Staphylococcus aureus* were highly sensitive. A few mutants became or were resistant. Resistance, the ability to produce penicillinase, was readily induced by contact with sub-lethal concentrations of penicillin. As penicillin use, and abuse, became more widespread, virtually all strains of *S. aureus* became resistant, especially those found in hospitals. This resistance is transmissible and causes major problems in hospitals, especially maternity wards and nurseries (Frobisher et al., 1974). The conjugative transfer of antibiotic resistance, from bacteria of wastewater origin to wild strains in bottom sediments, has been documented recently. In-situ studies showed the transfer of tetracycline resistance within 30 days at 10° C in marine sediments. The organisms used were strains of *E. coli* (Vasconcelos and Anthony, 1985).

The indiscriminate use of antibiotics in vast quantities, for uses where they have no effect, such as viral infections, encourages the spread of genes conferring resistance. Antibiotics are routinely used in animal feeds as a preventative and are available over the counter, without prescription, in many developing countries. This has allowed bacterial strains causing gonorrhea. tuberculosis, meningitis, typhoid fever and salmonellosis to become quite resistant. In Mexico, where over-the-counter anti biotic sales occur, over 20 percent of *Salmonella* strains are insensitive to 8 or more antibiotics. The centre for Disease Control in Atlanta, reports that 20-25 percent of salmonellosis in the United States is caused by bacteria resistant to one or more antibiotics. For example, a tetracycline-resistant *Salmonella* infection in Minnesota has been linked to South Dakota beef fed routinely with chlortetracycline. All 2 190 strains of *E. coli*, isolated from poultry in Nigeria which received antibiotics as a routine feed additive, were resistant to tetracyclines, streptomycin and sulfonamide. Most sewage treatment plants do not remove these resistant bacteria; the sludge and effluent are distributed to the environment with viable, resistant bacteria present. Food crops are commonly contaminated by bacteria resistant to as many as 8 antibiotics. The indiscriminate use of antibiotics, particularly in sub-therapeutic doses, and the lack of complete final disinfection of sewage plant effluents and sludges is a serious health hazard which is rapidly growing worse (Dixon, 1986).

Table 2.2 gives the percentage of *E. coli* and *S. aureus*, isolated from 10 Pacific Northwest beaches that were resistant to 12 antibiotics (Vasconcelos and Anthony, 1985). Advanced treatment of wastewater bearing organisms carrying transferable resistance to antibiotics is necessary. No coliform discharged should carry resistance to common drugs like ampicillin, kanamycin, chloramphenicol, streptomycin, sulfonamides, or tetracycline.

Such coliforms can not be considered as harmless indicators of fecal pollution, but as reservoirs of anti biotic-resistant genes which can be transferred to pathogens. Since drinking water should not contain any coliforms, this restriction would apply to effluent discharged to waters used for irrigation, recreation, shellfish and crustacean rearing, fish hatching and rearing, livestock watering and industrial use where the workforce has direct contact (Grabow, 1977). More detailed information on this subject may be found in reviews by Anderson, 1968; Grabow et al., 1974; Watanabe, 1971; Richmond, 1972; Watanabe, 1963; and Warrington, 1988.

Table 2.2. Percent Resistance of Multiple *E. coli* and *S. aureus* Isolates to 12 Antibiotics And Chemotherapeutic Agents[34]

			Antibiotics and Concentration (Table entries are % of Isolates Resistant)											
Beach or Location (i)	**Species of Bacteria**	**Number of Isolates**	**Pen 2 U**	**Amp 2 µg**	**Cep 30 µg**	**Ery 30 µg**	**Gen 10 µg**	**Fur 100 µg**	**Chlor 5 µg**	**Oxa 1 µg**	**Tetra 5 µg**	**Gran 1 µg**	**Clin 2 µg**	**Lino 2 µg**
Aliki Beach	*E. coli*	18	100	50	13	100	0	0	88	100	50	88	100	100
	S. aureus	17	17	17	0	17	0	0	84	17	0	0	34	0
Golden Gardens	*E. coli*	16	100	75	25	100	0	7	94	94	19	57	100	100
	S. aureus	12	50	50	0	50	0	0	50	100	0	0	100	100
Green Lake	*E. coli*	19	100	85	16	100	0	11	79	0	48	43	95	84
	S. aureus	11	28	28	10	19	19	19	82	37	28	19	55	17
Juanita Beach	*E. coli*	28	100	72	15	100	0	11	58	100	61	75	100	100
	S. aureus	13	16	0	16	16	0	0	70	39	0	25	47	60
Lake Sammanish	*E. coli*	12	100	84	42	100	17	25	59	100	50	34	100	100
	S. aureus	15	0	0	0	34	0	0	74	27	0	0	67	100
Suncrest Beach	*E. coli*	13	100	67	0	100	0	0	34	100	67	67	100	100
	S. aureus	12	0	0	0	0	9	0	50	25	17	34	10	84
Riverside Park	*E. coli*	12	100	84	34	100	25	17	59	92	42	59	100	100
	S. aureus	11	10	10	10	10	0	0	59	34	25	17	25	100
Swallows Nest	*E. coli*	14	100	79	22	100	15	22	65	100	50	43	100	100
	S. aureus	6	34	34	50	84	84	17	67	100	50	100	100	100
Hell's Gate Pk.	*E. coli*	7	100	58	29	100	29	29	86	100	58	43	100	100
	S. aureus	6	0	0	17	17	0	0	50	67	0	0	67	100
Lowell Park	*E. coli*	10	100	80	so	10	40	20	50	100	60	40	100	100
	S. aureus	6	0	0	0	0	0	0	50	0	0	17	0	50

µg - Micrograms; U - Units; Pen - Penicillin; Amp - Ampicillin; Cep - Cephalophin; Ery - Erythromycin; Gen - Gentamicin; Fur - Furadtin; Chlor - Chloramphenicol; Oxa-Oxacillin; Tetra - Tetracycline; Gran - Grantrisin; Clin - Clindamycin; Lino - Linomycin; *E. coli - Escherichia coli; S. aureus - Staphylococcus aureus*

(i) These are all Pacific Northwest beaches

3. INDICATORS: THE CONCEPT AND POTENTIAL INDICATOR SPECIES OR COMPOUNDS

3.1 The Indicator Concept

Epidemiological data and disease outbreak reports are direct measures of the risk of contracting a disease. When the presence of an infectious disease, which can be spread by water, is confirmed by health authorities, and pathogenic organisms can be directly measured in the water, then a known, quantifiable health hazard exists.

The microbiological quality of water is commonly estimated or monitored using a single indicator organism. The direct monitoring of all specific pathogens would be too slow and uneconomical for routine control purposes (WHO, 1984). There are problems with collection and analysis techniques for many of these pathogens. When indicators of fecal contamination are found the water is presumed to be contaminated by pathogens. Coliforms are the historical indicators, but they are only indicators, and are neither consistently nor quantitatively related to many pathogens of interest (Cabelli, 1977b; Health and Welfare Canada, 1983). Coliforms are not useful as indicators of pathogens responsible for eye, ear, nose, throat and skin infections, nor of the presence of viruses, protozoans, or worms (Health and Welfare Canada, 1978a; IJC, 1983). The traditional indicators generally do not persist as long as pathogens such as

enteric viruses and helminths. Thus the "absence of indicators does not implicitly denote absence of pathogens" and more effective indicator systems are required (McNeill, 1985). Establishing a microbial objective is quite complex and must deal with the statistical relationships between pathogens and indicators to find an indicator level which affords acceptable health risks at acceptable costs (IJC, 1980; McKee and Wolf, 1963).

The indicator concept depends upon the ratio of pathogen to indicator remaining constant (Smith and Twedt, 1971). This may hold true in a statistically large population unless there is an epidemic of some disease, but will not hold true in small populations or single individuals, where the presence of a diseased individual can markedly affect the ratio. Under such conditions the indicator may markedly underestimate the risk of pathogens being present.

Salmonella-caused diseases due to recreational use of fresh water are virtually non-existent. Good public health measures have reduced the number of carriers or infected individuals in the population, reducing the ratio of *Salmonella* to coliforms. The coliform guideline for recreation is now overprotective for *Salmonella* under normal, non-epidemic conditions. However, using coliforms as an indicator can be misleading unless the coliforms are consistently and quantitatively related to the pathogen density. This kind of relationship does not hold for *Salmonella* and fecal coliforms (Cabelli, 1977b) or *Vibrio parahaemolyticus* and *Escherichia coli* (Colwell and Kaper, 1977).

The indicator to pathogen ratio may vary with disease level in the population, the type of sewage treatment, the sewage dilution ratio, the relative multiplication and die-off rates of pathogens and coliforms in the environment, the distances from the sources of effluent contamination to the point of water use, the fluctuating ratios of the different effluent sources, the weather, and the microbiological competition in the receiving waters (Hunt, 1977).

The main danger associated with drinking water or recreational water is the possibility that it has recently been contaminated by sewage of human fecal origin by carriers or victims of infectious diseases, such as dysentry or enteric fever. When such pathogens are present in the water they are usually greatly outnumbered by normal excremental bacteria, such as fecal coliforms, which are easier to detect. Statistical analyses show that above a certain fecal coliform level there is a high probability of pathogens being present, while below that level the health hazard is negligible. The use of normal excremental bacterial as indicators provides a margin of safety, but there are considerable uncertainties in assigning a risk-of-infection index due to the variable size of the infectious dose for different pathogens and the variability of the immunological responses of the human hosts (WHO, 1958; IJC, 1980).

To determine whether or not the water is bacteriologically safe for shellfish harvesting, various indicators have been used. Fecal streptococci undergo multiplication in live shellfish above 11°C; coliforms, particularly *E. coli*, also multiply in shellfish. *Clostridium perfringens* is a spore-forming anaerobe which has been suggested as an indicator, but the resistance and longevity of its spores makes it less responsive to changing conditions (Wood, 1972).

Since human fecal wastes are the most hazardous form of microbiological pollution of water, fecal indicators and water quality indicators are viewed as synonymous. This is usually, but not always true (Cabelli, 1977b). If the source of the pathogen is not fecal, a fecal indicator is of no value. In addition, organisms of fecal origin which later multiply in the environment, or naturally occurring human pathogens, such as *Aeromonas hydrophila*, *Vibrio parahaemolyticus*, *Pseudomonas aeruginosa* and *Klebsiella* spp., are not quantitatively monitored by a fecal indicator which does not itself multiply at the same rate. However, an indicator which multiplied would lose its value as an indicator of recent or current fecal contamination.

Indicator species are generally thought of as protecting consumers of drinking water against gastro-intestinal diseases caused by bacteria. However, there are other pathogens in water including fungi, protozoa, invertebrate larvae, worms and their eggs, and viruses. In recreational uses of the water, pathogens may also attack other parts of the body including eyes, ears, nose, skin and vagina. These other pathogens and recreational activities are often associated with water specifically designated for drinking, and protected specifically for this purpose by indicators specific for gastro-intestinal pathogens. Thus when "drinking" water is also used for hot tubs, whirl pools and swimming pools where long incubation periods and poor sanitation/sterilization/filtration practices may occur, pathogens which are not pacifically monitored may be present. Instead of coliforms, indicators for water destined for non-consumptive recreational uses include, *Pseudomonas*, *Staphylococcus*, *Streptococcus* or *Enterococcus* species (Ontario Ministry of the Environment, 1978, IJC, 1980). The former two genera are indicators of the risk of eye, ear, nose, throat and vaginal infections; the latter two genera are for gastro-intestinal diseases.

The use of several different indicators can provide much additional information on the nature of the contamination. If the ratio of the fecal coliforms/fecal streptococci (FC:FS) is measured, it can indicate the source of the pollution. A ratio over four indicates a human origin, while a ratio under 0.7 indicates a non-human or animal source. Intermediate ratios occur for mixed sources. However, to get statistically significant ratios, the fecal coliform density should exceed 100/100 mL (Kay et al., 1982; Ontario Ministry of the Environment, 1978; Smith and Twedt, 1971). A sanitary survey is generally required for the interpretation of FC:FS ratios. The passage of time, or sampling further and further away from the source of the discharge can distort the ratio due to differential die-off or multiplication rates and differential transportation rates. Sampling should occur as close to the point of discharge as possible before extensive mixing takes place. Using *Clostridium* spores will indicate pollution which may have occurred some time ago but not necessarily indicate whether it is still occurring. Using short-lived *E. coli* will determine current contamination.

Table 3.1 below, gives several correlation coefficients of the relationship between the density of some indicators and the difference in frequency of gastrointestinal disease between swimmers and non-swimmers in marine waters (Cabelli et al., 1976; Cabelli, 1977b).

Table 3.1. Correlation Coefficients for Indicator Density and Incidence of Gastrointestinal Disease for Swimmers in Marine Waters

Indicator	**Correlation Coefficient**	
	(Cabelli et al., 1976)	(Cabelli, 1977b)
E. coli	0.711	0.95
Klebsiella	0.644	0.69
fecal coliforms	0.673	0.08
total coliforms	0.549	0.33
fecal streptococci	0.453	0.95
Pseudomonas aeruginosa	0.191	0.42

Bacterial species are operationally difficult to define. Many species are washed out of soil into the water; some. of these are soil bacteria, and others are gut bacteria of insects, other invertebrates and vertebrate animals. Many of these species are closely related to, and difficult to distinguish from those pathogenic to man. Species of *Klebsiella*, *Enterobacter*, *Vibrio*, *Citrobacter*, *Proteus*, *Aeromonas* and *Pseudomonas* have human pathogenic strains not readily differentiated from non-pathogenic strains. This compromises their usefulness as indicators (Farmer and Brenner, 1977).

Concentrations of indicator organisms are useful as an early warning system in disease outbreaks, but only the isolation and quantification of the specific pathogen involved can give a definitive health-hazard risk. It has been suggested that chlorine residual measurements might be more useful than bacteriological monitoring of drinking water as a measure of the risk of disease (McCabe, 1977). However, giardiasis would not be eliminated by chlorination; nor would ascariasis or cryptosporidiosis.

When epidemiological studies of specific disease outbreaks are being carried out, or where a certain population is being studied for evidence of water-borne diseases, the following pathogens should be monitored: *Aeromonas hydrophila*, pathogenic amoebae, *Campylobacter* spp., *Legionella* spp., *Salmonella* spp., *Shigella* spp., *Yersinia enterocolitica*, enteric viruses, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Vibrio* spp., *Proteus* spp., *Clostridium perfringens*, *Candida albicans* and *Mycobacterium tuberculosis* (IJC, 1982), *Giardia lamblia* and *Cryptosporidium* are also problems in British Columbia, but there are technical difficulties in monitoring these organisms and such monitoring may not be justified at present due to lack of consistent results.

Requirements of an Indicator

To be acceptable as an indicator of the microbiological quality of water an indicator should satisfy the following ideal requirements (Cabelli, 1977b; Health and Welfare Canada, 1983; Goyal, 1983):

- be present when pathogens are present, absent when pathogens are absent, and occur in a constant ratio to the pathogen
- be consistently and exclusively associated with the source or sources of pollution at a higher concentration than the pathogens
- be present in sufficient numbers to give a good density estimate of those pathogens present at unacceptably high risk levels
- behave very much like the pathogens with regard to natural and man-made components of the environment which might tend to affect pathogen densities, and be non-pathogenic
- be easily, accurately, precisely and economically quantifiable and not subject to false positive tests

3.2 Potential Indicators

3.2.1 *Staphylococcus aureus*

This bacterium is a normal inhabitant of the skin and mucous membranes, especially of the nose and mouth; it may cause purulent infections of skin, eyes and ears. It is a major component of the bacterial flora of swimming pools and recreational waters with a high density of people, and is a good index of the health hazard of such waters (Favero et al., 1964, Seyfried et al., 1985a). Due to its non-fecal sources it does not correlate well with fecal coliforms and needs to be independently monitored (Klapes and Vesley, 1986). It could be a good indicator for recreational, industrial, irrigation, drinking and livestock water uses. Development of an economical, fast assay method which is selective and reliable for quantitative recovery from water on a routine basis would help make this indicator more universally acceptable (Evans, 1977).

3.2.2 *Pseudomonas aeruginosa*

This bacterium is generally derived from human and domestic animal fecal wastes, but some independent growth and multiplication may occur. This means that it does not correlate well with other common indicators and needs to be independently assayed. It has a fairly short survival time in water, but is an opportunistic pathogen of man and animals. It is often isolated from soil, drinking water, farm water supplies, swimming pools, hot tubs (B.C. Ministry of Health, Division of Epidemiology, 1986a), and recreational surface waters. It has been recommended as an indicator of the health hazard of water used

for recreation, industry, irrigation, livestock and drinking (IJC, 1983; Manitoba Environment and Workplace Safety and Health Department, 1983; Hoadley, 1977). Several methods are available for the isolation and enumeration of *P. aeruginosa* in water (Hoadley, 1977; Grabow, 1977). *P. aeruginosa* may multiply in hot tubs and swimming pools if the pH rises above 7.8 or the free chlorine residual drops below 0.5 mg/L. Chlorine at 1.0 mg/L and pH between 7. 2 and 7. 7 are recommended for control of *P. aeruginosa* (B.C. Ministry of Health, Division of Epidemiology, 1986a). There is a quantitative relationship between the numbers of *P. aeruginosa* and the incidence of ear infections (otitis externa) in swimmers (McNeill, 1985).

3.2.3 *Bifidobacterium*

These bacteria are potentially good fecal pollution indicators since they do not multi ply in nature, have similar survival rates to other pathogens and fecal indicators, and do indicate fecal contamination. More research is needed on these organisms, and suitable assay techniques need to be developed before they can be recommended as an indicator (Levin, 1977; Goyal, 1983).

3.2.4 *Vibrio parahaemolyticus*

This species has been suggested as an indicator of bacteriological water quality in estuarine and marine waters; it is not found in fresh water. *Vibrio* spp. are fish and human pathogens, regularly isolated from sewage, but rarely from human feces, and are not appropriate as fecal indicators. *V. parahaemolyticus* spreads via contaminated seafoods, especially crustaceans, in estuaries. *V. cholerae* is found in brackish and fresh water. These species are responsible for food poisoning, wound infection and middle ear infections (Colwell and Kaper, 1977). Once sampling, culturing and assay techniques can be made quantitative and routine, *V. parahaemolyticus* would be an excellent indicator, in brackish waters, of pathogens not related to fecal contamination. It is not recommended as an indicator for any water use, but a health hazard exists if it is routinely isolated from the water (see Chapter 10).

3.2.5 *Klebsiella spp.*

These species are opportunistic pathogens of concern in hospitals and industries with high organic levels in process water. They are found in high concentrations in organic wastes associated with human activity, and may be indicators of degraded water quality. They are prevalent in pulp and paper mill effluent and recycled process waters (Kanarek and Capelenas, 1981; Caplenas et al., 1981), textile wastes (APHA, 1985; Stephenson, 1953) and sugar cane (Numez and Colmer, 1968), sugar beet and kelp processing wastes. *Klebsiella* has some unresolved taxonomic, isolation and identification problems which limit its use as an indicator at present (Vlassoff, 1977). *Klebsiella* is included in both total and fecal coliform assays, which is one of the reasons these indicators have limited value. *Klebsiella* is not specific for fecal contamination and may multiply in the environment. *Klebsiella* is also an opportunistic pathogen of man and is a significant cause of hospital infections such as pneumonia, genito-urinary infections and meningitis.

3.2.6 *Candida albicans*

This human pathogenic yeast has the potential to be an indicator of the health hazard of water for recreational uses. It does not appear to reproduce in nature and can be isolated from crustaceans, molluscs, swimming pools, shower rooms, seagulls, pigeons, and frequently from the skin of hospital patients. Australian surfers who suffer cuts and abrasions have become infected with *C. albicans*, which is also responsible for oral, vaginal and cutaneous mycoses, and is found associated with venereal disease, heart surgery, denture stomatitis, epithelial hyperplasia, cystic fibrosis, endophthalmites, and mucocutaneous candidiasis. *Candida albicans* is also associated with the following clinical conditions in people: paronchyia, oral thrush, urinary tract infections, endocarditis, meningitis and intertriginous, generalized cutaneous, vulvavaginal, occular, bronchial and pulmonary candidiasis (Taplin, 1976; Emmons et al., 1977; Montgomerie and Edwards, 1978; Kozinn et al., 1978). There are not yet any

definite epidemiological studies linking infections in man with occurrence in the water, but women swimming at marine beaches contaminated with intestinal fungi have a higher instance of vaginal infections due to *Candida* (Brisou, 1975). The distribution of *C. albicans* at Lake Ontario swimming beaches and techniques for isolation and identification have been reported (Sherry et al., 1979). It is not recommended as an indicator for any water use, but is noted as a health hazard if routinely isolated from bathing waters (Buck, 1977).

3.2.7 *Salmonella spp.*

Salmonella numbers decrease more slowly than fecal coliforms. This leads to *Salmonella* being present, particularly in the sea, after the fecal coliforms are no longer detectable and produces false negative tests for *Salmonella* when fecal coliforms are used as indicators. There are reports of a correlation between *Salmonella* presence and fecal coliform densities (Geldreich, 1970), but there is no correlation between the densities of *Salmonella* and fecal coliforms (Cabelli, 1977b). *Salmonella* has been responsible for disease outbreaks among swimmers when fecal coliform densities indicated no health hazard existed (Ross et al., 1966). This is a relatively rare occurrence associated with a local *Salmonella* epidemic which alters the usual *Salmonella* to fecal coliform ratio, but indicates the need to assay *Salmonella* independently and not rely on fecal coliform indicators (Leclerc et al., 1977; Yoshpe-Purer and Shuval, 1972). *Salmonella* is not recommended as an indicator, however, for the following uses of water - drinking, recreation, irrigation. livestock and industrial - a health hazard exists if it is routinely isolated from the waters.

3.2.8 *Clostridium perfringens*

This species is widespread in aquatic and terrestrial environments; it is defined as a sulphate-reducing, spore-forming, anaerobe which causes wound infection and gas gangrene. It is not a good general-purpose indicator, but is useful in specific instances. It can be used as a tracer of sewage or sludge (due to the long-term survival of the spores), to identify contaminated water which has been in contact with materials which destroy normal indicators, and to detect remote or intermittent sources of pollution. In tropical or subtropical areas, where large areas are drained by small intermittent streams which rise suddenly after heavy rainstorms, *C. perfringens* may be a good indicator of general non-point source contamination of the drainage basin (Fujioka and Shizumura, 1985). It has been used in Germany and France to test potable water from ground sources. There is no apparent distinct and constant relationship between fecal coliforms and *C. perfringens*; neither is an adequate indicator of the other. The absence of this species indicates no recent or remote contamination and may be a requirement for good quality drinking water. Such a requirement would be stricter than the standard coliform test, and useful as a long-range, long-term trace of chlorinated sewage contamination (WHO, 1958; Cabelli, 1977a; Suess, 1977; Goyal, 1983). *C. perfringens* is not recommended as an indicator, but has some obvious value under certain circumstances, particularly in sampling remote wilderness campsites, where there may be a considerable delay in getting samples to a laboratory. It is noted in Chapter 10 that a health hazard exists if this species is routinely isolated from the water.

3.2.9 *Shigella spp.*

Shigella spp. are more resistant to chlorination than fecal coliforms and thus must be assayed separately since the indicator value of fecal coliforms is lost when the water is chlorinated. *Shigella* may be responsible for disease outbreaks among swimmers when the fecal coliform index indicates bacteriologically safe water (McKee and Wolf, 1963). While *Shigella* is not recommended as an indicator, it is noted in Chapter 10 that a health hazard exists if *Shigella* is routinely isolated from the water.

3.2.10 *Mycobacterium tuberculosis*

This species is more resistant to chlorination than fecal coliforms, and thus is not adequately assayed by a fecal coliform indicator. It must be tested for independently. While it is not recommended as an indicator, it is noted in Chapter 10 that a health hazard exists if this species is routinely isolated from the water.

3.2.11 *Streptococcus spp.*

The enterococci, *Streptococcus faecalis*, *S. faecium* and· *S. durans*, are present in the feces of man and other warm-blooded animals. They survive longer in nature than fecal coliforms, but do not normally multiply in nature and are not pathogenic. They are possible indicators of sewage contamination of soils and vegetable crops by polluted irrigation water. Fecal coliforms do not survive as well out of water, on soil or plants, as some pathogens, and thus are not valid indicators under these conditions. There may be some difficulty in differentiating vegetation and insect biotypes of *Streptococcus* from human biotypes, and they do not make good indicators in water which receives waste from fruit and vegetable processing plants since they can multi ply in these waters. They are useful for assessing the quality of reservoirs and recreational waters, sewage-contaminated water supplies and chlorinated, organically rich water (McKee and Wolf, 1963; Suess, 1977; Cabelli, 1977b ; Clausen et al., 1977). They are considered better indicators than fecal coliforms (Hanes and Fossa, 1971).

The ratio of fecal coliforms to fecal streptococci is generally greater than 4 in human sewage and less than 0.7 in animal wastes (Geldreich, 1972; Geldreich and Kenner, 1969). Also *Salmonella* infection is usually high, 10-20%, in livestock as opposed to 1% in people. Thus predominantly livestock-contaminated water could be distinguished from human sewage contamination by the low FC/FS ratio and high *Salmonella* level. These levels and ratios may not be constant at all times and in all parts of the world.

Enterococci are recommended as indicators of water quality for the following uses: recreation, drinking water, industrial, wildlife, livestock and irrigation. Of all microorganisms considered as recreational water quality indicators, enterococci most closely meet the ideal characteristics (Cabelli, 1977b). Adequate routine procedures now exist for their sampling and enumeration and they should become more commonly used as indicators. There is a direct linear relationship between swimming-related gastroenteritis and the density of enterococci (Dufour, 1984). Enterococci are better indicators of gastroenteritis than *E. coli* for marine swimming beaches.

3.2.12 *Coliphages*

Coliphages, particularly MS2 and f2, have been advocated as indicators of enterovirus since they are found in the intestinal tract of humans and animals, survive as long as poliovirus-1 in nature, are as resistant to chlorination as poliovirus-1, and are readily assayed. However, there are also serious shortcomings: coliphages are constantly present in raw sewage which does not always have enteroviruses, treated effluent may be coliphage positive but enterovirus negative, enteroviruses may be isolated from some water samples that do not contain coliphages, oysters take up coliphages from 5-30 times more readily than they take up enteroviruses, and phages may replicate in estuarine waters when suitable bacteria are present (Kott, 1977; Goyal, 1983). Coliphages are not recommended as indicators since there are problems showing a constant quantitative relationship to disease risk (Metcalf et al., 1972). Coliphage f2 is not quantitatively related to enteroviruses during wastewater treatment (Balluz et al., 1978, Butler and Balluz, 1979).

3.2.13 *Viruses*

The use of coliforms to predict the virological quality of water is questionable since the behavior and fate of animal viruses have been shown to differ markedly from those of coliform indicators (Katzenelson, 1978, Block, 1983, Bitton et al., 1985). The densities of viruses and fecal coliforms do not correlate very

well (Berg and Metcalf, 1978). Viruses can be isolated from potable water which has been tested as bacteriologically safe to drink. Viruses. are more resistant to sewage treatment processes, environmental conditions and chlorination than are coliform indicators (Goyal, 1983). Polioviruses in sewage effluents may require 20 mg/L of chlorine to demonstrate 99.9% kill, while 2 mg/L will suffice for coliforms (Shuval, 1976). Polioviruses were isolated from finished water with turbidities below 1 NTU and free chlorine residuals over mg/L; no bacterial indicators were present under these conditions. These viral isolates had a chlorine resistance that was several orders of magnitude greater than naive laboratory strains. Repeated exposure to sublethal doses of chlorine leads to more resistant strains of poliovirus in a very few generations. Modern water treatment practices have little effect on removing the threat of viral diseases (Hoehn et al., 1977; Schaffer et al., 1980; Bates et al., 1979).

The best run sewage treatment plants will not reduce viral densities by more than a factor of 10^4. Viral densities are usually orders of magnitude greater than this and infectious doses are in the range of 10^0 - 10^2. Viruses in irrigation water will survive in the soil or on crops for extended periods. Only a virus is an adequate indicator for viruses . Enteroviruses would be good indicators of water quality for the following water uses: recreation, drinking water, livestock, wildlife, aquatic life, industrial and recreation (Kraus, 1977); Goyal, 1983). While sampling and enumeration procedures are available and given by the American Water Works Association (AWWA, 1979) they are not yet 'routine'. Monitoring is recommended by the World Health Organization (WHO, 1979) and standards are set by Arizona (Arizona Water Quality Control Council, 1979).

3.2.14 *Fecal Sterols*

Coprostanol and cholesterol are fecal sterols which are positively correlated with each other, are unequivocal qualitative indicators of fecal contamination, but have no quantitative relationship with bacterial indicators or pathogens. Either of these two compounds may be used as an indicator of sewage contamination, but cholesterol is not specific to feces (IWD, 1972). Neither are detected in non-polluted waters, and both are readily degraded by microbial action, and can be used as indicators of the efficiency of biological sewage treatment processes. Fecal sterols are not affected by normal chlorination, and are thus good indicators of fecal contamination even when the bacteria have been reduced by chlorination. Thus fecal sterols may be useful as qualitative indicators of possible viral contamination since viruses would also survive the chlorination that removed the bacterial indicators (Dutka and El-Shaarawi, 1975).

Most fecal sterols are particle bound and poorly dispersed. Their solubility in water is very low; several micrograms per litre at 30°C at best. Indigenous, mixed, microbial populations, which along with pathogenic bacteria are associated with the particulate matter, can degrade up to 90% of fecal sterols in two weeks. Thus sterols can be an indicator of fecal contamination where bacteria are not suitable, but are only indicators of continuing or recent contamination (Switzer-Howse and Dutka, 1978). This is complementary to the use of *Clostridium perfringens* as an indicator of past, but no longer current, contamination by sewage (Cabelli, 1977a).

The only well-documented source of coprostanol (5B-cholestan-3B-ol) is the feces of humans and the higher animals. It is relatively stable, non-pathogenic, can be detected even in the presence of other lipid-like compounds in water, and is apparently not affected by chemical disinfectants, toxic pollutants, or heat treatments. The presence of fecal sterols could indicate fecal pollution in areas where toxic industrial waste compromised other biological indicators. Coprostanol levels are highest in untreated raw sewage, and decrease as the sewage passes through the sewage treatment plant. Levels are also higher near sewage plant outfalls, and decrease as one moves away from the point source discharge (Switzer-Howse and Dutka, 1978)

Fecal sterols are not recommended as indicators, but they are potentially very useful in certain circumstances, particularly for recent contamination by wastes which may be toxic to standard indicators. The high cost of analyses also preclude routine use.

3.2.15 *Coliforms*

This is a large and heterogeneous group of organisms which are aerobic but facultatively anaerobic, gram-negative, non-spore-forming, rod shaped, cytochrome oxidase negative, and 11 a bl e to ferment lactose with gas formation within 48 hours at 35°C". This is valid for the multiple-tube fermentation (MPN) technique. For the membrane filtration (MF) technique, the latter part of the definition above should read as follows: "produce a dark colony with a metallic sheen in 24 hours at 35°C on an Endo-type lactose medium". The fecal coliform subgroup forms gas in 24 hours at 44.5°C (Health and Welfare Canada, 1979; APHA, 1985; Washington Department of Ecology, 1982; IJC, 1980; McNeely et al., 1979). The fecal coliform test detects *Escherichia coli* predominantly, but also gives positive results for *Klebsiella* and occasionally other genera (Vasconcelos and Anthony, 1985; Dufour, 1977). In areas where there are effluents from food, dairy, and pulp and paper mills the *Klebsella* density may be very high (Leggatt, 1986) and the effluents will give a high positive fecal coliform test yet have no fecal origin.

These coliforms are the most commonly used indicators of the microbiological quality of water and such tests, as indicators of health risks in drinking and recreational waters, have a long history of use. Theoretically and practically, fecal coliforms are indicators of gastrointestinal disease risks in water contaminated by feces for the following reasons: there are many pathogenic organisms in feces, each with its own dose-dependent risk of disease; monitoring each pathogen individually and routinely is presently impractical; methods to quantify some pathogens are not available, while for others the task is difficult; pathogen density is difficult to interpret due to time-consuming, expensive, imprecise, and inaccurate methodology, and poor dose-response data; one is not trying to index pathogen presence, but rather their potential to be present in numbers considered a health risk. However, "there is little if any proof that disease hazards are directly associated with large numbers of coliforms" (Public Health Activities Committee, Sanitary Engineering Division, American Society of Civil Engineers, 1963).

It is fecal contamination, not sewage presence, that one wishes to index; the two are usually, but not necessarily, synonymous (Cabelli, 1977b). Total coliforms include such genera as *Escherichia*, *Klebsiella*, *Enterobacter* and *Citrobacter* as well as other common sewage organisms. All ·or these are not necessarily of fecal origin, and some may multiply in sewage and treatment plants (EPS, 1973). Fecal coliforms are less likely to grow outside a host, and are better indicators than total coliforms of fecal contamination and the risk of pathogens being present (Alberta Ministry of the Environment, 1977). Under some conditions some genera, notably *Klebsiella*, can multiply in nature compromising their value as an indicator of pathogen density (Huntley et al., 1976; APHA, 1985; Stephenson, 1953; Dutka, 1973; Caplenas et al., 1981; Campbell et al., 1976; Numez and Colmer, 1968).

Good enumeration methods are now available for *E. coli* (Cabelli, 1977b; Her Majesty's Stationery Office, 1968; Dufour et al., 1975), although contrary opinions exist (Health and Welfare Canada, 1983). *E. coli* should therefore replace total and fecal coliforms as an indicator of fecal contamination, since it is more specific for human fecal contamination than the other coliform groups (Dufour, 1977). The World Health Organization and Germany use *E. coli*, fecal streptococci and *Clostridium perfringens* as indicators of fecal contamination (Muller, 1977; Suess, 1977). Generally, pathogens excreted in human feces are found in lower numbers in wastewater, and are more sensitive to environmental conditions and sewage treatment plant practices, such as chlorination, than *E. coli*. Thus *E. coli* is a conservative indicator with a built-in safety factor. There are some organisms which are, for various reasons, not quantitatively related to the *E. coli* level, such as viruses, *Salmonella*, *Shigella* and others for which *E. coli* is not an adequate indicator. These specific pathogens must be tested for separately (Kott, 1977). In addition, *E. coli* is meant as an

indicator of the risk of gastrointestinal disease when water is ingested and is not an adequate indicator of non-gastrointestinal infections related to recreational use of water.

In Canadian fresh waters, the proportion of the fecal coliforms which is *E. coli* varies quite widely, but it is usually quite high (Vlassoff, 1981). *E. coli* constitutes 80-90% of the coliforms in a domestic septic tank which is slightly less than the 90-96% *E. coli* in human fecal matter. Septic tanks receive kitchen, bath and laundry wastewater which contribute some non-fecal coliforms. However, in wastewater entering and leaving sewage treatment plants, the proportion of *E. coli* is down to about 25%, due primarily to introduction of other non-fecal coliforms from surface runoff. These other coliforms are about 25% *Klebsiella*, which is included in the fecal coliform test, and 50% other total coliform organisms, predominantly *Enterobacter* and *Citrobacter* (Carr, 1985). Thus if we wish to convert a fecal coliform criterion to an *E. coli* criterion which accurately reflects the contribution from sewage treatment plants, we need to reduce the fecal coliform criterion to about 50% of its value (Dufour, 1977), A ratio of 1:5, *E. coli*:fecal coliforms, was used in Australian criteria of 200/100 mL for *E. coli* in 1981 (Australia Environment Protection Authority, 1981) and 1000/100 mL for fecal coliforms in 1974 (Hart, 1974). However, the ratio of *E. coli* to fecal coliforms is likely quite site specific and dependent upon local pollution sources. Unless epidemiological or other direct-measurement data indicate otherwise one should assume that all the fecal coliforms are *E. coli*. This has proven to be the case in British Columbia shellfish harvesting sites (Kay, 1987), but regression equations for primary-contact recreation developed by EPA indicated a ratio closer to the above mentioned 1:2 for *E. coli*: fecal coliforms (U.S. EPA, 1986b).

With the increased requirement to re-use water several times, there is a greatly increased need to develop fast, economical and reliable water quality tests. While total and fecal coliforms have been the classical indicators for fecal contamination, many people and institutions have recently begun to question their usefulness as the sole indicator of microbiological risk to health (Dutka, 1973). *E. coli* is an improvement and should be used in place of total and fecal coliforms, but additional more suitable tests, and more use-specific indicators, are needed. An ideal indicator of fecal contamination is one which is found consistently in high concentrations in raw sewage and polluted waters, absent from non-fecally contaminated water, readily distinguished from other pollutants, is readily· quantified and is non-pathogenic (Switzer-Howse and Dutka, 1978). Such an indicator may not exist and separate monitoring of several specific pathogens may always be necessary. *E. coli* is the coliform indicator of choice for the health hazards associated with the recreational use of waters polluted by fecal wastes. There is a direct linear relationship between swimming related gastroenteritis and the density of *E. coli* (Dufour, 1984). There is no reason why *E. coli* should not replace total and fecal coliforms (Cabelli, 1977b) in fresh water. In marine water enterococci are a better indicator for primary contact recreation.

4. SAMPLING AND ANALYSIS OF MICROBIOLOGICAL INDICATORS

4.1 Sampling Procedures

Water samples for microbiological examination must be collected under aseptic conditions in sterile bottles. The bottles must be kept cool and should reach the laboratory within 24 hours (Health and Welfare Canada, 1979; Ontario Ministry of the Environment, 1978). Even shorter transit times are needed for marine water samples due to poorer survival of the indicator organisms (Kay, 1987).

In the Guidelines for Canadian Drinking Water Quality (Health and Welfare Canada, 1979), the recommended sampling frequency for coliforms depends upon the size of the population served, source water quality, the number of water sources, the past frequency of unsatisfactory samples, the adequacy of treatment, the capacity of the treatment plant, the size and complexity of the distribution system and

the type of disinfection. In Canada a minimum of 4 or 5 samples per month is recommended. In addition, for populations over 5 000 people, there should be an extra sample per month for every 1 000 people up to a population of 100 000. For populations over 100 000, there should be an extra sample per month for every 10 000 people. Local experience may necessitate some modification of this schedule at certain periods in the year and when problems arise. Sampling is necessary to isolate the problem. Generally, the absolute levels are not so important as sudden unseasonal changes in the coliform levels. Sampling of raw water is necessary to provide information to the water treatment plant since treatments may vary seasonally as different loads and different contaminants need to be removed. This report deals only with ambient supplies, not water delivered to the consumer, which is a Ministry of Health responsibility, and 10 samples in 30-days is recommended (see section 5.3).

For recreational waters, sampling should be done on a seasonal basis according to the site, type of use, and season of use. Routine sampling should be carried out at 15-30 cm depth (Health and Welfare Canada, 1983) and at the surface film. A number of samples are required at each beach in representative areas, depending upon local conditions of stream flow, wind direction and duration, tidal cycles, density of use, and nearby point and diffuse sources of pollution which may affect the beach. A sanitary survey is also necessary in addition to a sampling program (Health and Welfare Canada, 1983). The surface film is the water most likely ingested by swimmers and often has a higher concentration of bacteria than the bulk water.

Due to the normal accumulation of water-borne pathogens in bottom sediments, or at the water/sediment interface due to sedimentation (Hendricks, 1971), a 100 to 1 000-fold increase in concentration may occur in the sediments over the levels in the water column. sampling recreational beaches must take this into account, by sampling while bathers a.re present to get representative samples of the water, or else by deliberately stirring up some of the sediment before sampling (Schillinger and Gannon, 1985). However, high turbidity levels are a problem when using a membrane filtration technique, and this will cause problems when sampling some recreational waters, such as near the mouth of the Fraser River during freshets. Algal blooms also affect membrane filtration techniques. Such considerations must also be taken into account when doing shellfish surveys since it is at or near this sediment layer that shellfish have their incurrent siphons (U.S. EPA, 1976). Shellfish may be taking in water with a higher bacterial count than indicated by sampling of the overlying water. Sampling of shellfish waters should also take place during worst case pollution and hydrographic conditions and is very site specific (Kay, 1987).

4.2 Analysis of Samples

The use of the multiple-tube fermentation (MPN) or membrane filtration (MF) techniques to estimate coliform levels requires a culture medium on which these organisms can grow. Many modified media have been touted as being more selective or better able to support the growth of certain organisms for certain types of samples. However, each medium supports the growth of a slightly different group of coliforms in different ratios to each other, and this compromises any comparisons of the relative efficiencies of the different media. If different jurisdictions in the world use different media to culture their bacteria for MPN or MF determination, it then becomes inappropriate to compare standards and results to determine the relative level of protection afforded by these jurisdictions.

Kay (1978) compared the APHA Standard Method to a modified A-1 medium to determine efficiency of recovery of *Escherichia coli* and fecal coliforms from sea water. A modified A-1 method which includes a 3-hour resuscitation period at 35°C was also tested. The modified A-1 method was superior in recovering *E. coli* from marine waters, and as good as the Standard Method in recovering fecal coliforms. The A-1 method was more selective for *E. coli* than the other methods (Kay, 1978). The A-1 method was developed

for monitoring shellfish growing water in estuarine and marine conditions and may not be applicable for other samples or fresh water monitoring (Kay, 1987).

Four media were tested to compare their ability to quantify coliform bacteria from sewage, effluent and fresh water. Two of the methods were APHA Standard Methods. The first was an MPN technique using lauryl tryptose broth and brilliant green bile 2% broth (BGB). The second was an MF technique using an Endo agar LES. The non-standard methods were an MF (mC agar) technique developed for seawater, and an Indian fresh-water MPN technique using Parhad chemically-defined synthetic medium (PCDS) and BGB. Maximum population estimates were achieved by the MF Endo agar LES procedure, but each technique was selective for different genera of the Enterobacteriaceae (Dutka and Tobin, 1976). Thus, trying to compare results conducted on different media is meaningless since different species compositions are being compared. What is required is a standardized method against which all variants can be tested and regressions or nomographs constructed. Only then could one compare population estimates determined by different methods. Since different media are selective for different genera of bacteria, a medium suitable to the local conditions should be chosen for local use.

There are currently three accepted methods in use in Canada for the detection of coliforms. The multiple-tube fermentation (most probable number or MPN) and the membrane filter (MF) methods are standard quantitative techniques, and are outlined in 'Standard Methods for the Examination of Water and Wastewater' (APHA, 1985). These two procedures do not give strictly comparable results, but the confidence limits of the two methods at low coliform levels do overlap. The presence-absence (P-A) test is a modified MPN technique in which only one analysis bottle is used per sample. It is a sensitive, economical, efficient, but qualitative test, and a positive result must be quantified by either MF or MPN procedures (Health and Welfare Canada, 1979).

Techniques are available to detect enteroviruses as low as 1 TCD50/mL in routine virus laboratories (TCD50 is defined as the tissue culture infective dose that affects 50% of the roll tubes of the specific tissue cells when the usual 10-fold dilution series is carried out). Techniques are available for concentration and detection below 1 TCD50/mL, but there is no evidence that enteroviruses, like polio, are infectious to man below this level (Hart, 1974).

4.3 Statistical Considerations

The MPN and MF numbers calculated are only population estimates, based on limited sampling of the organisms. In practice these organisms are rarely evenly distributed in a body of water. The very wide 95% confidence intervals surrounding the reported results reflect this uncertainty. This is in marked contrast to the results for most inorganic water quality variables.

Table 4.1 gives the upper and lower 95% confidence limits for the number of organisms present in 100 mL of water as estimated by the MPN technique using five 10 mL tubes (Health and Welfare Canada, 1979).

Table 4.1. MPN and 95% Confidence Limits with Five 10 mL Tubes

		95% Limits	
Positive Tubes	**MPN**	**Lower**	**Upper**
0	0	0	6.0
1	2.2	0.1	12.6
2	5.1	0.5	19.2
3	9.5	1.6	29.4
4	16.0	3.3	52.9

5	Infinite	8.0	Infinite

Table 4.2 gives the upper and lower 95% confidence limits for the number of organisms present in 100 mL of water as estimated by the MPN technique using one 50 mL tube and five 10 mL tubes (Health and Welfare Canada, 1979).

Table 4.2 MPN and 95% Confidence Limits with Five 10 mL and One 50 mL Tubes

Positive Tubes			**95% Confidence Limits**	
50 mL	**10 mL**	**MPN**	**Lower**	**-Upper**
0	1	1	0.5	4
0	2	2	0.5	6
0	3	4	0.5	11
0	4	5	1.0	13
1	0	2	0.5	6
1	1	3	0.5	9
1	2	6	1.0	15
1	3	9	2.0	21
1	4	16	4.0	40

Table 4.3 gives the upper and lower 95% confidence limits for the MF technique for the number of organisms present in 100 mL of water.

Table 4.3. 95% Confidence Limits for MF Counts in 100 mL of Water

	95% Confidence Limits	
Count	Lower	Upper
0	0.0	3.7
1	0.025	5.6
2	0.24	7.2
3	0.62	8.8
4	1.1	10.2
5	1.6	11.7
6	2.2	13.1
7	2.8	14.4
8	3.5	15.8
9	4.1	17.1
10	4.8	18.4

Standard Methods (APHA, 1985) gives more complex tables for various combinations of tubes and dilution ratios whereby MPN's up to 2 400 and upper 95% confidence intervals up to 5 800 can be read. It also gives a formula for calculating combinations not found in the tables.

The percentile adjuncts to microbiological criteria are included to take the following into account: errors in count determination due to sampling technique or laboratory errors; unusual or infrequent changes in natural conditions due to storms, droughts or rainfall which alter normal levels; temporary malfunctions, overflows or bypasses in sewage treatment plants; rare and unusual point-sources of contamination; intermittent, incomplete mixing of plumes which produces uneven distribution of the same total bacterial load at different points (IJC, 1980); and the inherent variability of the test procedure, particularly the MPN method (Kay, 1987).

If, for example, the criterion is a log mean of 200/100 mL with not more than 10% of the samples to exceed 00/1 00 mL based on at least five samples in a 30-day period, some calculations yield the following relationships. The logarithmic standard deviation (base 10) of the log normal distribution is typically around 0.7. It may be as low as 0.3 in well-mixed water, and as high as 1.0 or 2.0 in poorly-mixed water which produces intermittent plumes. At 0.3, 20% of the samples will exceed 360 and 10% of the samples will exceed 500; at 0.7, 20% will exceed 800 and 10% will exceed 1 600. If the percentile clause is to represent typical conditions, such that an increase in pollution in normally mixed waters will cause the log mean to be exceeded, the 0.7 standard deviation should be chosen. This still allows a few poorly mixed samples to be covered by the percentile clause, but insures that if poor mixing becomes the norm then the water will fail to meet the criterion. Either discharge levels must be reduced or mixing must be improved to meet the criterion. The inclusion of the 10% not to exceed 400/100 mL clause in the example above-creates a more restrictive criterion than simply giving the criterion as a log mean of 200/100 mL. The clause requires very good mixing and a low standard deviation, a lower discharge rate if mixing is not very good, or a great many samples if poor mixing produces occasional high values (IJC, 1980).

5. DRINKING WATER

5.1 Effects of Water-borne Pathogens in Drinking Water

The principal effect of pathogens is to cause disease in the consumer of the water. The original source of the infectious organism was a sick person or carrier who eliminated the pathogen. If the waste treatment is inadequate the organism remains viable. If poor disposal practices occur the organism may reach public water supplies. When inadequate treatment of the water supply occurs the organisms remain viable at the consumer's tap and will now make another person sick, thus repeating the cycle. This is one way that epidemics get started and are maintained, but this scenario is not necessarily inevitable. The infection/reinfection cycle can be broken at any point by proper sanitary procedures.

In the United States, mortality from typhoid and paratyphoid fevers has dropped from 7.6 to 0.0/100,000 between 1920 and 1967, the dysentry mortality rate from 4.0 to 0.1/100, 000 and the gastritis, duodenitis, enteritis and colitis mortality rate from 53. 7 to 3. 8/100, 000. These are all diseases spread through contaminated water. Even though the rates have dropped and modern medical techniques have improved, there is still, except for typhoid fever, a finite mortality rate which is not negligible and the morbidity rate is much higher. There is considerable room for improvement in waste and water treatment processes. Salmonellosis outbreaks affecting thousands of people still occur and viral hepatitis is on the increase (Anonymous, 1973).

Older people who already have other chronic health problems are much more prone to such waterborne disease outbreaks, as indicated in Table 1. According to EPA impure tap water is a growing health hazard in the United States despite the assumption that high quality drinking water can be taken for granted. In 1961-1970 there were 130 officially recorded waterborne disease outbreaks in the United States involving 46,000 cases of morbidity and 20 cases of mortality from gastroenteritis, hepatitis and typhoid fever. Of

446 water systems in 6 States, potentially hazardous wat-er was being delivered to small systems serving 5000 people or less, with one fifth of them delivering water exceeding Federal fecal coliform limits for over 2 months of the year in 1972.

Table 5.1. Mortality Related to Water pollution By Age United States, 1920-1967, By Race, Rate/100,000

Cause/Age	1920		1967	
	White	Other	White	Other
Typhoid fever				
65-74	6.0	16.8	0.0	0.1
75-84	3.4	12.6	0.0	---
85+	1.3	13.1	0.1	0.9
Dysentery				
65-74	10.3	35.6	0.2	0.2
75-84	33.7	89.7	0.2	0.4
85+	73.2	1114.3	0.4	1.7
Gastritis, Duodenitis, Colitis Enteritis				
65-74	31.8	48.0	12.9	12.2
75-84	108.2	45.1	30.2	18.7
85+	261.7	223.0	79.0	35.3

Although the technology is adequate, and in some localities the treatment of drinking water can be excellent, generally the treatment of drinking water in British Columbia does not meet the existing Canadian and British Columbia standards presently in existence (Richards, 1983-1986). A few examples of problems with drinking water quality in British Columbia are listed below and other examples could be given. The 100 Mile House community water supply, which was chlorinated surface water from Bridge Creek, became contaminated with *Giardia lamblia* in 1981 (B.C. Ministry of Health, Division of Epidemiology, 1982). The Nakusp town water supply, which is unchlorinated surface water, was contaminated with *Campylobacter jejuni* in July 1980 (B.C. Ministry of Health, Division of Epidemiology, 1981). The portion of the Chilliwack municipal water distribution system supplied from Elk Creek and Dunville/Nevin Creek, became contaminated by *Salmonella typhimurium*, *Giardia lamblia* and *Campylobacter* in 1985 (B.C. Ministry of Health, Division of Epidemiology, 1985). Several Giardiasis outbreaks and one of Diphyllobothriasis in British Columbia are also reported in "Disease Surveillance" over the last five years. This information from the British Columbia Ministry of Health, Epidemiology Division, probably represents only a small portion of the actual number of outbreaks since not all such incidents are recognized, have the vector identified and are published (Fisk and Kornder, 1986). Infected food is far more commonly recognized as a source of disease epidemics in British Columbia than is infected water, but constant vigilance is required to maintain the relatively high quality of potable water enjoyed in British Columbia (Health and Welfare Canada, 1979). Table 5.2 lists waterborne disease outbreaks in the U.S. from 1946 to 1975 (IJC, 1983).

The treatment and disposal of wastes is not always adequate and. can provide a large reservoir of pathogens which maintain the infection/reinfection cycle (Hoehn et al., 1977; Schaffer et al., 1980; Bates et al., 1979; Dixon, 1986). Malfunctioning septic fields can result in surface water and wells being contaminated with pathogens. The discharge of primary or secondary treated sewage, which contains pathogens, to surface waters can cause problems with drinking water supplies. The pathogen density in these discharges is many orders of magnitude above the infectious dose and while dilution decreases the

concentration, the organisms are still viable and survive for some time in the environment, even though they may not reproduce.

In addition to drinking the water, people also bathe in it, wash with it and play in it. As long as soaps and detergents are being used, most pathogens will be killed and there will be little health risk; but, if the water is used in hot tubs, whirlpools, and swimming and wading pools there will be long-term contact between people and the pathogens responsible for eye, ear, nose, throat, and skin infections. These organisms are not necessarily of fecal origin and do not need to be ingested to cause disease. They are not quantitatively related to fecal coliforms, nor are they as susceptible to chlorination. Hot tubs and whirl pools are being implicated in an increasing number of epidemiological studies as reservoirs for outbreaks of infectious diseases (B.C. Ministry of Health, Division of Epidemiology, 1986a), It is not always clear, however, whether the causative organisms entered via the domestic water supply used to fill the tubs or were later introduced by the bathers.

5.2 Criteria from the Literature

Table 5.3 (Chapter 16) gives some criteria used by other jurisdictions. Most references are concerned exclusively with fecal contamination and diseases caused by drinking the water; very few take into consideration diseases which can be spread by external contact with the water. Generally, the intent of the criteria is to permit no living organism of fecal origin to be present in water used for human consumption. Different indicator organisms and sampling and analysis techniques are used to achieve this goal and not all are equally effective. The goal is exemplified by the two following quotations:

"Ideally, drinking water sources, whether they are to be treated or used directly should not contain any organism that may be of fecal origin" (IWD, 1979). Since this objective can not be attained in practice, maximum acceptable levels are set (IWD, 1979).

Table 5.2. Numbers of Waterborne Disease Outbreaks in the United States From 1946 to 1975

Disease	Causal Agent	Number of Outbreaks	Number of Cases
Protozoan			
Dysentery	*Entamoeba histolytica*	5	75
Giardiasis	*Giardia lamblia*	22	5 473
Bacterial			
Typhoid Fever	*Salmonella typhi*	58	836
Shigellosis	*Shigella* (spp.)	48	10 813
Salmonellosis	*Salmonella* (spp.)	16	16 801
Gastroenteritis	*Escherichia coli* (Enteropathogenic)	4	188
Leptospirosis	*Leptospira* (spp.)	1	9
Tularemia	*Francisella tularensis*	2	6
Viral			
Infectious Hepatitis	Hepatitis A virus	67	2 201
Poliomyelitis	Poliovirus	1	16
Unknown Etiology			
Gastroenteritis		254	65 386

"Total coliform, fecal coliform and fecal streptococcus groups and pathogens such as *Pseudomonas aeruginosa* and *Staphylococcus aureus* should not be present in water used for human or animal consumption" (IJC, 1980).

For drinking water, but not for recreational waters, the need for a bacterial indicator could probably be eliminated by maintaining turbidities below 1 NTU and free chlorine residuals at 0.3 mg/L (Geldreich et al., 1972). However, polioviruses can be isolated from finished water with turbidities below 1 NTU, pH below 8.0 and free chlorine residuals over 1 mg/L (Hoehn et al., 1977), and thus a viral indicator would still be necessary. *Giardia*, *Cryptosporidium* and *Ascaris* would not be eliminated from such treated water either and· would have to be monitored or removed by fine filtration.

Generally, the concentration of pathogen indicators in raw water to be used as a public water supply is allowed to increase as more stringent and complex water treatment procedures are imposed. This assumes, as appears to be borne out in practice, that such increasingly complex treatments are able to remove greater and greater quantities of pathogens and other contaminants from the raw water permitting the final disinfection to achieve the desired level of no pathogens. Reclaimed wastewater is being treated in South Africa and then used as potable water (Grabow, 1977). It must be emphasized that no such treatment removes all pathogens; a final disinfection step is necessary. The treatments not only reduce pathogen density, but also reduce the levels of other constituents in the water, such as turbidity, ammonia, organic nitrogen, iron, manganese, hydrogen sulphide and high pH's, which limit the effectiveness of the disinfection step (Health and Welfare Canada, 1979).

5.3 Recommended Criteria

The B.C. Ministry of Health recommends that all supplies derived from surface water and shallow groundwater sources receive disinfection as a minimum treatment (B.C. Ministry of Health, 1982). The degree of treatment needed is a function of the quality of the raw water. Protection of surface water to a degree that would eliminate health risks without treatment is impractical in most cases. Criteria describe the raw water quality necessary for a given level of water treatment. If protection falls to maintain raw water quality, then additional treatments, with their added costs, become necessary (B.C. Ministry of the Environment, 1980).

Most water treatments eliminate viruses to a certain extent, but none except disinfection can do a complete job. Both chlorine and ozone are effective. At pH's below 8.0, turbidities below 1 NTU, temperatures above 4°C, and a free chlorine residual above 0.5 mg/L, 30 minutes exposure is required to achieve "virus-free" water (Health and Welfare Canada, 1979). However, exceptions occur and monitoring must take place (Hoehn et al., 1977).

Some references from which the recommended criteria were derived are indicated. Since most were set for the use of fecal coliforms they may need to be adjusted to reflect the use of *E. coli* as the specific fecal indicator which is recommended in this report, rather than the more inclusive fecal coliforms. Fecal coliform criteria are also given and are intended as interim criteria while the change to *E. coli* is taking place. This change should occur over several years with sampling of both the old and the new indicators taking place so that an accurate correlation between the two, if there is one, can be determined for each location; otherwise much of the value of historical records would be lost.

5.3.1 *Raw Water Receiving Disinfection Only*

Fecal coliforms should not exceed 10/100 mL in more than 10% of the raw water samples taken in a 30-day period (B.C. Ministry of Health, 1982; Health and Welfare Canada, 1979; B.C. Ministry of the Environment, 1980, Hart, 1974).

Escherichia coli should not exceed 10/100 mL in more than 10% of the raw water samples taken in a 30-day period (EEC, 1975b, Hart, 1974).

Enterococci should not exceed 3/100 mL in more than 10% of the raw water samples taken in a 30-day period (EEC, 1975b; IJC, 1983; Muller, 1977; Suess, 1977; U.S. EPA, 1986b).

5.3.2 *Application of Criteria*

The recommended criteria for raw water are not meant to be necessarily sufficient, but only represent minimum guides. After treatment, the finished water must meet the British Columbia Drinking Water Quality Standards (B.C. Ministry of Health, 1982) at the consumer's tap. If the indicated raw water treatment cannot produce water of the required quality from the raw water supply, then either better quality raw water must be sought or more advanced treatment used. A minimum number of samples is required to meet the criteria which specify that no more than 10% of the samples in a 30-day period should exceed a given limit. When the criterion is 10%, then 10 samples are required. Fewer samples may be taken in a 30-day period under normal routine conditions, but if levels approaching the criterion level are found, more intensive sampling would be required to determine if the criterion was being met. The fecal coliform criteria are the same as the CCREM guidelines (CCREM, 1987); no exact conversion is possible to the other proposed criteria.

5.4 Rationale

The criteria for enterococci are recommended since these organisms are considered better indicators than fecal coliforms (Hanes and Fossa, 1971) for assessing water quality in reservoirs, sewage-contaminated water supplies and chlorinated water rich in organics (McKee and Wolf, 1963; Suess, 1977; Cabelli, 1977b; Clausen et al., 1977). See Chapter 3, section 3.2.11 for further discussion. Regression equations developed by the U.S. EPA (1986b) show a 4:1 ratio. between the criteria for *E. coli* and the criteria for enterococci, at the recommended risk level of 8/1000.

Enteric virus criteria are necessary since bacterial indicators do not adequately monitor viral concentrations in water; only another virus is an adequate indicator. Modern water treatment processes can reduce, but not eliminate, the threat of viral diseases (Goyal, 1983; Hoehn et al., 1977; Schaffer et al., 1980; Bates et al., 1979). Simple screening or rapid filtration would have little if any effect on virus levels; only complete treatment would reduce viral levels significantly. See Chapter 3, section 2.1.3 for further discussion. However, current technology is not adequate to justify routine, economical monitoring of viruses; only spot checks are recommended.

Escherichia coli criteria should replace total and fecal coliform criteria. Total coliforms includes organisms which are not necessarily of fecal origin, which may multiply in sewage, and which may enter the sewage from surface runoff. Thus they are not good indicators of fecal contamination. Fecal coliforms are usually exclusively *E. coli*, but the test also includes *Klebsiella* which is not of fecal origin. *K. pneumoniae* can multiply in organic-rich water and in pulp and paper process water, particularly when it is recycled. Thus fecal coliforms are not always strictly fecal indicators. *E. coli* is strictly a fecal indicator which does not naturally multiply outside the body so it is a quantitative indicator of fecal contamination.

The *E. coli* criteria may need to be about 50% of the fecal coliform criteria to give equivalent protection since the *E. coli*: fecal coliform ratio in sewage is about 1:2 as determined by Carr (1985). He found that coliforms in sewage contained 25% *E. coli*, 25% *Klebsiella* and 50% *Enterobacter* and *Citrobacter*. Since *E. coli* and *Klebsiella* are fecal coliforms and *Enterobacter* and *Citrobacter* are included in the total coliforms, the ratio is 1 :1 for fecal coliforms: total coliforms, and within the fecal coliform group the ratio is 1 :1 for *E. coli*:*Klebsiella*. However, the ratio of *E. coli* to fecal coliforms may be quite site specific and until comparative measurements establish the correct site-specific ratios we will recommend the same numerical values for *E. coli* as for fecal coliforms.

Now that good enumeration methods exist (Cabelli, 1977b; Her Majesty's Stationery Office, 1968; Dufour et al., 1975), *E. coli* should replace fecal and total coliforms as an indicator of fecal contamination, since it is more specific for fecal contamination than the other coliform groups (Dufour, 1977), See Chapter 3, section 2.15 for further discussion.

Giardiasis and Cryptosporidiosis may be a problem in remote areas and campgrounds accessible only by hikers. Unless the hikers themselves bring in bacterial pathogens, and contaminate the water through poor sanitary practices, there is little risk of bacterial diseases. Various products are on the market to sterilize drinking water under these conditions and they will control bacterial pathogens. Viruses may not be completely controlled by these products, and cysts of *Giardia lamblia* and *Cryptosporidium* are not affected by normal chlorination (Hoff, 1979). Boiling the water is the only presently practical method to protect against these protozoans. Residential water supplies that receive only disinfection with chlorine or disinfection plus rapid filtration can not be considered *Giardia* and *Cryptosporidium* free. Only full treatment including flocculation, sedimentation and slow or pressure filtration through a fine-pore bed will remove all *Giardia* and *Cryptosporidium* cysts.

6. AQUATIC LIFE

6.1 Effects on Aquatic Life

Aquatic organisms include, but are not limited to, algae, plants, zooplankton, benthic invertebrates, fish, reptiles, amphibians, mammals, birds, bacteria and viruses. Bacteria and viruses of non-human and non-agricultural origin are neither of concern here nor amenable to control. They form a natural background, dependent upon the species, numbers, and health of the plants and animals present. What is of concern is the additional anthropogenic load of human and farm animal pathogens. Most of these are not infective to the native flora and fauna; we are rarely concerned for their health per se. However, aquatic organisms can act as carriers and reservoirs of human and animal pathogens, and thus maintain an infection/ reinfection cycle. It is not in man's best interests to permit the survival of human and farm animal pathogens in nature. These pathogens in human sewage and wastes should be killed before the waste, which may otherwise be very valuable for irrigation or recharging groundwater reservoirs, is returned to the environment (IJC, 1980).

Coliforms in bivalves may be concentrated up to 100 times over the ambient level (U.S. EPA, 1976). *Salmonella* and coliforms may survive in the shell liquor of bivalves up to two months after harvest (McKee and Wolf, 1963). Infectious hepatitis, poliovirus, and various enteric bacteria and viruses can be transmitted to consumers (McKee and Wolf, 1963). When *Salmonella* occurred in 4.7% of water samples having 1-29/100 mL fecal coliforms, oysters accumulated 33-2 200 fecal coliforms/100 g of meat and *Salmonella* was present in 6.1% of the samples (U.S. EPA, 1976).

The inadequacy of bacterial indicators in predicting the virological quality of bivalves has been demonstrated by outbreaks of hepatitis A and gastroenteritis caused by enteric viruses when no fecal coliforms could be detected. Typhoid fever appears to be adequately monitored by coliforms, but this is not the case for viral diseases which may survive up to six weeks in bivalves (Gerba and Goyal, 1978; Linco and Grohmann, 1980; Cabelli, 1978; Portnoy et al., 1975; Mackowick et al., 1976; Fugate et al., 1975; Goyal et al., 1979).

Due to the long survival times of pathogens in bivalves the cleansing period for bivalves harvested from water not known to be pathogen-free could be up to ten weeks. This cleansing period can be eliminated if testing shows the meat to be free of pathogens or to meet the criterion for bivalve meat.

6.2 Criteria from the Literature

The criteria given in the literature, Table 6.1 (Chapter 16), are almost exclusively concerned with the ultimate effect on human health; rarely is there any documentation of effects on the aquatic life itself. Because of the high specificity of pathogens for their hosts, it is unlikely that human pathogens would cause disease in aquatic organisms, or vice-versa, except for the rare mammalian aquatic animals. There is concern that filter-feeders like bivalves will become carriers or concentrators of human pathogens and complete the infection/reinfection cycle. Aquaculture of such organisms requires very high quality water, better than primary-contact recreation water quality, since bivalves concentrate pathogens which can remain infectious within their tissues for several months.

The levels of fecal coliforms in the meat and in the intervalvular liquid of bivalves delivered to the consumer is regulated by many government agencies. The EEC set a level of 300/100 g in 1979 (EEC, 1979); 230/100 g was set by the United States in 1968 (APHA, 1985) and adopted by British Columbia in 1969 (B.C. Health Services and Hospital Insurance, 1969). These levels are based upon a wet weight of the shellfish meat.

6.3 Recommended Criteria

There are insufficient data to set criteria for the protection of the health of the aquatic organisms themselves.

7. WILDLIFE

7.1 Effects on Wildlife

Little information is available concerning the effects of pathogens on wildlife. Animals are certainly subject to waterborne diseases and parasites; there may be a substantial reservoir of such pathogens in wildlife populations. As long as wildlife remains 'wild' there is little man can do to interfere in the infection/reinfection cycle of natural pathogens in wildlife. What can be done *is* to reduce the chances of wildlife acquiring and spreading human pathogens.

Domestic and wild animals are a significant *Salmonella* reservoir and some are carriers. Effluents from slaughterhouses and meat packing plants help recycle infections in animals (Reasoner, 1979). *Salmonella* species introduced to the Netherlands on imported, contaminated meat, passed through the sewage to surface waters, then to wild and domestic animals and finally to people (Kampellmacher et al., 1977). The whole problem could have been prevented by adequate sewage treatment.

Many pathogens are host specific and do not readily adapt to a host transfer, or if they do, may cause different diseases or severity of disease in different hosts. There is minimal concern of wildlife contracting diseases from human pathogens and then either infecting each other or reinfecting man. However, since many bacteria can transfer genes readily, there is a real danger that bacteria in wastewater from hospitals, feedlots, poultry farms, and urban areas - which may have genes providing resistance to various antibiotics - will transfer this resistance to native bacteria. (See Chapter 2). Wildlife would then spread these bacteria and their genes throughout the environment. The spread, which could be for long distances, as for example in Cariboo or bird migrations, could ultimately see antibiotic-resistant human and animal pathogens found in recreational or drinking waters and on land used by free-ranging cattle. There should not, however, be any health risk to man using such wildlife for food, providing that the meat was adequately cooked.

7.2 Criteria from the Literature

It is public policy in Montana to conserve water by protecting, maintaining and improving the quality and suitability of water for wildlife and other uses (Montana Health and Environmental Sciences, 1979). In Alberta, criteria provide a basis for maximum utilization of water resources and prevent "unreasonable use" of the water (Alberta Department of Health, 1970). There is a use and value of water resources for wildlife as well as other uses and values (Alberta Ministry of the Environment, 1977). Washington State has three distinct criteria for wildlife depending upon the nature of the water; lakes have the strictest criteria, followed by marine and finally river water (Washington Department of Ecology, 1982). Many jurisdictions use livestock criteria for wildlife. This is most effective when man is the ultimate consumer who is being protected, but it is not necessarily valid when the animal is being protected for its own sake. Few criteria are available in the published literature; some representative current values for wildlife are given in Table 7.1 (Chapter 16).

7.3 Recommended Criteria

No criteria are set for this use of fresh or marine waters.

7.4 Rationale

There is a complete lack of any epidemiological or other type of objective evidence to justify any criterion. No CCREM recommendation is made for this use of the water (CCREM, 1987).

8. LIVESTOCK

8.1 Effects on Livestock

Very little attention has been given to the microbiological quality of drinking water for farm animals, even though it can have far-reaching implications. Polluted water can cause death or disease of livestock and contaminate animal products. Livestock, ill due to waterborne diseases, will grow more slowly, convert feed to product less efficiently, and not reach optimum size. This causes the cost per kilogram of meat or dozen eggs to rise beyond the necessary minimum, resulting in lower profits for the farmer and/or higher costs for consumers. The usual response to this problem is to keep the animals on a constant low level of antibiotics which has serious human health repercussions since it leads to the spread of antibiotic-resistant bacteria throughout the environment (Kampellmacher et al., 1977; Dixon, 1986). A dependable source of livestock water of good quality is necessary for the profitable production of animals. While human drinking water standards may not be justified in all cases, they might be desirable since the water is often used for other purposes on the farm and people generally come in contact with this water (APHA, 1985).

Young dairy calves may suffer from scours (diarrhea) when their drinking water exceeds 1/100 mL total coliforms. Older calves can tolerate up to 20-50/100 mL total coliforms without apparent adverse effects (Rodenburg, 1985).

The danger of direct infection of livestock which consume pathogen-contaminated water is real and deserves more attention; many diseases of livestock have been associated with sewage contamination of livestock drinking water. Beef measles and *Stephanuria dentatus* infection of pigs are two such diseases (Hart, 1974). Waterborne viral diseases of livestock include: foot and mouth disease, poliovirus, coxsackie virus, rhinoviruses, picornaviruses, teschen/talfen, avian encephalomyelitis, swine vesicular disease, enteric cytopathic human orphan viruses, African horse sickness, encephalomyocarditis, parovirus,

adenovirus, canine hepatitis, rinderpest, hog cholera (swine fever), African swine fever, mucosal disease and blue tongue virus. of sheep and cattle (APHA, 1985; Hart, 1974),

Water is also the vehicle for the spread of colibacillosis, erysipelas, leptospirosis, listeriosis, salmonellosis, streptococcosis, staphylococcosis and tuberculosis, Almost all trematode, cestode and nematode parasites are waterborne for at least one stage of their life cycle. Fungi, amoebic dysentry and diarrhea are also spread through water (APHA, 1985).

In an alkaline aqueous medium, erysipelas in pigs, sheep and turkeys, vibrio fetus in cattle and sheep, and vibrio dysentry in cattle may be transmitted. Bacillary hemoglobinuria occurs in western North America in areas with alkaline, anaerobic, soil-water environments. The organisms have a soil phase of their life cycle, but pH's must be up around 8 for successful growth (APHA, 1985).

8.2 Criteria from the Literature

Table 8.1 (Chapter 16) gives some recent criteria from other jurisdictions for the use of water by livestock. There are few criteria written specifically for livestock; most are for general use of the water for other than human consumption or recreation purposes, and there is no specific epidemiological evidence to determine livestock criteria. However, the Ontario Ministry of Environment has stated that "total coliform, fecal coliform and fecal streptococcus groups and pathogens such as *Pseudomonas aeuruginosa* and *Staphylococcus aureus* should not be present in water used for human or animal consumption" (Ontario Ministry of the Environment, 1978). These criteria are equivalent to the drinking water criteria for raw water without treatment or disinfection, given in Chapter 5, section 3.1 of this report. The other criteria from Australia, Alaska and Manitoba are for *E. coli* in the 100-200/100 mL range.

Not all of the dally pathogen load for livestock comes from the water. Some is also introduced in the feed, and some by subsequent contamination of feed and water once these are made available to the animals. Other factors affecting the water criteria are daily water requirements, species, age, general health of the animal, type of feed and weather conditions. Animals accustomed to high bacterial levels may be able to tolerate these levels, but a sudden change to higher levels may not be acceptable to non-tolerant animals. High levels of pathogens may not be acceptable in animal products destined for human consumption. Due to such variables, the following criteria may not be acceptable under all conditions and thus water supplies may need to be assessed in relation to specific uses (Ontario Ministry of the Environment, 1978).

8.3 Recommended Criteria

Three criterion are set forth below; one for free-ranging animals, one for general livestock use and one for closely confined animals (battery or feed lot operations). For the free-ranging animals, the wildlife criterion is recommended; for the closely confined animals, the human drinking-water criteria for raw water are recommended; and for general livestock use the Manitoba criterion is recommended.

8.3.1 *Free-ranging Animals*

No criterion is recommended for this use of fresh water.

8.3.2 *General Livestock Use*

The fecal coliform density, in fresh water suitable for general livestock use should not exceed 200/100 mL (Manitoba Clean Environment Commission, 1979).

The *Escherichia coli* density in fresh water suitable for general

livestock use should not exceed 200/100 mL.

The enterococci density in fresh water suitable for general livestock use should not exceed 50/100 mL.

8.3.3 *Closely Confined Animals*

Closely confined animals (feed lot or battery operations) should receive piped water meeting the raw drinking water criteria (Ontario Ministry of the Environment, 1978, CCREM, 1987) as presented in Chapter 5, section 3.

8.4 Rationale

The criteria for closely confined animals are designed to eliminate the need for massive antibiotic doses in the water in order to prevent epidemics of waterborne disease. These criteria should be considered tentative, subject to revision when adequate epidemiological evidence becomes available. Water should be supplied in such a manner as to eliminate as much as possible the chances for animals to contaminate their water supply and for multiplication of such bacteria that may be introduced.

The fecal coliform criterion is from Manitoba. See the discussion in Chapter 5, section 4 and Chapter 3, section 2.15 regarding the use of *E. coli* rather than fecal coliforms. See section 3.2.13 and 5.4 regarding viruses. Regression equations developed by EPA (U.S. EPA, 1986b) show a 4: 1 ratio between the criteria for *E. coli* and the criteria for enterococci, at the recommended risk level of 8/1000.

The occurrence of a disease epidemic in closely confined animals is a constant threat which is not economically acceptable, and clean water supplies is a preferable alternative to treating the animals' water with continuous doses of antibiotics. This latter alternative leads to meat with levels of antibiotics unacceptable for human consumption, and to the generation of anti biotic-resistant bacteria. · Hamburger made from cattle fed sublethal doses of antibiotics resulted in at least 18 people becoming sick with *Salmonella newport* which was resistant to antibiotic therapy. In effect, the cattle became factories for the production of such antibiotic resistant bacteria (Holmberg et al., 1984). See Chapter 2 for further discussion on this subject.

It is unnecessary, and impractical, to supply free-ranging cattle with high quality water and since they are not closely and forcibly confined the chances of disease epidemics is much less. It is, however, considered environmentally unacceptable to allow livestock direct access to river banks or lakeshores (Manitoba Environment and Workplace Safety and Health Department, 1983).

There is no specific CCREM guideline for livestock water. The Council recommends that high-quality water be given to livestock in high density operations, and that the water supply of free-ranging livestock be monitored for pathogens and chlorinated if necessary (CCREM, 1987).

9. IRRIGATION

9.1 Effects

Generally speaking, human and animal pathogens derived from sewage contaminated water will not affect the growth or quality of crops. It is the pathogens which remain on the harvested crop which are of concern to the health of the people or animals eating the crops, and to the farm workers who come in contact with the irrigation water or the crops. For these reasons, the water quality must meet human health standards for the pathogens even though the organisms are not of direct concern to the crop itself. Plant diseases can be spread by reuse of water which has already irrigated an infected crop, but this is rarely of major concern. Irrigation is the largest consumptive use of water in agriculture and quality control is an economic necessity.

9.2 Application Methods and Crop Types

Spray or sprinkler irrigation requires the highest microbiological water quality since the water and pathogens are sprayed directly onto aerial plant parts such as fruits, leafy crops, forage, grain and berries. In crops such as lettuce and cabbage, the pathogens can find their way into the heads where superficial rinsing will not remove them, and where moist conditions and protection from solar radiation are conducive to their long-term survival. For many crops, the safe length of time between the last spray application with sewage-contaminated water, and harvest, is too long to be practical. In addition, aerosols containing pathogens are produced during spray irrigation. These may drift a considerable distance and are a health hazard to workers and nearby people. Table 9.1 gives some survival times of pathogens on food crops, soil and in water (Bryan, 1974).

Table 9.1. Survival Times of Pathogens on Crops, Soil and in Water

Organism	**Media**	**Survival Time (Days)**
Ascaris -ova	Vegetables	27 - 35
	Soil	730 - 2010
Entamoeba histolytica	Vegetables	3
	Soil	6 - 8
	Water	60+
Mycobacterium tuberculosis	Soil	180+
	Grass	10 - 40
	Water	30 - 90
Salmonella spp.	Vegetables	3 - 40+
	Soil	15 - 280+
	Pasture	200+
	Grass	100+
Salmonella typhi	Vegetables	10 - 53
	Lettuce	18 - 21
	Soil	2 - 120
	Water	87 - 104
Shigella spp.	Vegetables	7
	Grass	42
Shigella sonnei	Tomatoes	2 - 10
Streptococcus faecalis	Soil	26 - 77
Vibrio cholerae	Vegetables	5 - 14
Poliovirus	Water	20

Flooding and furrow irrigation have less risk of contaminating the edible portions of aerial crops, but root crops are still susceptible. However, splashing and wind *or* cultivation-disturbed dust can still deposit pathogens on crops such as strawberries. Subterranean irrigation is the safest method, but is generally also the least practical or most expensive method. It is rarely justified economically except for high density, high value greenhouse crops using hydroponics.

For some constituents of irrigation water**,** such as salts, the frequency and duration of irrigation, type of soil, and prevailing weather are very important variables. For pathogens these variables are much less critical and long-term accumulation problems are rare. Spores of species like *Clostridium perfringens*, (gastroenteritis), *Clostridium tetani* (Tetanus), and eggs of *Ascaris lumbricoides* (roundworm) and other worms are very resistant and long-lived. They may accumulate in the soil to high levels, but for most other

pathogens accumulation is not a problem. Some pathogens have different survival rates depending upon the soil type and pH (APHA, 1985). This may be of some concern when livestock is allowed to graze. on land which has previously been spray irrigated with water containing pathogens. Such grazing may occur after a forage crop of hay or silage has been harvested while there is still a reservoir of viable pathogens in the upper levels of the soil. Weather plays a minor role in some instances; hot, dry weather with extensive insolation will decrease survival times of exposed pathogens, and heavy rains will wash exposed pathogens off crops. However, the situations of most concern are not affected by either of these weather conditions. Pathogens washed down into the heads of leafy crops 1ike lettuce and cabbage are protected from ultra-violet light, from dehydration and from being rinsed away. They are also concentrated into small volumes. They thus survive much better than exposed pathogens, remain on the crop in spite of superficial rinsing, and are more likely to reach infectious dose levels than are surficial pathogens.

Bacteria may live for weeks on soil or crops, see Table 9.1. Coliforms sprayed on tomatoes survived over a week; *Salmonella cerro* and *Escherichia alkalescens* disappeared in 2-7 days. There is a direct correlation between the coliform count of the spray irrigation water and that of the crop. Sprinkler-applied *Salmonella* survived up to 40 days on soil and potatoes, 10 days on carrots, and 5 days on cabbage and gooseberries. Grass sprayed with sewage was positive for typhoid/paratyphoid organisms, which only began to die off after 3 weeks; however, 5% of the samples were still infective after 6 weeks. Various reports put the survival of bovine tuberculosis bacteria on sewage irrigated land from 14 days on pasture, 3 months in water, and 6 months in soil. Cholera organisms can be spread by spray irrigation of sewage-contaminated water (APHA, 1985).

9.3 Criteria from the Literature

9.3.1 *Irrigation with Reclaimed Wastewater*

While this report deals with ambient water supplies and not effluent, it is Instructive to look at the concerns of other jurisdictions with regard to the microbiological quality of wastewater used for irrigation, and the restrictions which are applied to the use of wastewater for irrigation. It should not matter whether water used for irrigation, or any other use (as drinking water (Grabow, 1977), as industrial cooling water (Wolman, 1948) or for recreational impoundments (California Public Health Department, 1968)), is sewage-contaminated ambient water or reclaimed wastewater. It is the microbiological and other characteristics of the water quality that matter and not the source of the water. However, pathogens are expected to occur fairly uniformly in wastewater, whereas the probability of their occurrence in ambient water is much more variable. Criteria set for the use of wastewater in irrigation its major use, which protect human health should be more than adequate for ambient water supplies. The history of the water does not preclude its present use for any purpose, only the present quality is important.

In California, 80% of the reclaimed wastewater is used for irrigation (Crook, 1981), and strict microbiological criteria are in place for all types of irrigation or other uses for wastewater (California Sanitary Engineering Section, Health Services Department, 1978). Table 9.2 lists the type of use and quantity of wastewater reused in California in 1978 (Ling, 1978).

The value of effluent for irrigation is considerable and serves several functions simultaneously. The crops benefit from the water and the nutrients which would otherwise have to be supplied from another source. Such sources are becoming increasingly rare and expensive and the fertilizer value of sewage has been considered an economic necessity in parts of Europe. The disposal problems of wastewater become assets instead, and environmental problems associated with waste discharges are eliminated. Since sewage effluent usually has to be treated in some fashion before disposal, there may be little additional burden in sufficient treatment for use as irrigation water. Treatment is required since contaminated crops can not

be sold, improper irrigation can render soil unsuitable for agriculture, and the health of farm workers must be protected.

Table 9.2. Type and Quantity of Wastewater Reuse in California in 1978

Type of Reuse	Number of Use Areas	Quantity of Wastewater Reused (Acre-Ft/Yr)
Fodder, Fiber, and Seed-Crop Irrigation	190	104 200
Landscape Irrigation - Golf Courses etc.	77	21 150
Landscape Irrigation - Parks etc.	27	2 735
Orchard and Vineyard Irrigation	21	8 050
Construction and Dust Control	12	190
Industrial Uses	8	8 610
Food-Crop Irrigation	8	4 970
Restricted Recreational Impoundments	6	2 300
Landscape Impoundments	6	2 135
Groundwater Recharge	5	25 950
Nonrestricted Recreational Impoundments	1	2 450
Wetlands - Marsh Enhancement	1	622
Aquaculture - Salmon-Rearing Ponds	1	2
Total	363	184 000

The primary concern in the literature is spray irrigation of pathogen-contaminated water onto crops which may be eaten raw**.** In Arizona, direct use of sewage or industrial waste treatment effluents for irrigation of crops used for human consumption or for watering of cattle is prohibited. All sewage or industrial waste effluents used for irrigation shall be treated, discharged, or disposed of in such a manner as will conform to the requirements of the State Department of Health (Arizona Department of Health, n.d.). Florida does not permit sewage, industrial wastes, or other wastes to be used for irrigation unless they have been effectively treated or controlled to the satisfaction of the regulatory agency (Florida Air and Water Pollution Control Commission, 1969). In Kansas, effluent used for irrigating any crop must be chlorinated to protect farm workers. In Missouri, a 90% reduction in coliforms is required for forage crop irrigation and a 98% reduction for human food crops irrigation. In New Mexico, forage crops, but not vegetables, may be irrigated with treated sewage. Montana prohibits the sale of vegetables grown on farms irrigated with human sewage to prevent the possible transmission of typhoid fever. Texas does not permit the irrigation of any crop with raw sewage, primary treatment is not adequate for crops grown for human consumption, and complete treatment is preferred for feed and pasture crops used for animal consumption (Sepp, 1971). In Pennsylvania, the equivalent of secondary treatment must precede irrigation, whose rates are not to exceed 2 inches per week and 0.25 inches per hour, and which may be applied only one day per week (Pennsylvania Environmental Resources Department, 1972. In Oregon, raw or untreated sewage shall not be used for land irrigation or disposal; fresh vegetables, garden produce, root crops and berries shall not be irrigated with sewage effluents. Primary effluent is not generally adequate for land irrigation or disposal. Where public contact is possible - golf courses, playgrounds, parks, dairy or beef cattle pasture, landscape shrubbery, row irrigation, or orchards and pole crops where the produce is processed before consumption - disinfected secondary effluent is required. The same treatment, although a higher coliform density is allowed, is required for non-public contact irrigation of alfalfa, stubble, timber, grass seed crops and fodder (Oregon Public Health Department, 1969). California has comprehensive regulations governing sewage disposal which vary with the type of crop and method of irrigation. Orchards and vineyards may be surface irrigated and fodder, fibre and seed crops may be

surface or spray irrigated with waste water which has been at least primary treated. If food for human consumption is to be surface irrigated, additional treatment to destroy pathogens is required (California Public Health Department, 1968).

The recommended procedures for the use of wastewater (treated sewage effluent) in British Columbia are found in the publication "Health Aspects of Sewage Effluent Irrigation" (Parsons, 1975). Primary treatment alone is not considered adequate for any use. Buffer strips around spray irrigated areas are required in order to reduce public contact with contaminated aerosols. The type and degree of treatment required is a function of the crop being irrigated, equipment being used and public contact possible:

Pastures, Forests and Range-lands - Secondary effluents, unless they have undergone several months detention time, should be disinfected. There should be a 1-hour chlorine residual of 1.0 ppm. For livestock grazing a week's delay from the last irrigation or filtration and one week of settling should occur, unless the effluent has undergone several months of detention.

Silage and Hay Crops - Irrigation should cease at least one week prior to cutting and hay should be stored for a month prior to use by livestock. Secondary effluents, unless they have undergone several months of detention, should be disinfected. There should be a 1-hour chlorine residual of 1.0 ppm.

Recreational Areas and Vegetable Crops - Only vegetables which will be cooked should be irrigated with effluent. Following secondary treatment, effluent should be clarified by sand filtration and disinfected. There should be a 1-hour chlorine residual of 3. 0 ppm followed by one month of storage before irrigation.

9.3.2 *Irrigation with Ambient Water*

Table 9.3 (Chapter 16) gives some criteria from the recent literature. The general consensus of the references is to allow a maximum level of about 200/100 mL fecal coliforms for general irrigation use and one order of magnitude less for spray irrigation of crops to be eaten raw. The use of ground water supplies requires the density of fecal coliforms to be reduced a further order of magnitude in Alaska's criteria (Alaska Department of Environment and Conservation, 1979). The Alaska and Arizona criteria are stricter than most Canadian criteria; Arizona is in the process of switching to the stricter levels from a level comparable to the usual Canadian criteria. The California criteria are very strict and based on total coliforms in reclaimed wastewater as opposed to fecal coliforms in ambient water -for the other criteria listed. However, these California criteria are designed to give protection against viral infections using a bacterial indicator and are thus very overprotective for bacterial diseases.

9.4 Recommended Criteria

These criteria are designed to protect the ultimate consumer of the crop, grazing animals, farm workers and, in the case of non-farm irrigation, the public. The criteria depend upon the method of applying the irrigation water, the type of crop grown, and the way the crop is used. The references upon which the recommended criteria are based are shown.

9.4.1 *Irrigation of Crops Eaten Raw*

Water used for the sub-surface, surface or spray irrigation of produce which may be eaten raw, which cannot be adequately washed, or is not processed sufficiently to kill pathogens should ideally meet Drinking Water Criteria, Chapter 5, section 3, except that the *Pseudomonas aeruginosa* criterion would not apply (Bouwer et al., 1982; Alaska Department of Environment and Conservation, 1979; California Public Health Department, 1968). Examples are lettuce, cabbage, cauliflower, and broccoli. Vineyards and orchards are included here if spray irrigation occurs. However, until epidemiological evidence becomes available we propose using the primary-contact recreation criteria as is done in Ontario (Ontario Ministry of the Environment, 1978/1984).

The fecal coliform level for the irrigation of crops eaten raw should not exceed 200/100 mL as a geometric mean. There should be a least 5 samples in a 30-day period (CCREM, 1987).

The *E. coli* level for the irrigation of crops eaten raw should not exceed 77/100 mL as a geometric mean. There should be at least 5 samples in a 30-day period (CCREM, 1987).

The enterococci level for the irrigation of crops eaten raw should not exceed 20/100 mL as a geometric mean. There should be at least 5 samples in a 30-day period (Ontario Ministry of the Environment, 1974).

9.4.2 *Irrigation of Public or Grazing Access Areas*

Water used for the irrigation of parks, playgrounds and school yards or where there is public or grazing access to the recently irrigated area or the aerosols during irrigation should meet the following secondary-contact recreation criteria:

The *E. coli* level for public or grazing access irrigation should not exceed 385/1 00 mL as a geometric mean. There should be at least 5 samples in a 30-day period (McNeely et al., 1979; Dufour, 1982; CCREM, 1987; U.S. EPA, 1986b).

The Enterococci level for public or grazing access irrigation should not exceed 100/100 mL as a geometric mean. There should be at least 5 samples in a 30-day period (IJC, 1983; Dufour, 1982; CCREM, 1987; U.S. EPA, 1986b).

The *Pseudomonas aeruginosa* level for public or grazing access irrigation should not exceed 10/100 mL as the 75th percentile. There should be at least 5 samples in a 30-day period (CCREM, 1987).

9.4.3 *Other Types of Irrigation*

Water for all other irrigation uses where there is no public or grazing access, and the crops are not eaten raw by humans should meet the following Manitoba, Saskatchewan and Alberta criteria:

The fecal coliform level for irrigation should not exceed 1000/100 mL as a geometric mean. There should be at least 5 samples in a 30-day period (EPS, 1973; Manitoba Environment and Workplace Safety and Health Department, 1983).

The *E. coli* level for irrigation should not exceed 1000/100 mL as a geometric mean. There should be at least 5 samples in a 30-day period (EPS, 1973; Manitoba Environment and Workplace Safety and Health Department, 1983).

The enterococci level for irrigation should not exceed 250/100 mL as a geometric mean. There should be at least 5 samples in a 30-day period (EPS, 1973; Manitoba Environment and Workplace Safety and Health Department, 1983).

9.5 Rationale

Drinking water criteria are preferred for crops eaten raw by humans because vegetable decontamination trials have shown that washing vegetables with plain water or detergents does not effectively remove bacteria or helminth eggs. Helminth eggs are also very resistant to chemical disinfectants. Thus, for food crops, the emphasis should be placed on eliminating any pathogens which may be present from the irrigation water, processing the crop to destroy pathogens prior to sale of the crop, er preventing direct contact between water containing pathogens and the edible portion of the crop (Crook, 1981). For some crops, processing will remove pathogens acquired from irrigation water. These are crops that are generally peeled, shelled, cooked or otherwise processed. Crops like fruit on trees and vines can be protected by using furrow or subsurface irrigation, rather than spray, so the irrigation water does not come in contact with the crop. However, there are a number of crops which are eaten raw, mostly salad greens like

cabbage, lettuce, broccoli, and cauliflower, but also some like strawberries, which are in contact with the soil and can not be rinsed clean once contaminated. These crops should have pathogen-free water unless subsurface irrigation is employed. Salad greens may concentrate pathogens deep in the heads where they are protected from desiccation or irradiation. Some root crops, which are eaten raw, need pathogen-free water for subsurface or injection irrigation, but not necessarily for surface-supplied irrigation.

The tentative recommendation of CCREM is a maximum of 100/100 mL of fecal coliforms in all irrigation water from a surface or groundwater source (CCREM, 1987). The Ontario recommendation is for 100/100 mL fecal coliforms (Ontario Ministry of the Environment, 1978) for crops eaten raw or unprocessed. We believe that crops which can not be adequately rinsed in clean water, should be irrigated with water of drinking quality to protect the health of the consumer. However, until epidemiological evidence becomes available, we will use the primary contact recreation Criteria for this irrigation use. The California criterion of 2.2 total coliforms for reclaimed wastewater used for this purpose (California Public Health Department, 1968) can not be converted exactly to a fecal coliform or *E. coli* criterion. The approximate equivalence would be a fecal coliform or *E. coli* level closer to 0 than to 1, which is essentially finished drinking water quality. For crops not eaten raw, the California criterion is 23/100 mL total coliforms which is approximately equal to 5/100 mL fecal coliforms. However, these California criteria are designed to give protection against viruses present in wastewater whereas the criteria we propose protect only against bacterial organisms.

We believe that different types of irrigation, with their inherent differing risks of causing human health problems, should have different criteria. For irrigation of public access or grazing areas, particularly where the public or livestock may come in contact with the aerosols, we believe that the risk is approximately that of secondary-contact recreation and thus secondary-contact recreation criteria are proposed. There is little public health hazard during on-farm furrow or flood irrigation of crops destined for processing before being delivered to the consumer, and thus much higher coliform levels can be tolerated.

Considering the lack of epidemiological evidence for these criteria, they should be considered tentative and subject to change when adequate epidemiological studies are carried out. First priority should be given to carrying out proper epidemiological studies on crops eaten raw. These studies will determine what the *E. coli* and enterococcus levels should be to give an acceptable risk of becoming ill from a bacterial pathogen, when the irrigation water is contaminated with human fecal waste or with animal fecal waste.

10. RESEARCH AND DEVELOPMENT NEEDS

Extensive epidemiological studies are, required in order to generate defensible, quantitative data upon which to set criteria for all uses of water, except drinking. Both marine and freshwater studies are needed and data should be collected in such a manner as to permit the generation of regression equations and correlation coefficients for all water uses, all the following potential indicators and pathogens, and for several different pollution levels. Both gastrointestinal and external diseases should be monitored.

This work would allow health and environment agencies to set defensible criteria for any use, using the best indicator under the given circumstances, and to determine precisely the level of risk. The costs of achieving certain water quality criteria could then be directly compared with the savings in health costs achieved by using the new water quality criteria.

Organisms which should be monitored include, but are not restricted to: *Escherichia coli*, *Vibrio* spp., *Candida albicans*, *Pseudomonas aeruginosa*, *Campylobacter*, enterococci, *Salmonella* spp., *Staphylococcus aureus*, *Clostridium perfringens*, *Shigella flexneri*, *Citrobacter* spp., *Aeromonas hydrophila*,

Enterobacter spp., *Klebsiella* spp., coliphages, enteroviruses, *Entamoeba histolytica*, *Giardia lamblia*, *Legionella* spp., *Leptospira* spp., *Mycobacterium* spp., *Yersina enterocolitica* and *Cryptosporidium*.

While there have been a few epidemiological studies. on the primary-contact use of water (IJC, 1983; Health and Welfare Canada, 1983), these have not been extensive enough to yield sound, defensible criteria. Missing were the diversity in organisms monitored and the inclusion of sufficient variability in water quality or geographic location. There are virtually no data to quantify risks from secondary-contact recreational pursuits. No data exist upon which to set criteria protecting the health of aquatic organisms from human fecal contamination. Livestock, wildlife and irrigation criteria can not be adequately defended by epidemiological data. Considerable research is required to determine if the indicator species used are consistently and quantitatively related to levels of all the pathogens of interest under various ecological conditions and wastewater treatment regimes. Of first priority is a study on the quality of water required for the irrigation of crops which are eaten raw and cannot be adequately washed. Recreation and irrigation of public areas are the next priority items.

The type of research project outlined above will be very costly. It will take many years, a great deal of field and laboratory manpower, extensive laboratory analyses, joint efforts by several levels of government across Canada, and high levels of funding committed for the duration of the project. The results should be worth the effort since criteria can then be set with known cost/benefit ratios. One would know how many health care dollars would be saved for every environmental pollution control dollar spent, and the economical break-even point could be chosen or a politically expedient health-risk level chosen.

Considerable research is required in the field of microbial transfer of genetic resistance to antibiotics from one species to another, particularly from innocuous carriers to virulent pathogens. This process has been documented (Holmberg et al., 1984, U.S. EPA, 1976, Vasconcelos and Anthony, 1985; see 2.0, 7.1, 8.4 and Table 2.1), but the quantitative significance is not yet clear. The potential for a serious problem exists since the loss of many existing antibiotics, which are very costly to develop, would be detrimental to health care. If the problem does prove to be quite significant, then the cost in wastewater treatment to insure that no live, antibiotic resistant organisms are discharged from treatment plants, will be very considerable.

As indicated by Hart (B.C. Ministry of Health, 1982, Hart, 1974), Block (1983) and others, research is required in the field of virology as it affects human health and water quality criteria, Topics for research include:

- the prevalence of viruses in natural water bodies
- the fate of viruses after discharge into flowing and stationary fresh water and tidal or open marine waters
- the influence of environmental factors on viral survival in water
- development of an economical, routine, virus isolating and identifying procedure to make viral monitoring a practical process.
- the relationship between tissue-culture infective-dose and human-host infective-dose
- the infectivity, for man, of combinations of sub-infective dose quantities of several viral species to determine if synergistic infectivity occurs.

All of the new indicators recommended in this report have adequate, existing methods of analysis reported in the literature. There is a need, however, to train personnel and equip laboratories in British Columbia to carry out these methods on a routine basis. Some key references are:

- *E. coli*: membrane filtration technique; Dufour, et al. 1981.
- Enterococci: membrane filtration technique; Levin, et al. 1975.
- *Pseudomonas aeruginosa*: Hoadley, 1977; Grabow, 1977
- Enteric viruses: Gerba, 1983.

11. GLOSSARY

Coliform bacteria - A large and heterogeneous group of bacteria which are aerobic, but facultatively anaerobic, are gram-negative, are not spore-forming, are rod-shaped, are cytochrome oxidase negative and can ferment lactose with gas formation within 48 hours at 35°C. Includes *Escherichia*, *Klebsiella*, *Citrobacter* and *Enterobacter*. See Fecal Coliforms.

Conjugation - The transfer of genetic material, chromosomes or fragments of chromosomes containing genes, from one bacterial cell to another via a conjugation tube. Transfer is one-way from a donor to an acceptor. See transformation and transduction.

Criterion A maximum or minimum 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.

Drinking water - either 'Raw water' or 'Treated water' (see definitions following) which is used for human consumption.

Enterococcus (plural enterococci) -A) "fecal streptococci" and "enterococci" have been used interchangeably in the past but more recently fecal streptococci have been restricted to the Lancefield Group D organisms which includes *Streptococcus faecalis*, S. *durans*, *S. faecium*, *S. bovis* (cattle) and *S. equinus* (horses) (Frobisher et al., 1974).

-B) fecal streptococci are large, ovoid, gram-positive bacteria occurring in chains. They are defined as those species of streptococci which are recovered from feces in significant quantity (Clausen et al., 1977). Originally this included only Lancefield's group D streptococci but now *S. mitis*, *S. salivarius* and *S. avium* are included (Dufour, 1982). "Group D" includes *S. faecalis*, *S. faecium*, *S. durans*, *S. bovis* and *S. equinus*. "Non-enterococcal fecal streptococci" are those not conforming to the Sherman criteria and include *S. bovis* (cattle), *S. equinus* (horse), *S. mitis* and *S. salivarius* (not in animal feces. The "enterococcus" group is a part of Group D that conforms to the Sherman Criteria and includes *S. faecium*, *S. durans* and *S. faecalis* along with related biotypes (Dufour, 1982).

-C) the mE (Levin, et al. 1985) procedure for enterococci, a membrane filter test which counts only enterococci, and not other fecal streptococci as measured by mEnterococcus or KF methods, is the procedure on which the regression equations are based. This definition of enterococci and these test methods are the recommended ones to use as these regression equations are the basis of the criteria chosen (IJC, 1983).

Fecal coliform - Same as coliform except that gas formation takes place within 24 hours at 44.5°C. Primarily *Escherichia*, but also includes *Klebsiella*. See coliform bacteria.

Fecal streptococci - See enterococcus.

Indicator organism - A microbiological organism which is relatively easy and economical to assay quantitatively, is non-pathogenic, and has a known quantitative relationship with pathogens whose concentration can thus be inferred from the density of the indicator.

Lipolytic bacteria - bacteria which break down fats. See Proteolytic bacteria.

MF - Membrane filtration: a bacterial sampling and analysis technique for quantifying population densities.

MPN - Multiple tube fermentation: a bacterial sampling and analysis technique for estimating population densities.

Pathogen - An organism capable of producing disease symptoms in another organism.

PFU - Plaque forming units: a measure of virus density levels.

Potable water - Water suitable for drinking and cooking purposes on the basis of both health and aesthetic considerations.

Primary-contact recreation - Activities where a person would have direct contact with water over most of the body's surface, to the point of complete submergence, or where there is substantial risk of ingestion or intimate contact with eyes, ears, nose, mouth or groin.

Some examples of activities include swimming, diving, wading, SCUBA and water sports where dunking is commonly expected such as white water canoeing, kayaking and rafting, board and windsurfing, water skiing, log birling, snorkeling, etc. See Secondary-Contact recreation.

Some specific activities could go in either primary-contact recreation or secondary-contact recreation, depending upon the conditions and skill of the participant. For example, experienced windsurfers and kayakers are unlikely to get dunked except under adverse conditions, whereas novices will likely get dunked under ideal conditions. The above activities were placed in the primary-contact category to provide protection to novices and to experienced people during adverse conditions.

Proteolytic bacteria - bacteria which break down proteins.

Psychrophile - Cold-loving bacteria, or other organisms that can grow and multi ply in water just above the freezing point. They are a problem in milk storage and other dairy operations where raw milk must be held for some time before pasteurization. These organisms are often very resistant to chlorination, even up to chlorine residuals of 10 mg/L, and to iodine. They are acutely proteolytic (break down proteins) or lipolytic (break down fats) and may be putrefactive.

Raw water without treatment - Surface water that is available as a source of drinking water, and does not receive any subsequent treatment.

Secondary-contact recreation - Activities where a person would have very limited direct contact with the water, usually only the feet and hands, and little risk of ·complete immersion or ingestion.

Some examples of activities include boating, fishing, flat water kayaking,·canoeing and rafting, etc. See primary-contact recreation. Some specific activities could go in either primary-contact recreation of secondary-contact recreation, depending upon the conditions and skill of the participant. For example, experienced windsurfers and kayakers are unlikely to get dunked except under adverse conditions, whereas novices will likely get dunked even under ideal conditions.

Transduction - Transfer of genetic material, genes or chromosome segments from one bacterial cell to another mediated by a bacteriophage. See Transformation and Conjugation.

Transformation - Transfer of genetic material, genes or chromosome fragments between two bacterial cells. See Transduction and Conjugation.

Treated water - Surface water that is available as a source of drinking water, and has received some necessary treatment to meet health or aesthetic criteria.

11.1 Index to Some Major or Common Diseases and Infections

Abscesses - see *Staphylococcus aureus*

Amoebiasis - see *Entamoeba histolytica*

Amoebic dysentry - see *Entamoeba histolytica*

Ancylostomiasis - see *Necator* and *Ancylostoma*

Ascariasis - see *Ascaris lumbricoides*

Bacillary dysentry - see *Shigella*
Vibrio

Boils - see *Staphylococcus aureus*

Botulism - see *Clostridium botulinurn*

Brucellosis - see *Brucella*

cattle - see *Brucella abortus*

goats - see *Brucella melitensis*

pigs - see *Brucella suis*

Bubonic plague - see *Yersinia pestis*

Candidiasis - see *Candida albicans*

Cisticercosis - see *Taenia solium*

Coxsackie disease - see Viruses, Coxsackie

Cholera - see *Vibrio cholerae*

Dental caries - see *Streptococcus salivarius*

Diarrhea - see *Clostridium perfringens*
Vibrio cholerae
Escherichia coli
Salmonella
Pseudomonas aeruginosa
Viruses - coxsackie

Diphyllobothriasis - see *Diphylloliothrium*

Dysentry (amoebic) - see *Entamoeba histolytica*
(bacillary) - see *Shigella flexneri*
Shigella sonnei
Vibrio
Campylobacter

Ear infections - see *Stephanuria dentatus*

Pseudomonas aeruginosa

Clostridium intermedius

Clostridium freundis

Vibrio

Enterobiasis - see *Enterobius*

Erysipelas - see *Erysipelothrix rhusiopathiae*

Food poisoning - see *Clostridium botulinum*

Salmonella

Staphylococcus aureus

Vibrio

Gangrene - see *Clostridium perfringens*

Gastroenteritis - see Clostridium perfringens

Escherichia coli

Proteus

Salmonella

Giardiasia - see *Giardia lamblia*

Gonorrhea - see *Neisseria gonorrhoeae*

Hookworm - see *Ancylostoma*

Necator

Impetigo - see *Staphylococcus aureus*

Infectious hepatitis - see Viruses

Leptospirosis - see *Leptospira*

Listeriosis-see *Lactobacillus*

Lockjaw - see *Clostridium tetani*

Mastitis - see *Staphylococcus aureus*

Meningitis - see *Branhamella*

Viruses - coxsackie

Monihasis - see *Candida albicans*

Qxyuriasis - see *Enterobius*

Paratyphoid fever - see *Salmonella paratyphi*

Pinworm - see *Enterobius vermicularis*

Pneumonia - see *Klebsiella pneumoniae*

Yersinia pestis

Poliomyelitis - see Viruses

Septicemia - see *Enterobacter aerogenes*

Enterobacter cloacae

Yersinia enterocolitica

Salmonellosis - see *Salmonella*

Shigellosis - see *Shigella*

Smallpox - see Viruses

Staphylococcosis-see *Staphylococcus*

Streptococcosis-see *Streptococcus*

Taeniosis - see *Taenia*

Tapeworm - see *Taenia*

Tetanus - see *Clostridium tetani*

Trichuriasis - see *Trichuris trichiura*

Tuberculosis - see *Mycobacterium*

Tularemia - see *Francisella tularensis*

Typhoid fever - see *Salmonella typhi*

Venereal disease - see *Candida albicans*

Vibrio dysentry - see *Vibrio*

Vibrio fetus - see *Vibrio*

Whipworm - see *Trichuris trichuria*

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13. TABLES

Table 13.1 Microbial Criteria for the Use of Water for Human Consumption (Values from the Recent Literature)

Statement and Conditions	Criteria	Reference	Date
When *AEROMONAS* is present in more than 25% of the samples or in successive samples from a site, the water quality is poor	0/100 mL *AEROMONAS*	104 Ontario	1983
If *PSEUDOMONAS AERUGINOSA* is present in any sample the water quality is poor	0/100 mL *PSEUDOMONAS AERUGINOSA*	104 Ontario	1983
"…and pathogens such as *PSEUDOMONAS AERUGINOSA*…should not be present in water used for human or animal consumption	0/100 mL *PSEUDOMONAS AERUGINOSA*	36 Ontario	1978
…and pathogens…*STAPHYLOCOCCUS AUREUS* should not be present in water used for human or animal consumption	0/100 mL *STAPHYLOCOCCUS AUREUS*	36 Ontario	1978
If *STAPHYLOCOCCUS AUREUS* is present in any sample the water quality is poor	0/100 mL *STAPHYLOCOCCUS AUREUS*	104 Ontario	1983
Water to be given a simple physical treatment, such as rapid filtration and disinfection should not exceed 0/5000 mL *SALMONELLA*	0/5000 mL *SALMONELLA*	9 Europe (EEC)	1975
Water to be given a normal physical treatment, chemical treatment and disinfection i.e., prechlorination, coagulation, flocculation, decantation, filtration and disinfection (final chlorination) should not exceed 0/1000 mL *SALMONELLA*	0/1000 mL *SALMONELLA*	9 Europe (EEC)	1975
The desirable limit for TOTAL BACTERIA in public water supplies 1s 1000/100 mL	1000/100 mL TOTAL BACTERIA	28 Ontario	1974
The permissible limit for TOTAL BACTERIA in public water supplies is 100 000/100 mL	100 000/100 mL TOTAL BACTERIA	28 Ontario	1974
Water which will receive only disinfection should not exceed 10/100 mL *ESCHERICHIA COLI* in more than 5% of the year's samples	10/100 mL *ESCHERICHIA COLI*	55 Australia	1981
Water which will receive treatment and disinfection should not exceed 100/100 mL *ESCHERICHIA COLI* in more than 10% of the year's samples	100/100 mL *ESCHERICHIA COLI*	55 Australia	1981
"…and FECAL STREPTOCOCCI…should not be present in water used for human or animal consumption."	0/100 mL FECAL STREPTOCOCCI	36 Ontario	1978
Water to be given a simple physical treatment, such as rapid filtration and disinfection should not exceed 20/100 mL FECAL STREPTOCOCCI	20/100 mL FECAL STREPTOCOCCI	9 Europe (EEC)	1975
Water to be given a normal physical treatment, chemical treatment and disinfection i.e., pre-chlorination, coagulation, flocculation, decantation, filtration and disinfection (final chlorination), should not exceed 1000/100 mL FECAL STREPTOCOCCI	1000/100 mL FECAL STREPTOCOCCI	9 Europe (EEC)	1975
Water to be given an intensive physical and chemical treatment, extended treatment and disinfection i.e., chlorination to the breakpoint, coagulation, flocculation, decantation, filtration,	10000/100 mL FECAL STREPTOCOCCI	9 Europe (EEC)	1975

Statement and Conditions	Criteria	Reference	Date
adsorption on activated carbon and disinfection (final chlorination) should not exceed 10000/100 mL FECAL STREPTOCOCCI			
If FECAL STREPTOCOCCI are present in any sample the water quality is poor	0/100 mL FECAL STREPTOCOCCI	104 Ontario	1983
Water to be given a simple physical treatment, such as rapid filtration, and disinfection should not exceed 20/100 mL FECAL COLIFORMS	20/100 mL FECAL COLIFORM	9 Europe (EEC)	1975
Water to be given a normal physical treatment, chemical treatment and disinfection i.e. prechlorination, coagulation, flocculation, decantation, filtration and disinfection (final chlorination), should not exceed 2000/100 mL FECAL COLFIORMS	2000/100 mL FECAL COLIFORM	9 Europe (EEC)	1975
Water to be used for domestic drinking water should not exceed 10/100 mL FECAL COLIFORMS at the 90th percentile	10/100 mL FECAL COLIFORM	57 Manitoba	1983
It is recommended that the geometric mean, in raw surface water to be used for human consumption, not exceed 2000/100 ml FECAL COLIFORMS	2000/100 mL FECAL COLIFORM	12 U.S.A.	1973
The permissible level for public water supplies is 2000/100 mL FECAL COLIFORMS	2000/100 mL FECAL COLIFORM	20	1974
The desirable level of FECAL COLIFORMS for public water supplies is less than 20/100 mL	20/100 mL FECAL COLIFORMS	20	1974
II ...FECAL COLIFORM...should not be present in water used for human or animal consumption."	0/100 ml FECAL COLIFORM	36 Ontario	1978
The geometric mean FECAL COLIFORM level should not exceed 100/100 mL, with not over 10% of the samples to exceed 200/100 mL for domestic water supply use from rivers	100/100 mL (lotic) FECAL COLIFORM	37 Washington	1982
The geometric mean FECAL COLIFORM limit for domestic water use from lakes is 50/100 mL, with not over 10% of the samples to exceed 100/100 mL	50/100 mL (lentic) FECAL COLIFORM	37 Washington	1982
Water for domestic consumption should not have a FECAL COLIFORM log mean, based upon a minimum of 5 samples over a 30-day period, exceeding 200/100 mL and not more than 20% of the samples should exceed 800/100 mL	200/100 mL FECAL COLIFORM	38 IJC Canada U.S.A.	1980
Water to be treated and used as a potable water supply should have at least 90% of the samples less than 1000/100 mL FECAL COLIFORMS based on at least 5 samples in a 30 day period	1000/100 mL FECAL COLIFORM	29 Alberta 45 Sask.	1977 1975
With disinfection only at least 90% of the samples in a 30-day period should not exceed 10/100 mL FECAL COLIFORMS in raw water	10/100 mL FECAL COLIFORM	32 British Columbia	1980
With pre-treatment, filtration, or the equivalent, and disinfection, at least 90% of the samples in a 30-day period should not exceed 100/100 mL FECAL COLIFORMS in raw water	100/100 mL FECAL COLIFORM	32 British Columbia	1980
For untreated water supplies the FECAL COLIFORM count is satisfactory at 0/100 mL, suspicious at	0/100 mL FECAL COLIFORM	33 Australia	1974

Statement and Conditions	Criteria	Reference	Date
1/100 mL and unsatisfactory at >1/100 mL			
For raw water screened and disinfected only, FECAL COLIFORMS should not exceed a mean of 10/100 mL with no sample to exceed the mean by more than 5%	10/100 mL FECAL COLIFORM	33 Australia	1974
For raw water to be prechlorinated, coagulated, flocculated, sedimented, filtered, disinfected and corrected the FECAL COLIFORM count should not exceed a mean of 100/100 mL with no sample to exceed the mean by more than 10%	100/100 mL FECAL COLIFORM	33 Australia	1974
Based on a minimum of 5 samples over a 30-day period the mean FECAL COLIFORM count is not to exceed 3/100 mL MPN or 1/100 mL MF for groundwater	3/100 mL MPN 1/100 mL MF FECAL COLIFORM	43 Alaska	1979
Based en a minimum of 5 samples over a 30-day period the mean FECAL COLIFORM count is not to exceed 20/100 mL, and less than 10% of the samples are to exceed 40/100 mL, in surface water	20/100 mL FECAL COLIFORM	43 Alaska	1979
If FECAL COLIFORMS are present in any sample the water quality is unsafe	0/100 mL FECAL COLIFORM	104 Ontario	
If more than 10% of the raw water samples in any 30-day period have a FECAL COLIFORM density greater than 100/100 mL...the water should receive complete treatment consisting of coagulation-flocculation, sedimentation, filtration and disinfection	100/100 mL FECAL COLIFORM	4 Canada 3 British Columbia	1979 1982
If more than 10% of the raw water samples in any 30-day period have a FECAL COLIFORM density in the range 10 to 100/100 mL…the water should receive a combination of coagulation-flocculation, sedimentation and filtration (partial treatment) followed by disinfection	10 to 100/100 mL FECAL COLIFORMS	4 Canada 3 British Columbia	1979 1982
If any raw water sample contains FECAL COLIFORMS...disinfection is required	0/100 mL FECAL COLIFORMS	4 Canada 3 British Columbia	1979 1982
Water undergoing disinfection only should not exceed 100/100 mL TOTAL COLIFORM$ in 95% of the samples taken in a 30-day period	100/100 mL TOTAL COLIFORM	32 British Columbia	1980
Water pre-treated, filtered or the equivalent and disinfected should not exceed 1000/100 mL TOTAL COLIFORMS in 90% of the samples taken over a 30-day period	1000/100 mL TOTAL COLIFORM	32 British Columbia	1980
Water to be treated and distributed as a potable supply should not exceed 5000/100 mL TOTAL COLIFORMS in more than 10% of the samples taken in a 30-day period, based on a minimum of 5 samples	5000/100 mL TOTAL COLIFORM	29 Alberta	1977
The objective level for TOTAL COLIFORMS is 0/100 mL in treated water. The working level is 0/100 mL	0/100 mL TOTAL COLIFORM	33 Australia	1974

Statement and Conditions	Criteria	Reference	Date
in 95% of the year's samples with no sample to exceed 10/100 mL and no 2 successive samples shall exceed 0/100 mL			
Untreated water supplies shall be satisfactory if TOTAL COLIFORMS are not over 3/100 mL, suspicious between 3 and 10/100 mL and unsatisfactory over 10/1 00 mL	3/100 mL TOTAL COLIFORM	33 Australia	1974
Raw water to be treated by screening and disinfection only shall not exceed a mean TOTAL COLIFORM count of 100/100 mL and no sample shall exceed the mean by more than 5%	100/100 mL TOTAL COLIFORM	33 Australia	1974
Raw water to be treated by prechlorination, coagulation, flocculation, sedimentation, filtration, disinfection and correction shall not exceed a mean TOTAL COLIFORM count of 5000/100 mL and no sample shall-exceed the mean by more than 10%	5000/100 mL TOTAL COLIFORM	33 Australia	1974
Raw water suitable for treatment and use as a potable water supply should have a TOTAL COLIFORM count less than 5000/100 mL in at least 90% of the samples, based on at least 5 samples in a 30-day period	5000/100 mL TOTAL COLIFORM	45 Sask.	1975
Water treated by conventional means including disinfection should not exceed a geometric mean of 200/100 mL TOTAL COLIFORMS and not over 10% of the samples in a 30-day period should exceed 400/100 mL	200/100 mL TOTAL COLIFORM	47 Montana	1974
Water receiving disinfection only should not exceed 100/100 mL TOTAL COLIFORMS in more than 5% of a year's samples	100/100 mL TOTAL COLIFORM	55 Australia	1981
Water used for human consumption after treatment should not exceed 100/100 mL TOTAL COLIFORMS at the 90th percentile	100/100 mL TOTAL COLIFORM	57 Manitoba	1983
Raw groundwater not requiring any treatment should not exceed 1/100 mL, MF, TOTAL COLIFORMS	1/100 mL (well water) TOTAL COLIFORM	42 Alaska	1982
For water given a simple physical treatment like rapid filtration, followed by disinfection the TOTAL COLIFORM count at 37°C should not exceed 50/100 mL as a guide	50/100 mL TOTAL COLIFORM	9 Europe (E.E.C.)	1975
For water given a normal physical treatment, chemical treatment and disinfection such as pre-chlorination, coagulation, flocculation, decantation, filtration, disinfection and a final chlorination the TOTAL COLIFORM count should not exceed 5000/100 mL at 37°C as a guide	5000/100 mL TOTAL COLIFORM	9 Europe (E.E.C.)	1975
Water to be given an intensive physical, chemical and extended treatment such as chlorination to break point, coagulation, flocculation, decantation, filtration, adsorption on activated carbon and final disinfection (final chlorination), the TOTAL COLIFORM count at 37°C should not exceed	50000/100 mL TOTAL COLIFORM	9 Europe (E.E.C.)	1975

Statement and Conditions	Criteria	Reference	Date
50000/100 mL			
The maximum TOTAL COLIFORM count (MF) for raw water without treatment should not exceed 1/100 mL average/month, or 4/100 in more than 1 sample if less than 20 samples are taken/month, or 4/100 mL in over 5% of the samples if 20 or more samples are taken/month	1/100 mL 4/100 mL TOTAL COLIFORM	53 U.S. A.	1978
The maximum acceptable TOTAL COLIFORM level in water for human consumption is 10/100 mL in any sample; no more than 10% of the samples taken in a 30-day period should shown any coliforms and not more than 2 consecutive samples from the same site should show any coliforms	10/100 mL TOTAL COLIFORM	4 Canada 3 British Columbia	1979 1982
If more than 10% of the raw water samples in any 30-day period have...a TOTAL COLIFORM density greater than 1000/100 mL the water should receive complete treatment consisting of coagulation-flocculation, sedimentation, filtration, and disinfection. Where the TOTAL COLIFORM index exceeds 5000/100 mL in more than 10% of the samples, auxiliary treatment consisting of pre-chlorination or pre-sedimentation, or their equivalents, and post-chlorination should be used	1000/100 mL TOTAL COLIFORMS 5000/100 mL TOTAL COLIFORM$	3 British Columbia 4 Canada	1982 1979
If more than 10% of the raw water samples in any 30-day period have a ... TOTAL COLIFORM density between 100 and 1000/100 mL, the water should receive a combination of coagulation-flocculation, sedimentation and filtration (partial treatment) followed by disinfection	100 to 1000/100 mL TOTAL COLIFORMS	3 British Columbia 4 Canada	1982 1979
If more than 5% of the raw water samples in any consecutive 30-day period have a TOTAL COLIFORM density greater than 10/100 mL, disinfection is required	10/100 mL TOTAL COLIFORMS	3 British Columbia 4 Canada	1982 1979
If the TOTAL COLIFORM density is 5 or more, MPN or MF, the water quality is unsafe	5/100 mL TOTAL COLIFORM	104 Ontario	1983
If the TOTAL COLIFORM density is 1-4, MF or MPN, the water quality is poor	1-4/100 mL TOTAL COLIFORM	104 Ontario	1983
It is desirable that no VIRUS be detectable in 1000 L of drinking water	0/1000 L VIRUS	4 Canada	1979

Table 13.2 Microbial Criteria for the Use of Water by Aquatic Life (Values from the Recent Literature)

Statement and Conditions	Criteria	Reference	Date
For fish migration, the production of edible fish and crustaceans and the maintenance of aquatic ecosystems and riparian vegetation the *E. COLI* density should not exceed a geometric mean of 200/100 mL based on a minimum 5 samples in a 42-day period with no more than 20% of the samples to exceed 400/100 mL	200/100 mL (400/100 mL) fresh and marine water *E. COLI*	55 Australia	1981
Water suitable for the growth and propagation of salmonids and aquatic life should not exceed a geometric mean of 200/100mL FECAL COLIFORMS and no more than 10% of the samples in a 30-day period may exceed 400/100 mL	200/100 mL (400/100 mL) fresh water FECAL COLIFORMS	47 Montana	1979
Water suitable for the harvesting of shellfish for human consumption should not exceed a median of 14/100 mL FECAL COLIFORMS	14/100 mL marine FECAL COLIFORMS	56 U.S. A. 22,56 B.C.	1982 1981 1982
Water suitable for the harvesting of shellfish for human consumption should not exceed a median of 14/100 mL FECAL COLIFORMS and not more than 10% of the sample should exceed 43/100 mL MPN	14/100 mL (43/100 mL) FECAL COLIFORMS	27 U.S.A. 2 B.C. 11 Canada 31 Washington	1976 1982 1979 1982
Class 2C water suitable for coarse fish should not exceed a median FECAL COLIFORM density of 400/100 mL MPN	400/100 mL fresh water FECAL COLIFORM	39 Manitoba	1979
Class 2B water suitable for cool or warm, sport or commercial fisheries should not exceed a median FECAL COLIFORM density of 200/100 mL MPN based upon at least 5 samples/month	200/100 mL fresh water FECAL COLIFORMS	39 Manitoba	1979
Class 2A water suitable for cold or warm water, sport or commercial fisheries should not exceed a median FECAL COLIFORM density of 20/100 mL MPN based upon at least 5 samples/month	20/100 mL fresh water FECAL COLIFORMS	39 Manitoba	1979
Lake water suitable for the spawning, rearing and harvesting of crayfish, clams, mussels and salmonids and other fish, and for fish migration should not exceed a geometric mean FECAL COLIFORM density of 50/1 00 mL nor should more than 1 0% of the samples exceed 100/100 mL	50/100 mL (100/100 mL) fresh water (lentic) FECAL COLIFORMS	37 Washington	1982
Marine waters suitable for the spawning and rearing of non-salmonid fish, clams, oysters, mussels and crustaceans, the harvesting of non-salmonid fish and crustaceans, and the rearing and harvesting of salmonids should not exceed a geometric mean FECAL COLIFORM density of 100/100 mL with no more than 10% of the sample to exceed 200/100 mL	100/100 mL (200/100 mL) marine water FECAL COLIFORMS	37 Washington	1982
Fresh water suitable for salmonid spawning should	100/100 mL	37	1982

Statement and Conditions	Criteria	Reference	Date
not exceed a geometric mean FECAL COLIFORM density of 100/100 mL with no more than 10% of the samples to exceed 200/100 mL	(200/100 mL) fresh water FECAL COLIFORMS	Washington	
Marine water suitable for salmonid and other fish migrations should not exceed a geometric mean FECAL COLIFORM density of 200/100 mL with no more than 10% of the samples to exceed 400/100 mL	200/100 mL (400/100 mL) marine water FECAL COLIFORMS	37 Washington	1982
Fresh water suitable for the rearing and harvesting of salmonids, other fish, and crustaceans and the spawning and rearing of clams, mussels, crustaceans and non-salmonid fish should not exceed a geometric mean FECAL COLIFORM density of 200/100 mL with no more than 10% of the samples to exceed 400/100 mL	200/100 mL (400/100 mL) fresh water FECAL COLIFORMS	37 Washington	1982
Water used for fresh and marine aquaculture of products cooked before consumption may have a mean FECAL COLIFORM density of 200/100 mL with not over 10% of the samples to exceed 400/100 mL, based upon a minimum of 5 samples in a 30-day period	200/100 mL (400/100 mL) fresh and marine waters FECAL COLIFORMS	43 Alaska	1979
Marine and fresh waters used for aquaculture of products eaten raw may not exceed a mean FECAL COLIFORM density of 20/100 mL with not over 10% of the samples to exceed 40/100 mL, based on a minimum of 5 samples in a 30-day period	20/100 mL (40/100 mL) fresh and marine waters FECAL COLIFORMS	43 Alaska	1979
Groundwater used for aquaculture of products eaten raw must have a mean FECAL COLIFORM density not exceeding 3/100 MPN or 1/100 MF, based on at least 5 samples in 30 days	3/100 MPN 1/100 MF fresh water FECAL COLIFORMS	43 Alaska	1979
A health investigation of the water used for mollusc harvesting may be required when, based on a minimum of 5 samples in a 30-day period during which fecal contamination is most probable, either the median density for FECAL COLIFORMS exceeds 15/100 mL or over 20% of the samples exceeds 50/ 100 mL	15/100 mL (50/100 mL) marine water FECAL COLIFORMS	26 Australia	1981
Class 2C waters, suitable for coarse fish, should not exceed a median TOTAL COLIFORM density of 1000/100 mL MPN, based on at least 5 samples/month	1000/100 mL fresh water TOTAL COLIFORMS	39 Manitoba	1979
Class 2B waters suitable for cool or warm water fisheries should not exceed a median TOTAL COLIFORM density of 500/100 mL MPN, based on at least 5 samples/month	500/100 mL fresh water TOTAL COLIFORMS	39 Manitoba	1979
Class 2A waters suitable for cold or warm water fisheries should not exceed a median TOTAL COLIFORM density of 100/100 mL MPN, based on at least 5 samples/month	100/100 mL fresh water TOTAL COLIFORMS	39 Manitoba	1979
Water in which shellfish are grown and from which they will be harvested for human consumption,	70/100 mL (230/100 mL)	58 California	1968

Statement and Conditions	Criteria	Reference	Date
should not exceed a mean TOTAL COLIFORM density of 70/100 mL with not over 10% of the samples to exceed 230/100 mL unless there is proof that none of the coliform are of fecal origin	fresh and marine water TOTAL COLIFORMS		
Shellfish which are allowed to cleanse themselves in clean water or chlorinated water before sale or consumption may be grown in water with a mean TOTAL COLIFORM density up to 700/100 mL if not over 10% of the samples exceed 2300/100 mL	700/100 mL (2300/100 mL) fresh and marine water TOTAL COLIFORMS	58 California	1968
The median TOTAL COLIFORM MPN of waters in which shellfish are grown for harvest should not exceed 70/100 mL and not more than 10% of the samples are to exceed 230/100 mL in 5 tube method, or 330/100 mL in 3 tube method	70/100 mL (230/100 mL) (330/100 mL) fresh and marine water TOTAL COLIFORMS	23 U.S. A.	1968
The recommended TOTAL COLIFORM density in 90% of the samples is not to exceed 70/100 mL. The informal limit for TOTAL COLIFORMS is a median MPN not over 70/100 mL	70/100 mL fresh water TOTAL COLIFORMS	16 Canada	1972
Samples are not to exceed a TOTAL COLIFORM density of 230/100 mL MPN in marine water	230/100 mL marine water TOTAL COLIFORMS	16 Canada	1972

Table 13.3 Microbial Criteria for the Use of Water by Wildlife (Values from the Recent Literature)

Statement and Conditions	Criteria	Reference	Date
The guideline for livestock and wildlife watering is an ENTEROCOCCI level less than a geometric mean of 40 organisms per 100 mL of water	40/100 mL fresh water ENTEROCOCCI	28 Ontario	1974
For the maintenance and preservation of aquatic ecosystems and associated wildlife the *E. COLI* geometric mean shall not exceed 200 organisms per 100 mL of water based on 5 samples taken within a 42-day period. No more than 20% of these samples shall exceed 400/100 mL	200/100 mL 400/100 mL) fresh water *E. COLI*	55 Australia	1981
For furbearers and waterfowl the geometric mean FECAL COLIFORM level shall not exceed 200 organisms per 100 mL of water and not more than 10% of the samples in a 30-day period shall exceed 400/100 mL	200/100 mL (400/100 mL) fresh water FECAL COLIFORMS	47 Montana	1979
Water for wildlife use should not exceed 200 FECAL COLIFORMS per 100 mL of water (MPN) as a mean of at least 5 samples per month	200/100 mL fresh water FECAL COLIFORMS	39 Manitoba	1979
The geometric mean for FECAL COLIFORMS in water which forms wildlife habitat depends upon the type of water. In rivers, the mean shall not exceed 200 organisms per 100 mL of water with no more than 10% of the samples to exceed 400/100 mL. In marine waters, the mean shall not exceed 100/100 mL with no more than 10% of samples to exceed 200/100 mL. In lakes, the mean shall not exceed 50/100 mL with no more than 10% of the sample to exceed 100/100 mL	200/100 mL (400/100 mL) fresh water, lentic; 100/100 mL (200/100 mL) marine water; 50/100 mL (100/100 mL) fresh water lotic; FECAL COLIFORMS	37 Washington	1982
The FECAL COLIFORM density in waters withdrawn for treatment and distribution as a potable supply, or used for outdoor recreation other than direct contact, should not exceed 1000/100 mL in at least 90% of the samples in a 30-day period and the TOTAL COLIFORM density should not exceed 5000/100 mL. At least 5 samples shall be taken in the 30-day period	1000/100 mL fresh water FECAL COLIFORMS 5000/100 mL fresh water TOTAL COLIFORM$	29 Alberta	1977

Table 13.4 Microbial Criteria for the Use of Water by Livestock (Values from the Recent Literature)

Statement and Conditions	Criteria	Reference	Date
PSEUDOMONAS AERUGINOSA should not be present in water used for human or livestock consumption	0/100 mL fresh water *PSEUDOMONAS AERUGINOSA*	36 Ontario	1978
STAPHYLOCOCCUS AUREUS should not be present in water used for human or livestock consumption	0/100 mL freshwater *STAPHYLOCOCCUS AUREUS*	36 Ontario	1978
FECAL STREPTOCOCCI should not be present in water used for human or animal consumption	0/100 mL fresh water	36 Ontario	1978
Livestock waters should be free of barnyard runoff and from effluent contamination from either man or animals. The geometric mean of ENTEROCOCCI at 35°C incubation should be less than 40 per 100 mL	40/100 mL fresh water Enterococci	11 Ontario	1979
The *E. COLI* geometric mean, based on a minimum of 5 samples taken over a 42-day period, should not exceed 200/100 mL, and not more than 20% of the samples should exceed 400/100 mL	200/100 mL (400/100 mL) fresh water *E. COLI*I	55 Australia	1981
For livestock watering without injury or growth inhibition, the maximum FECAL COLIFORM level is 200/100 mL	200/100 mL fresh water FECAL COLIFORMS	39 Manitoba	1979
FECAL COLIFORMS should not be present in water used for human or animal consumption	0/100 mL fresh water FECAL COLIFORMS	36 Ontario	1978
For livestock watering, the mean FECAL COLIFORM density should not exceed 200/100 mL based on a minimum of 5 samples in a 30-day period; not over 10% of the samples should exceed 400/100 mL	200/100 mL (400/100 mL) fresh water FECAL COLIFORMS	43 Alaska	1979
TOTAL COLIFORMS should not be present in water used for human or animal consumption	0/100 mL fresh water TOTAL COLIFORMS	36 Ontario	1978

Table 13.5 Microbial Criteria for the Use of Water for Irrigation (Values from the Recent Literature)

Statement and Conditions	Criteria	Reference	Date
The ENTEROCOCCI density in irrigation water for both acidic and fine-textured alkaline soils for either continuous or short-term use, should not exceed a geometric mean of 20/100 mL. The desirable limit is 0/100 mL	0/100 mL (20/100 mL) fresh water ENTEROCOCCI	28 Ontario	1974
For all irrigation needs, the *E. COLI* density should not exceed a geometric mean of 200/100 mL based on a minimum of 5 samples in 42 days; no more than 20% of the samples may exceed 400/100 mL	200/100 mL (400/100 mL) fresh water *E. COLI*	55 Australia	1981
Irrigation water for crops eaten raw or unprocessed, when spray irrigation ls used, must meet bathing standards of 1000/100 mL TOTAL COLIFORMS calculated as a geometric mean	1000/100 mL fresh water TOTAL COLIFORMS	36 Ontario	1978
Water used for vegetable irrigation should not exceed a geometric mean, based on at least 5 samples for a 30-day period, of 1000/100 mL of TOTAL COLIFORMS. Not more than 20% of the samples may exceed 1000/100 mL, and no sample may exceed 2400/100 mL	1000/100 mL (2400/100 mL) fresh water TOTAL COLIFORMS	29 Alberta 45 Sask.	1977 1975
Reclaimed waste waters used for the irrigation of golf courses, landscaping, cemeteries, pastures used by milk cow or goats and for the spray irrigation of food for human consumption which will be processed sufficiently to kill pathogens shall be adequately disinfected oxidized waste water. The median MPN, determined for the last 7 days for which analyses are available and complete, shall not exceed 23/100 mL TOTAL COLIFORMS	23/100 mL fresh water TOTAL COLIFORMS (reclaimed waste water)	99 California	1968
Water used for surface irrigation of produce or spray irrigation of produce fresh water which may be eaten raw or not processed sufficiently to kill pathogens, or used to irrigate lawns, parks, playgrounds, schoolyards or any area where the public has access, shall not exceed a median MPN of 2.2/100 mL TOTAL COLIFORMS	2.2/100 mL TOTAL COLIFORMS (reclaimed waste water)	99 California	1968
Where it is the sole source of greenhouse irrigation, and there is no worker contact, water should not exceed a geometric mean of 1000/100 ml FECAL COLIFORMS with no single sample to exceed 2000/100 mL	1000/100 mL (2000/100 mL) fresh water FECAL COLIFORMS	57 Manitoba	1983
For supplementary outdoor irrigation and greenhouse use where workers come in contact with the water, the geometric mean FECAL COLIFORM density should not exceed 200/100 mL, with no single sample to exceed 400/100 mL	200/100 mL (400/100 mL) fresh water FECAL COLIFORMS	57 Manitoba	1983
Irrigation water for crops eaten cooked should not exceed a mean FECAL COLIFORM density of 200/100 mL, based on at least 5 samples in a 30-day period; no more than 10% of the samples may exceed 400/100 mL	200/100 mL (400/100 mL) fresh water FECAL COLIFORMS	43 Alaska	1979

Statement and Conditions	Criteria	Reference	Date
For crops eaten raw, the mean FECAL COLIFORM density, based on at least 5 samples over a 30-day period, should not exceed 20/100 mL, and not over 10% of the samples should exceed 40/100 mL for surface water supplies. For groundwater supplies, the limits are 1/100 MF or 3/100 MPN	20/100 mL (40/100 mL) surface fresh water 1/100 MF 3/100 MPN fresh groundwater FECAL COLIFORMS	43 Alaska	1979
Irrigation water should not exceed 1000/ 100 mL FECAL COLIFORMS	1000/100 mL fresh water FECAL COLIFORMS	12 United States	1973
Water for unrestricted irrigation use should not exceed 200/100 mL FECAL COLIFORMS. This limit is to be reduced to 2.2/100 mL with no sample to exceed 25/100 mL	2.2/100 mL (25/100 mL) (200/1 00 mL) fresh water FECAL COLIFORMS	1 Arizona	1982
For general agricultural use, water should not exceed a geometric mean of 200/100 mL FECAL COLIFORMS in a 30-day period, and no more than 10% of the samples are to exceed 400/100 mL	200/100 mL (400/100 mL) fresh water FECAL COLIFORMS	47 Montana	1979
For all soil types and for continuous irrigation, the geometric mean FECAL COLIFORM density is 100/100 mL	100/100 mL fresh water FECAL COLIFORMS	28 Ontario	1974
Water used for vegetable irrigation should not exceed a geometric mean, based on at least 5 samples in a 30-day period, of 200/100 mL FECAL COLIFORMS. Not more than 20% of the samples should exceed 200/100 mL	200/100 mL fresh water FECAL COLIFORMS	29 Alberta 45 Sask.	1977 1975
Irrigation water sprayed on crops eaten raw or unprocessed, must meet bathing criteria and the geometric mean FECAL COLIFORM density should not exceed 100/100 mL	100/100 mL fresh water FECAL COLIFORMS	36 Ontario	1978
Lake water used for agricultural purposes should not exceed a geometric mean density of 50/100 mL FECAL COLIFORMS with no more than 10% of the samples to exceed 100/100.mL	50/100 mL (100/100 mL) fresh water (lentic) FECAL COLIFORMS	37 Washington	1978
River water used for agricultural purposes should not exceed a geometric mean density of 200/100 mL FECAL COLIFORMS, with no more than 10% of the samples to exceed 400/100 mL	200/100 mL (400/100 mL) fresh water (lotic) FECAL COLIFORMS	37 Washington	1978
Irrigation water used on crops eaten raw or with little processing, and which are spray irrigated should meet the swimming objective of 100/100 mL FECAL COLIFORMS as a geometric mean	100/100 mL fresh water FECAL COLIFORMS	204 Ontario	1984

14. APPENDIX

Descriptions of Common Diseases Associated with Fecal Contamination of Water

Bacterial

Dysentry or Shigellosis: Usually caused by *Shigella sonnei* and *S. flexneri*. This is an intestinal infection characterized by diarrhea, malaise, fever and cramps, but mild cases may not suffer much diarrhea. Transmitted by ingesting water, milk or food contaminated by feces of an infected person, by direct anal-oral transfer, or by flies in which the bacteria may multiply. The disease is virtually absent from areas with high levels of sanitation including flush toilets and hot running water.

Brucellosis: Caused by *Brucella melitensis* in goats, *B. abortus* in cattle and *B. suis* in pigs. This is a systemic infection with headaches, fever, aches, chills and sweating. Transmission is by contact with infected animals, animal tissues or secretions, or by ingestion of milk, dairy products or meat. Canada was certified Brucellosis-free in 1970 after *B. abortus* was eradicated; the other species never did occur in Canada.

Cholera: Caused by *Vibrio cholerae*. The symptoms include vomiting, diarrhea, dehydration, loss of minerals and increased blood acidity leading to death. Mild cases which resemble gastroenteritis are less common than severe cases. Transmission is by contact or through food and water contaminated by feces. Flies may spread the bacteria from feces to food or directly to people.

Leptospirosis: Caused by *Leptospira pomona*, *L. canicola* and *L. interrogans*. These are acute, systemic diseases with headaches, fever, chills, vomiting and muscle aches. Rats and dogs may be carriers, with rats not clinically affected. The bacteria are excreted in the urine and may be spread through contact with contaminated water.

Otitis externa: Caused by *Pseudomonas aeruginosa* in bathing waters. Ear infections are more common in small children since it is more difficult to dry the ears completely after immersion.

Paratyphoid fever: Caused by *Salmonella paratyphi*, strains A, B and C. Fever and diarrhea are symptoms; death is less common than for typhoid fever. The feces and urine of infected people are the source of infection, and the disease may be spread by direct contact or through food, milk, milk products or shellfish.

Salmonellosis: Caused by *Salmonella newport*, *S. typhimurium* and other *Salmonella* species. This is an acute intestinal infection with diarrhea, abdominal cramps and usually fever, nausea and vomiting. The feces of infected people and animals are infection sources, and it is usually spread directly through contact with an infected person or animal or through improperly prepared or insufficiently cooked foods and unpasteurized milk or dairy products.

Tuberculosis: Caused by *Mycobacterium tuberculosis* which usually develops in the lungs but can infect almost any body tissue. It is a chronic disease causing death in much of the world. The tubercules break open into the bronchi and virulent bacteria are released by coughing, sneezing or spitting. Flies may carry bacteria. Bovine tuberculosis is transmitted by drinking unpasteurized milk or eating dairy products from tuberculous cows. Pasteurization of the milk kills the bacteria.

Typhoid Fever: Caused. by *Salmonella typhi*. It is a systemic infection with continued fever and enlargement of spleen, involving lymphoid tissues and causing constipation. The spread is by direct contact or indirectly through contaminated food and water. Raw fruits and vegetables, milk, milk products, shellfish, swimming in sewage-contaminated marine waters or drinking from wells contaminated by septic tank effluent may all cause or spread the disease.

Improved detection, use of vaccines and sanitary conditions in food, water and milk preparation and distribution have greatly reduced the disease incidence in Canada. Most new cases are imported in food or visitors.

Viral

Coxsackie disease: Caused by viruses similar to polio viruses and has symptoms similar to polio, but apparently affects the muscles directly rather than via the nervous system. The virus can be found in flies and their feces, and is regularly found in both influent and effluent streams of sewage treatment plants.

Poliomyelitis: Caused by polioviruses Types 1, 2 and 3. Affects the central nervous system and causes fever, malaise, headache, stiffness, paralysis of voluntary muscles and the presence of white blood cells in the cerebrospinal fluid. Man is the reservoir discharging viruses in feces and pharyngeal secretions. Transmission is commonly by direct contact, and although the virus is recovered from rivers and sewage, there is not much clear evidence of spread by food, insects or contaminated water.

Infectious hepatitis: Caused by infectious hepatitis virus. Characterized by fever, gastrointestinal distress, impaired liver function and jaundice. Spread by contact or through water contaminated by human feces. Contaminated milk or food may also spread the disease, which is less prevalent where flush toilets and hot running water are available.

Protozoan

Amoebiasis or amoebic dysentry: Caused by *Entamoeba histolytica* world-wide and affects up to 5% of the population in the U.S. There are many symptoms including abdominal discomfort, diarrhea, acute dysentry, and amoebic liver abscess; death is rare. Transmission is usually by food or drink contaminated by feces containing cysts. Houseflies spread the cysts and use of human feces as fertilizer on fruit and vegetable crops may spread the infection.

Giardiasis: Caused by *Giardia lamblia*, an intestinal protozoan which affects the mucosa of the duodenum. The trophozoites, when present in large numbers, interfere with nutrient absorption. Malabsorption symptoms and diarrhea may occur, especially in children.

Worm

Ancylostomiasis or hookworm infections: Caused by *Necator americanus* in west Africa and the southeastern U.S., and by *Ancylostoma duodenale* in the Mediterranean. It is a chronic, debilitating disease with anaemia, malnutrition, and mental and physical retardation in children. Eggs are discharged in feces. Larvae in the soil penetrate to the body, usually through the feet but may enter by mouth. Larvae in the skin migrate to lymph and blood, then to the lungs, alveoli, trachea, and pharynx from whence they are swallowed and reach the small intestine where they attach and mature.

Enterobiasis, Oxyuriasis or pinworm infections: Caused by *Enterobius vermicularis*, an intestinal roundworm which affects only man. It is a non-fatal intestinal infection which causes irritation and disturbed sleep, and may affect up to 20% of the U.S. population. Transmission of eggs by direct anal-oral transfer is common as well as through food, water and contaminated articles. Eggs hatch in the stomach and small intestine, young worms mature in the intestine, cecum and colon; mature worms migrate from the rectum through the anus to nearby skin where eggs are discharged.

Ascariasis or roundworm infections: Caused by *Ascaris lumbricoides*, a large intestinal roundworm. Light infections may be asymptomatic; heavy infections cause digestive disturbances, abdominal pain, vomiting and restlessness. Infection results from ingestion of embryonated eggs from fecally contaminated soil, water, food or drink.

Eggs hatch in the intestine. The larvae penetrate the intestine and migrate through lymph and blood systems to the liver and lungs. From the lungs they migrate up the bronchial tubes and are swallowed. Growth, maturity and mating occur in the small intestine and eggs are discharged in the feces.

Trichuriasis or whipworm infections: Caused by *Trichuris trichiura*, the human whipworm. Light infections may be asymptomatic; heavy infections cause anaemia and abdominal discomfort. Ingested, embryonated eggs hatch and attach to the mucosa of the cecum and colon. Eggs, passed in the feces require at least 10 days in the soil for embryonation before they become infective.

Taeniasis or **beef tapeworm infection:** Caused by the beef tapeworm *Taenia saginata*. Asymptomatic in light infections; insomnia, nervousness, weight loss and abdominal pain in heavy infections. Eggs or segments discharged in the feces infect cattle ingesting contaminated feed or water. Eggs hatch in the intestine of cattle and larvae migrate through the body to muscle tissues such as jaw, heart or diaphragm where they encyst. In 2 or 3 months they become infective to people eating infected beef which is raw or incompletely cooked. The cycle is man-feces-cattle-man.

Taeniasis or pork. tapeworm infection: Caused by *Taenia solium*. This follows the same pattern as for beef tapeworm.

Cysticercosis or pork tapeworm infection: Caused by *Taenia solium*. This infection bypasses the pig and completes the life cycle in man. Eggs swallowed by man hatch in the small intestine and larvae develop in. subcutaneous tissue, striated muscles, heart, eye, and central nervous system. Eggs produced by adults in the intestine are passed in the feces and may be transmitted to man again by ingestion of food or water or directly by hand to mouth transfer.

Diphyllobothriasls or fish tapeworm infections: Caused by the adult fish tapeworm *Diphyllobothrium latum*. Eggs from adult fish tapeworms in the human intestine are discharged in the feces. They must reach fresh water where they mature, hatch and infect copepods. Fish eating the copepods become infected and pass the worms to people when raw or inadequately cooked fish is eaten. The cycle is thus man-feces-copepod-fish-man.