A Guide to Waterworks Design

January 2008

EPB 201

Saskatchewan
Ministry of
Environment

www.environment.sk.ca

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Foreword

This document replaces A Guide to Waterworks Design published by Saskatchewan Environment; March, 1996.

The design guide applies to all waterworks controlled by *The Water Regulations, 2002* and should be used as a companion to the applicable Acts, regulations and other provincial publications currently in use or as may be published from time to time. These include:

- *The Environmental Management and Protection Act, 2002*
- *The Water Regulations*, 2002
- Guidelines for Canadian Drinking Water Quality, 6th Edition, 1996
- Saskatchewan Drinking Water Quality Standards and Objectives EPB 207
- Municipal Drinking Water Quality Monitoring Guidelines EPB 202
- Guidelines for Chlorine Gas Use in Water and Wastewater Treatment, 1999 WQ 31
- A Guide to Aquatic Nuisances and Their Control EPB 47

For private and municipal designers and waterworks owners, the guidelines:

- identify items and factors that should be considered for waterworks; and
- provide accepted practices suitable for Saskatchewan conditions.

The design guide is not intended to be a detailed engineering manual. However, the guide addresses the aspects pertinent to the design of water treatment units so as to safeguard the public and protect the environment.

Please forward inquiries concerning the guidelines to:

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1. Information Submissions for Approvals

1.1 General

An approval to construct, extend, or alter any waterworks must be obtained from Saskatchewan Ministry of Environment before starting construction of such works. Applications for approval are required to be made on prescribed forms obtained from SE.

Applications for approvals are required to contain information as outlined below. Information should be in a concise form and logical order. Drawings and plans should conform to good engineering practices. Previously submitted information need not be resubmitted unless it is affected by the construction, extension or alteration or updating is appropriate.

The following summarizes the regulatory requirements and includes other recommended submissions that will facilitate the review and processing of applications.

When a person makes an application for a permit to construct, extend or alter waterworks as required in Section 22 of the Act, he/she shall include in the application:

- engineering reports for new systems and major modifications;
- name(s) of owners and responsible party for operation and maintenance;
- designer or responsible engineer or engineering firm;
- proposed period of construction and anticipated operation date;
- cost estimates for the work including applicable local improvement or capital portions; and
- if applicable, application for permit shall include easement agreement containing the following information and provisions:
  a) the name of the person proposing to construct, extend, alter or operate the waterworks that is the subject of the easement;
  b) the nature and extent of the construction, extension, alteration or operation of the waterworks that is the subject of the easement;
  c) the name of the registered owner of the land on which the waterworks that is the subject of the easement is to be constructed, extended, altered or operated and, if different, the name of the registered owner of the land affected by the waterworks that is the subject of the easement;
  d) the legal description of the lands mentioned in clause (c); and
  e) a provision that:
    i. grants an easement by the registered owners of the lands affected by the waterworks that is the subject of the easement;
    ii. conveys a right to use the land for the purposes and to the extent required to construct, alter, extend or operate the waterworks that is the subject of the easement; and
    iii. states that the easement runs with the land and is binding on the present and subsequent registered owners of the lands affected by waterworks that is the subject of the easement and their heirs, executors, administrators and assigns.

Municipalities and other waterworks owners are advised that First Nations and Métis Consultation must take place before any waterworks or distribution system construction, upgrading or decommissioning activities that could adversely affect Treaty or Aboriginal rights is developed or put in place. Although the need for notification or consultation will depend on the specific circumstances of construction, upgrading or decommissioning, such consultation is to begin at the earliest possible time (conceptual stage) and to some degree could involve the municipalities or other waterworks owners and their consultants. More information Government of Saskatchewan Guidelines for Consultation with First Nations and Métis Consultation people can be obtained at: http://www.fnmr.gov.sk.ca/documents/policy/consultguide.pdf. Municipalities and other waterworks owners are also advised that such construction, upgrading or decommissioning activities with a significant areal impact will need to have an initial review called a Heritage Resource Review or HRR which will determine if a broader Heritage Resource Impact Assessment or HRIA is necessary.

1.2 Water Supply

- site plan showing source location, other relevant features, and means of access;
- water quality characteristics and potential variability including general chemical, health and toxicity related chemical, bacteriological (surface water) and biocides (surface water);
- description of relevant local activities, uses or other factors that may impact on the water quality;
- drawings and specifications showing structural, piping, and equipment details for pump houses together with description of capacities, etc;

- plan and profile of the water supply main indicating the size, material, location, depth and appurtenances;
- for groundwater supplies, the depth, diameter, screen details and the rated capacity of the well together with the type and capacity of the pumps; and
- for surface water supplies, details of impoundments, intake works, the type and capacity of pumps, hydrological projections, intake operating mode and planned or contemplated source treatment.

1.3 Water Treatment

- procedures and results of treatability studies including projected water quality;
- site plan showing location of treatment facilities, wastewater discharge system and means of access;
- calculations used to determine the size and capacity of treatment units and the equipment;
- process flow diagram including optional treatment procedures, hydraulic flow diagram and monitoring features;
- the principles of treatment and capacities of individual treatment units of the proposed water treatment facility;
- drawings and specifications giving the structural, piping and equipment details;
- description or listing of laboratory and safety equipment; and
- description of proposed plant operational modes and the required operational capability.

Use of non-conventional or innovative treatment processes should have substantial documentation to support the applicability of the process to a particular water supply. The supporting documentation should be submitted to SE for review. Such innovative process may be subjected through an environmental assessment process.

1.4 Water Storage

- site plan showing location of reservoir, waste discharge system and connections;
- drawings and specifications giving the structural, piping and equipment details; and
- description of the capacity and mode of operation.

1.5 Distribution

- plan of the distribution system showing the location of the pipe in the street in relation to other underground utilities, the depth of pipe burial, profile elevations, the type and size of pipe, and location of hydrants, valves and appurtenances;
- description of the water main location using street referencing where possible; and
- design information for the distribution or water transmission system including flow capacity, areas served and future areas to be served.

2. Water Supply

2.1 General

2.1.1 Approvals

During the investigation for water supplies, the requirements of other administrative authorities with respect to water rights, groundwater exploration, environmental impact assessments, planning, and intake siting, etc., should be reviewed and applicable consultation undertaken. Required approvals from other authorities should be obtained as soon as possible.

2.1.2 Characteristics

The water supply should be of such quality so that the municipal drinking water quality objectives can be achieved with appropriate treatment technology. Quality considerations should include potential future changes and other variables that may impact on treatment capability or water safety. The capacity of the supply should be checked to provide confidence in the long-term expectations for the source.

2.1.3 Multiple Supplies

Where multiple supply sources are desired due to water quantity or quality factors, consideration should be given to optimizing water quality and minimizing variability. If feasible, water from different sources should be blended prior to distribution.

Considerations for the provision of standby or emergency supplies should include:

- primary source reliability and risk for potential problems;

- storage capacities with respect to demands;
- anticipated maintenance and repair schedules; and
- alternate supply options.

2.1.4 Purchased Supplies

Waterworks using water supplies provided by others should carefully consider:

- a long-term agreement;
- water quality;
- water delivery rates and reliability of delivery; and
- responsibilities of the supplier and user. Waterworks obtaining treated water provided by others should have disinfection capabilities and records of supplied water quality.

2.2 Surface Water

2.2.1 Capacities

Storage reservoirs situated in watercourses should have usable storage capacity of at least two years average demand with allowances given to:

- evaporation, seepage, siltation and ice formation losses;
- hydrological records and characteristics of the contributing drainage area;
- future demand increases; and
- current and future demands of other applicable users.

Direct in-stream supplies should have sufficient flow to meet forecast peak demands at all times and consideration should be given to operational practices of current and foreseeable upstream water development projects.

Where a watercourse has highly variable flows and/or water quality, consideration should be given to the provision of off-stream storage to ensure use of adequate water supplies of the best available quality. The capacity of off-stream storage should be based on the hydrological and quality characteristics of the primary supply.

2.2.2 Source Protection

During the selection of a surface water supply source, the impact of other users should be reviewed with consideration given to:

- point and non-point sources of potential pollutants;
- potential for hazardous substance spills entering the supply;
- multipurpose use conflicts; and
- protection and activity controls near the intake.

2.2.3 Water Quality

Raw water quality should be adequately defined or projected to account for seasonal and hydrological variations. In addition, the water quality evaluation should consider plankton and aquatic vegetation, sediments, wind and ice cover effects and groundwater inflows. As well as variables or constituents that are listed in Saskatchewan Municipal Drinking Water Quality Standards and Objectives, the water quality assessment should include variables that may affect water treatment or finished water quality.

In general, supplies created by new impoundments or water development projects should be assessed prior to the design of waterworks facilities. Where this is not feasible, projections based on upstream data or from similar impoundments within the drainage basin could be made.

2.2.4 Source Treatment

During the development of a supply project and particularly impoundments or reservoirs, efforts should be undertaken to remove vegetation, organic soils or other materials which may adversely affect water quality. In addition, the hydraulic structure arrangement should accommodate flushing.
Consideration should be given to the potential needs and implementation of control programs for algae, aquatic weeds or other undesirable aquatic organisms. Consideration should be given to the potential needs, benefits and methods for *insitu* treatment like aeration.

2.2.5 Intakes

In addition to economic and construction factors, intake-siting considerations should include:

- water quality;
- water circulation patterns;
- bank stability and localized erosion potential;
- bottom sediment buildups and silting potential;
- accessibility;
- protection from other users; and
- location of outfalls.

Intakes should be accurately marked or mapped to enable their location during any season. In water supplies susceptible to vertical water quality variations, inlets should be placed to allow withdrawal of the best water quality. In general, inlets should be placed no lower than 0.75 m (2.5 ft.) off the bottom and the top inlet should be at least 2 m (6.5 ft.) below the low surface level where depths permit.

Intakes should be suitably anchored and marked if they may interfere with other users. Intakes should be designed to prevent entry of fish and debris and entrance velocities should be kept to a minimum especially where frazil ice may be a problem. On large intakes, mechanical screening is recommended. For small gravity intakes, a means of back flushing should be provided.

Where use of submerged infiltration-type intakes are proposed for small capacity facilities, consideration should be given to the potential water quality impact of the media and the capability for periodic cleaning and/or replacement of the media face.

2.3 Groundwater

2.3.1 Hydrogeological Characteristics

The long-term safe yield and recommended pumping rate of a well supply should be established. The following information should be obtained:

- pump test and recovery data and curves;
- depth and extent of the aquifer;
- geological profile of the aquifer overburden;
- probable source of aquifer recharge; and
- location and characteristics of observation wells.

2.3.2 Source Protection

Wells should be sited away from existing or potential sources of pollution and should be located or suitably protected from flooding. Land use and agricultural practices around a well and a recharge area, if defined, should be assessed and, if appropriate, measures should be instituted to ensure protection of the groundwater supply.

Where artificial recharge is proposed, the source water should be free of contaminants. A sample of the proposed source water should be analyzed and the results discussed with SE.

Drilled wells should be of watertight construction to exclude contamination from the surface and designed to seal off formations that are, or may be, contaminated or yield undesirable water.

Provision should be made for proper disinfection of the well during drilling, construction, and repair operations as follows:

- during drilling operations: by the application of chlorine to the water in the well each day in sufficient quantity to obtain a chlorine concentration of 50 mg/L in all the water in the well; and by cleaning and disinfecting the gravel pack materials and pumping equipment before placement;
- after completion of well construction and before use: by thoroughly removing foreign substances including swabbing the casing pipe using alkalis if necessary to remove oil, grease or other material; application of sufficient chlorine to the well to ensure a chlorine residual in the well water of at least 50 mg/L for at least 12 but not more than 24 hours. Disinfection of wells should follow appropriate standards such as AWWA C654; and
- after a repaired pump has been reinstalled or a new pump has been installed: by chlorine application as noted above.

Observation wells when not being used must be properly sealed to prevent the entry of surface water, dirt or other material into the well.

2.3.3 Water Quality

Water quality information consisting of specific conductance, pH, alkalinity, hardness, iron, manganese, sulphates and nitrates should be obtained prior to well development for a preliminary water quality assessment. Reliable field test equipment may be used for performing the preliminary water quality assessments. In addition, these variables should be determined during pump testing.

Following development of a well, the water quality should be determined to include the appropriate variables or constituents listed in Saskatchewan Municipal Drinking Water Quality Standards and Objectives. In addition, the potential for undesirable dissolved gases and bacteriological growths should be assessed. Sufficient analyses should be obtained to account for potential groundwater quality and sampling variability.

2.3.4 Other Design Considerations

Wells should have year-round accessibility for inspections, measurements, cleaning, and repair purposes. Provisions should be made for regular water level measurements in production and observation wells and periodic acidizing and disinfection of production wells as may be required.

2.4 Pumping Stations

2.4.1 Siting and Construction

Pumping stations should be readily accessible at all times for inspections, maintenance and repair functions. The station should not be subject to flooding.

Consideration should be given to:

- provision of adequate space for servicing, potential pre-treatment additions and the installation of additional units;
- protection of the station against vandalism and unauthorized entries;
- facilities and openings for the servicing, removal and replacement of equipment;
- appropriate frost protection, heating, ventilation and lighting.
- Drainage and discharge of wastewaters; and
- safe siting and storage of fuels and chemicals or other potential contaminants.

For wells, the casing should extend at least 0.2 m (8 inches) above the pump house floor and all piping or conduit entrances into the well should be adequately sealed to prevent the entry of contaminants. Where pitless well units are considered desirable for particular applications, the following features should be incorporated:

- watertight construction and tightly connected to the casing;
- extension of at least 0.4 m (16 inches) above final ground elevation and not subject to flooding;
- access for well disinfection and water level measurements; and
- protection against the entry of contamination through the top cap, electrical conduits or casing vent.

2.4.2 Pumping

Pumping capacity should be consistent with the supply and aquifer capacity and the water treatment capability. In general, for single supply sources, the pumping rate should equal the maximum daily demand based on the plant's operating time.

The number of pumps should be consistent with the pattern of flow requirements and the method of flow control. At least two pumps are recommended for single surface supply sources. Pumping capacity should be met with the largest unit out of service. Pumps should be chosen to operate over a full range of flows and adequate control valving installed.

Where only one pump is used to service small waterworks, consideration should be given for emergency or standby units.

2.4.3 Controls and Appurtenances

Where pumping stations are relatively remote, consideration should be given to providing automatic standby equipment in the event of power failure. Remote controlled stations should have signals to indicate the station is out of service and that water is being delivered. Manual overrides should also be provided. Pumps should have individual discharge pressure gauges. Consideration should be given to measurement of pump discharge rates. Discharge lines should have water sampling facilities.

2.5 Supply Pipelines

2.5.1 Capacity

Pipeline capacity should be based on maximum day demands with consideration given to supply and treatment capacities and potential demands within the life of the pipeline.

2.5.2 Materials

Supply lines should be of durable material and pipe, fittings and appurtenances should conform to applicable standards or specifications issued by AWWA, CSA, CGSB or other acceptable references. Pipe selection should be based on careful consideration of pressure regimes including transient pressures such as surge and external loading. In addition, the material should be assessed with respect to both external and internal corrosion potential. Where necessary, corrosion protection measures should be incorporated.

Interior lining should conform to AWWA standards is available. Consideration should be given to potential water quality effects from the lining.

2.5.3 Location

Where possible, supply pipelines should be located in stable areas and where the line is readily accessible for repair. Care should be taken to avoid installation near areas of potential contamination. Sufficient bury should be provided to prevent freezing with special attention given to road crossings. Consideration should be given to grading the line to facilitate draining and the installation of drainage facilities.

2.5.4 Appurtenances

Air release valves should be provided at high points along the line where needs dictate. The use of reliable automatic valves should be considered on long lines. Air release valves should be protected from damage and accessible for testing or repair.

Isolation valves should be considered for long pipelines and should be placed at the terminal ends of underwater crossings to facilitate testing or repairs. Valve locations should be well marked and readily accessible. Valve selection should include considerations for minimizing water hammer and the use of pipeline cleaning materials such as pigs or swabs.
Pipeline design should consider flushing, cleaning, and disinfection needs during construction and subsequent use. For pipelines susceptible to chemical or biological deposits, provisions for pig or swab launching and exit facilities should be made.

Where supply connections are made for other users in addition to the engineering and operational problems, consideration should be given to the execution of agreements covering water quality aspects and for the prevention of cross-connection.

Backflow prevention devices should be installed to prevent backflow occurring at the point of a cross-connection. It is important that the backflow prevention device match the particular hydraulic conditions at that location and is suitable to protect against the degree of hazard present. Generally, cross-connection and backflow prevention utilize five control measures including:

- air gap (AG);
- reduced pressure zone backflow preventer (RPZ);
- double check valves (DCs);
- pressure vacuum breaker (PVB); and
- atmospheric vacuum breaker (AVB).

3. Treatment

3.1 General

3.1.1 Objectives

The objectives of a public water supply water system are to provide safe and aesthetically appealing water to the customers without interruption and at a reasonable cost, an adequate quantity of water at sufficient pressure for fire protection and industrial water for manufacturing.

3.1.2 Selection of Water Treatment Processes

Selection of a suitable water treatment process for a given utility is always a complex and diverse task. Conditions are likely to be different for each water utility, adoption of an appropriate water treatment process by a water utility is influenced by the necessity to meet the regulatory guidelines, the desire of the utility and its customers to meet other water quality standards and objectives and the need to provide water service at the lowest reasonable cost. A water treatment plant should be designed considering the fact that it should supply continuous and safe water to the customers regardless of the raw water characteristics and the environmental conditions. Hence, the selection of treatment process is important in the plant design. The ultimate plant design has a system that is proven to be simple, effective, reliable, durable and cost-effective.

The design of water treatment plant starts with the preliminary studies that include:

- design period;
- water supply areas – identifying the areas to be served;
- population – estimating the present and future population;
- estimating maximum daily water demand;
- evaluation and selection of the water source;
- size of the treatment plant;
- location of the treatment plant site; and
- financing.

Engineers/designers should conduct a preliminary engineering study and consider the following basic rules prior to design work:

- standards and objectives of the finished water quality;
- source treatment and potential water quality changes during supply transmission;
- treatability of raw water – various treatment options to be considered;
- recommend a treatment process that is cost-effective;
- keep an alternate treatment process;
- design a plant that is easy to construct and safe to operate; and
- confirm that the plant meets the structural and geotechnical design specifications, hydraulic grade across the plant and legal requirements.

For waterworks serving the public, the treated water quality shall meet the current Saskatchewan municipal drinking water quality standards and should also meet the objectives. Where a treatment facility serves more than one supply source, careful consideration should be given to ensure the treatment processes are applicable and compatible for the sources.

The selection of package treatment plants and special proprietary devices or processes should be based on proper consideration of:

- raw water condition and demand variability;
- operation and maintenance;
- servicing, repairs or replacement; and
- operational flexibility.

3.1.3 Capacities

The water treatment plant production capacity should be on the basis of the maximum day demand at the design year with consideration also given for capacity to address storage or fire flow needs.

Treatment process capacity should be based on the plant production capacity, the in-plant water use and allowances for treatment component downtime such as filter washing. Consideration should also be given to capacity restrictions during periods of worst water quality. Where feasible, recycling of non-sanitary wastewater should be considered.

Treatment capacities should consider future expansion needs and allowances should be made for logical staging of process units.

3.1.4 Plant Siting

The site evaluation is based primarily on the distance from the site, the layout of treatment units and the method of water distribution (gravity or pumping). Further, the following items must be considered in evaluation of the treatment plant site:

- neighbouring land use compatibility;
- availability of electric power and utilities;
- accessibility for vehicles including supplies and equipment transport;
- susceptibility to flooding;
- foundation stability;
- provision for future plant expansion; and
- plant wastewater disposal facilities.

3.1.5 Building Construction

Construction should be in accordance with applicable building standards and bylaws and should, as much as possible, be aesthetically compatible with neighbouring developments. Plants should be of fire resistive construction and should be protected against vandalism and unauthorized entry. The building should have access allowances for removal, replacement or addition of process equipment. Energy conservation measures, where practical, should be incorporated into a building design.

Interior finishes should be durable and easily cleaned. Floors should be finished to provide a smooth, dust free surface and should be graded to provide adequate drainage. Consideration should be given to ensure products or materials of construction will not affect water quality for both raw and treated water.

3.1.6 Building Services

For the design and installation of building services, reference should be made to applicable codes, legislation and approval requirements. Buildings should be adequately lighted throughout with special consideration given to areas requiring close inspections and equipment adjustment or maintenance.

Fuel storage should be sited and protective measures incorporated to avoid any potential contamination of raw or treated water.

Water service should be provided from a source that has had full treatment including adequate disinfection contact time. Consideration should be given to the provision of a hot water supply for sanitary and cleaning purposes. The water system should be properly protected from any cross-connections.

Electrical systems should be adequate to accommodate peak usage plus reserves for maintenance and repair equipment and potential upgrading. Main switch gear should be located above grade and not subject to flooding. Adequate electrical outlets should be provided for maintenance and other services.

Adequate heating should be provided with control levels depending on the type of area being heated. Consideration should be given to the provision of adequate building ventilation especially for below grade facilities and for dehumidifying needs.

3.1.7 Safety

Particular attention should be paid to ensuring the plant complies with the current occupational health and safety regulations. All necessary safety and protective equipment should be available at the time of plant start-up. Attention should be given to recommended safety measures as provided by suppliers of equipment and chemicals.

3.1.8 Piping and Appurtenances

All piping and appurtenances should be manufactured in accordance with AWWA, CSA, CGSB, ASTM or other recognized standards. Material selection should include consideration of corrosion, maintenance and required connection factors. Piping should have appropriate supports and restraints. For connections through a structure, a flexible coupling should be provided if the possibility of settlement exists.

Piping should be arranged so that all valves, meters or other appurtenances are conveniently accessible. Proper consideration should be given to installation of drains, air release valves and cleanouts and flushing facilities where applicable. A totalizing water meter should be provided and additional flow measuring devices should be installed as applicable to the treatment units. Piping should be designed with flow velocities based on process, hydraulic and retention time considerations.

It is recommended that piping be adequately identified as to contents and direction of flow. Where a facility does not have a standardized colouring or marking code, one should be adopted. The recommended colour code for the Water Treatment Plant Piping as per the "Ten State Standards" is shown in Table 3.1.

Table 3.1 Water Treatment Plant Piping – Recommended Colour Code

Pipes	Colour
Water Lines:	
Raw Water	Dark Green
Potable or Finished Water	Blue
Settled or Clarified water	Aqua
Chemical Lines:	
Alum or primary coagulant	Orange
Ammonia	White
Carbon Slurry	Black
Caustic	Yellow with Green Bands
Chlorine (Gas or solution)	Yellow
Fluoride	Light Blue with Red Bands
Lime Slurry	Light Green
Ozone	Yellow with Orange Bands
Phosphate Compounds	Light Green with Red Bands
Polymers or Coagulant aids	Orange with Green Bands
Potassium Permanganate	Violet
Soda Ash	Light Green with Orange Bands
Sulfuric Acid	Yellow with Red Bands
Sulfur Dioxide	Light Green with Yellow Bands
Waste Lines:	
Backwash Waste	Light Brown
Sludge	Dark Brown
Sewer (Sanitary or other)	Dark Gray

Notes:
1. The direction of flow and name of contents be noted on all lines.
2. The entire length of pipe to painted with recommended colour .
3. Bands, if necessary are to be located as follows:
   (a) at 9 m intervals, and/or
   (b) where the pipe enters and leaves a room.
4. Individual bands are to be 25 mm wide and a 25 mm space is to be left between bands.

3.1.9 Operations and Maintenance

Suitable storage arrangements should be provided for parts, tools and other materials consistent with the treatment facility and maintenance needs. Consideration should be given for suitable working areas and bench facilities. Where possible, an office area should be provided to include a desk or working table and storage for manuals, records, plans and relevant documents/books.

Suitable operations and maintenance manuals should be prepared and readily available to operating personnel at all times. It is suggested that manual include:

- drawings, installation descriptions, recommended lubrication and maintenance schedules, special operation and/or maintenance features, calibration requirements, spare parts listing, warrantees and parts and repair availability for all equipment;
- basic operating procedures.
- recommended testing and record keeping program;
- description of finishes; and
- any emergency procedures and troubleshooting instructions that may be applicable.

3.1.10 Personnel Facilities

Depending on the time period the plant is manned and the number of operating personnel, consideration should be given to provision of sanitary facilities, apparel storage and lunch and meeting room.

3.1.11 Monitoring, Surveillance

Sufficient and suitable sample taps should be provided to enable collection of representative water samples to assess the performance of the treatment units.

Analytical equipment and laboratory facilities should be provided with consideration given to:
- source water quality and its variability;
- treatment processes - their complexity, adjustment opportunity and performance assessment;
- operating personnel capability;
- optional analytical availability; and
- acquisition of reagents and equipment parts.

As a minimum, analytical equipment should be provided for conducting:
- free and total chlorine residual determination;
- fluoride residual determinations where water is fluoridated;
- jar testing where coagulation-flocculation is practiced;
- turbidity for surface water treatment;
- iron where iron removal is required; and
- manganese where manganese removal is provided.

Appropriate forms should be devised for maintenance of water treatment records for water usage, process operations and analytical test data.

3.1.12 Wastewater
All sanitary wastes should be segregated within the plant from process wastewaters and discharged to a sanitary sewage works or provided acceptable on-site or off-site treatment. Consideration should be given to recycling of process wastewaters where feasible.

3.1.13 Filter Backwash and other Process Waters
Backwash water and thickener supernatant, may contain high concentrations of pathogens including *Cryptosporodium* oocysts. Recycling of these waters may reintroduce contaminants that were removed during treatment. If adequate treatment of these waters is not provided before being returned, significant numbers of pathogens may re-enter the plant. Water treatment plants should discharge backwash and other process waters into sanitary sewers, separate storage ponds or sedimentation tanks. The hydraulic capacities of the sewage works should be assessed and discharge controls provided if necessary. The discharge such stream to other than sanitary sewage works should be carefully assessed to determine treatment requirements and discharge arrangements.
Recycling of these waters may be possible after gravity settling in storage ponds to ensure settling of solids at the bottom. The supernatant from the storage ponds could be returned prior to the point of primary coagulant addition.

Clarifier sludges should receive a minimum of sedimentation. The disposal of concentrated sludge should be considered.

3.2 Surface Water and Groundwater under Surface Influence
3.2.1 Processes
A water treatment plant should be designed so that the treated water meets turbidity and other water quality standards specified in the regulations. In general, treatment facilities for a surface water source or groundwater source directly affected by surface water shall include screening, coagulation-flocculation, sedimentation, filtration, taste and odour control and disinfection to ensure greater than 3-log (99.9%) removal and/or inactivation of *Giardia Lamblia* cysts and *Cryptosporodium parvum* oocysts and 4-log (99.99%) removal and/or inactivation of viruses. The removal/inactivation of microbial contaminants as a function of treatment processes are shown in Table 3.2.

Filtration of a surface water source or a groundwater source under the direct influence of surface water may not be necessary if *all* of the following conditions are met:

1. Overall inactivation is met using a minimum of two disinfectants:
    - ultraviolet irradiation or ozone to inactivate cysts/oocysts;
    - chlorine (free chlorine) to inactivate viruses; and
    - chlorine or chloramines to maintain a residual in the distribution system.

Disinfection must reliably achieve at least a 99% (2-log) reduction of *Cryptosporidium* oocysts,* a 99.9% (3-log) reduction of *Giardia lamblia* cysts and a 99.99% (4-log) reduction of viruses. If mean source water cyst/oocyst levels are greater than 10/1000 L, more than 99% (2-log) reduction of *Cryptosporidium* oocysts and 99.9% (3-log) reduction of *Giardia lamblia* cysts must be achieved. Background levels for *Giardia lamblia* cysts and *Cryptosporidium* oocysts in the source water should be established by monitoring as described in the most recent "Protozoa" guideline document produced by the Federal/Provincial/Territorial Committed on Drinking Water, or more frequently during periods of expected highest levels (e.g., during spring runoff or after heavy rainfall).

2. Prior to the point where the disinfectant is applied, the number of *Escherichia coli* bacteria in the source water does not exceed 20/100 mL (or, if *E. coli* data are not available, the number of total coliform bacteria does not exceed 100/100 mL) in at least 90% of the weekly samples from the previous 6 months.

3. Average daily source water turbidity levels measured at equal intervals (at least every 4 hours), immediately prior to where the disinfectant is applied, are around 1.0 NTU but do not exceed 5.0 NTU for more than 2 days in a 12-month period. Source water turbidity also does not show evidence of protecting microbiological contaminants.

4. A watershed control program (e.g., protected watershed, controlled discharges, etc.) is maintained that minimizes the potential for faecal contamination in the source water. The Ministry must be informed and consulted on any watershed control program.

Table 3.2 Log Removal/Inactivation for Treatment Processes

Process	***Giardia* cysts**	***Cryptosporodium parvum* oocysts**	**Virus**
Conventional sedimentation/filtration credit	2.5	2.0	2.0
Disinfection inactivation required	0.5	1.0	2.0
Direct filtration credit	2.0	2.0	1.0
Disinfection inactivation required	1.0	1.0	3.0
Slow sand filtration credit	2.0	2.0	2.0
Disinfection inactivation required	1.0	1.0	2.0
Diatomaceous earth filtration credit	2.0	2.0	1.0
Disinfection inactivation required	1.0	1.0	3.0
No filtration	0.0	0.0	0.0
Disinfection inactivation required	3.0	3.0	4.0

In the selection of a water treatment process, consideration should also be given to provide appropriate control measures to control the disinfection by-products (DPBs) that are formed during the disinfection process. However, this should not be done in manners that would compromise the efficiency of the disinfection process. Special treatment processes for controlling the specific contaminants would have to be reviewed on an individual basis.

3.2.2 Chemical Application

Only those chemicals for which National Sanitation Foundation standards exist should be used. Care should be taken to select chemicals that do not contain excessive impurities. In general, all chemicals must be approved for water use. Approval agencies include Health Canada, National Sanitation Foundation and US Environmental Protection Agency. Requirements of other agencies in terms of labeling, storage, safety, spill control and other factors should be considered.

Use of coagulant or flocculant aids should be based on appropriate bench or pilot testing for the specific water supply. Polyelectrolytes or other aids should be suitable and approved for use with water. Special consideration should be given to mixing needs, chemical agency application points, and dosage control.

Chemicals should be stored and handled in appropriate manners. Containers should be fully labeled to include chemical name, purity and concentration and supplier name and address. Segregated, interior storage space should be provided if possible with consideration given to:

- maintenance of inventory for at least 30 days supply unless short notice deliveries are assured;
- unloading and handling conveniences;
- maintenance of dry conditions;
- compatibility of chemicals or species hazards;
- protection from adulteration and spills; and

- suitable ventilation.

For critical operations like disinfection and coagulation, standby feeders should be available. Chemical feed equipment should have appropriate dust and gas control measures and siting considerations should include proximity to application points and accessibility for servicing, repair and observations. Measures should be taken to avoid potential cross-connection problems with water and potential chemical syphoning. In addition to ensuring feeders are suitable for the form and characteristics of the chemical, selection considerations should include:

- adequate capacities to meet anticipated maximum dosages;
- ability to control feed rates; and
- reliability of operation, availability of parts and repairs and repair capability.

Chemical application points should be carefully evaluated for such factors as:

- treatment efficiency;
- safety to operators;
- flexibility for process modifications;
- mixing;
- antagonistic effects of different chemicals;
- impact on facility materials; and
- feed line maintenance.

3.2.3 Aeration

Aeration is effective for removing dissolved gases and highly odorous compounds such as hydrogen sulfide. Aeration is the first step in treating impounded surface waters or well water, and may achieve any of the following: removal of hydrogen sulfide; reduction of dissolved carbon dioxide; and addition of dissolved oxygen for oxidation of iron and manganese. Examples of aeration processes include diffused mechanical nozzle spraying, multiple tray cascading and packed power type.

Forced or induced draft aeration devices should be designed to ensure even water distribution, adequate counter currents of air and proper external exhausting. As a guide, the loading should be within the range of 0.7 to 3.4 L/s per m^2 of total tray area (0.8 to 4 gpm/ft^2) and 5 or more trays used with separations not less than 150 mm (6 inches). Where pressure aeration is proposed for oxidation purposes, consideration should be given to compressed air quality and mixing, the scaling potential of the water and subsequent air release. Aerators should have a bypass and provisions should be made for inspection and cleaning of the devices. Exhaust gases should be vented outside the building.

3.2.4 Coagulation – Flocculation

Coagulation is used to destabilize the charge on colloids and suspended solids, including bacteria and viruses. Flash mixing is an integral part of coagulation. To achieve proper coagulation, high intensity rapid mixing is considered necessary. It is recommended that rapid mixing be accomplished by either an in-line mixing device or mixing in a separate process tank. Typical energy gradients (G values) would be in the range of 1000 sec^{-1}. It is recommended that some flexibility be provided in rapid mix design if possible.

Flocculation is the gentle mixing phase that follows the dispersion of coagulant by the flash mixing unit that is necessary to condition the suspended material for subsequent treatment. The design of flocculation systems should allow for low velocities and avoidance of rapid acceleration to ensure maintenance of a good floc. When designing a flocculation process, selection of the mode of mixing and determination of the physical relations and characteristics of the flocculation tanks and clarifiers (sedimentation tanks) are among the first decisions to be made; either hydraulic mixing or mechanical mixing may be chosen. Where sedimentation follows flocculation, the retention time for floc formation should be at least 30 minutes.

Flocculation tanks should be designed to permit flexibility of operation and for ease of maintenance and cleaning. Features that should be considered are a minimum of two tanks and appropriate drainage and access for removal of sludge and basin cleaning.

Consideration of mechanically or hydraulically mixed tanks should ensure sufficient flexibility of operation is possible and that G values can be varied to approach optimum flocculation. Incorporating the flocculation basin into the clarifier unit is considered as the most efficient and economical design.

The general basic criteria for a basic rectangular flocculation tank with 2 to 6 flocculation stages are as follows:

Energy input	$Gt = 3\times10^4$ to 2×10^5 t is in seconds (5×10^4 average) or $G = 10$ to $70\ S^{-1}$ ($30\ S^{-1}$ average)
Detention time	20 to 30 min at maximum daily flow rate.

3.2.5 Sedimentation Tanks (Clarifiers)

This process is designed to remove a majority of the settleable solids by gravitational settling, thereby maximizing the downstream unit processes such as filtration. The factors that influence sedimentation efficiency include:

- surface overflow rate (also known as surface loading rate);
- inlet and outlet arrangements;
- type of sedimentation tank;
- raw water characteristics; and
- local climate conditions.

There are three main configurations for sedimentation tanks: horizontal rectangular basins; upflow sedimentation tanks; and upflow clarifiers with sludge blanket. Regarding application, rectangular sedimentation tanks are suited to large-scale plants, whereas upflow and sludge blanket clarifiers are suited to small and mid-sized water utilities where the rate of flow and raw water quality are constant. The design details for some basic types of sedimentation tanks are shown in table 3.2. Sedimentation tanks should be designed on the basis of surface overflow rates (surface loading rates) with due consideration given to the type of floc generated and water temperature. Inlets of the sedimentation tanks should provide equal distribution and uniform velocities that maximize the opportunity for particles to settle. Outlets should be designed to maintain settling velocities and to minimize short-circuiting.

The sedimentation tank should be designed to accommodate the preferred method of sludge removal. Where a tank must be removed from service for cleaning, it is recommended two tanks be provided. Consideration should be given to ice formation potential, bypasses, overflows to prevent plant flooding and means for observing the settling performance.

Where tube settlers are used, the following should be considered:

- tank overflow rate of 3.8 to 6.3 m/h (1.3 to 2.1 gpm/ft²) for cold regions;
- maximum underflow velocity of 1 m/min (3.3 ft/min); and
- maximum velocity across the top of the tubes of 0.15 to 0.2 m/min (0.5 to 0.65 ft/min).

Table 3.3 Design Details for Sedimentation Tanks

Type of Sedimentation Tank	Some Design Details
Rectangular Tanks	Surface overflow rate: 0.8 – 2.5 m/h (0.27 – 0.83 gpm/ft^2) Detention time: 1.5 – 3 h Water depth: 3 – 5 m Width/Length: > 1/5 Weir loading: < 11 m^3/h.m (12.3 gpm/ft)
Upflow Clarifiers	Surface overflow rate: 1.3 – 1.9 m/h (0.43 – 0.63 gpm/ft^2) Detention (settling) time: 1 – 3 h Water depth: 3 – 5 m Weir loading: 7 m^3/h.m (7.8 gpm/ft) Upflow velocity: < 3 m/h
Sludge Blanket Clarifiers	Surface overflow rate: 2 – 3 m/h (0.67 – 1 gpm/ft^2) Detention (settling) time: 1 – 2 h Weir loading: 7 - 15 m^3/h.m (7.8 – 16.77 gpm/ft) Upflow velocity: < 0.6 m/h Flocculation time: approximately 20 min

Note: Surface overflow rate: m/h = (m^3/m^2.d) ÷ 24; 72 m^3/m^2.d = 1 gpm/ft^2.
Weir loading: m^3/m.h = (m^3/m.d) ÷ 24; 175 m^3/m.d = 8.15 gpm/ft.

3.2.6 Filtration

In general, minimum of two filters should be provided, with a design working capacity equal to the plant capacity and each capable of independent operation and backwash. In larger facilities with more than two filters, production capacity should equal the maximum plant capacity with the largest filter removed from service.

3.2.6.1 Gravity Filtration

Gravity filters comprised of porous granular material, and these filters commonly use a substantial depth of sand or anthracite coal or granular activated carbon or combinations thereof. Gravity filtration, also known as ‘rapid sand filtration’ or ‘rapid granular filtration’ typically has a filtration rate in a range of 5 and 12.5 m/h (1.67 to 4.17 gpm/ft^2). Filtration rate is a function of factors such as the size of the filter medium, the quality of raw water, the degree of pretreatment and the quality control measures. In certain instances, the filtration rate can go beyond 12.5 m/h (4.17 gpm/ft^2) based on the demand of produced water or raw water characteristics or type of filter medium used or combinations thereof. The details about the filter medium used in the filtration process are shown in Table 3.3. Filter media should be durable and conform to applicable specifications such as AWWA specifications.

The design of a gravity filter should provide:

- adequate headroom above the filter to permit inspection and operation and provide reasonable access to the filters for observation;
- protection against floor drainage entering the filter, by means of a suitable curb or roof drainage entering the filter;
- an overflow to prevent flooding, unless provided elsewhere in the raw water supply system;
- a means of cleaning influent pipes or conduits where solids loadings are high;
- effluent piping arranged to prevent backflow of air into the filter;
- a means of drainage and a waste wash-water drain of sufficient capacity;
- operation with a minimum water depth in excess of the design terminal head loss to prevent negative pressure and air binding of the filter;
- an acceptable method of regulating flow; and
- indicating instruments at least for loss of head and rate of flow.

Filter media depths should not be less than 600 mm (24 inches). As a guide, a gravity filter could consist of a lower level of silica sand, not less than 200 mm (8 inches) deep and an upper layer of anthracite coal not less than 450 mm (18 inches) deep. The use of multi-media or proprietary mixed media designs should be based on examination of data and operating experience to demonstrate their suitability.

Appropriate support media should be provided consistent with the underdrain and wash water distribution system characteristics.
Filter bottoms or underdrains should be designed to provide uniform distribution of backwash water and/or scouring air. Porous plate bottoms should not be used with waters high in iron or manganese, scale forming waters or those susceptible to algal or other biological growths. Filter bottom design should be such that essentially all head losses in backwashing occur at the final openings. Careful consideration should be given to the type of filter operation to be employed such as declining rate filtration, influent flow splitting, and constant rate filtration.

The appropriate backwash rate should be determined by the specific gravity of the medium, the size of the medium grains and the water temperature. The backwash rate, usually recommended in the filtration process, falls in the range between 36 and 45 m/h (12 – 15 gpm/ft^2). There should be enough headspace over the filter medium for the expansion of the medium during backwashing procedures.

Designers/Engineers should consider several additional issues when designing a granular bed filtration process: the use of wash troughs, the amount of allowable headloss for filtration, the type of underdrain, type of filter and waste wash-water handling facility.

Table 3.4 Types of Filter Medium and Design Details

Filter Medium	Design details
Fine Sand	Effective size: 0.25 – 0.35 mm Uniformity coefficient: 2 – 3 Depth: 1 – 1.2 m (3.3 – 4 ft)
Medium Sand	Effective size: 0.45 – 0.65 mm Uniformity coefficient: 1.4 – 1.7 Depth: 0.6 – 0.75 m (2 – 2.5 ft)
Coarse Sand	Effective size: 0.8 – 2 mm Uniformity coefficient: 1.4 – 1.7 Depth: 0.8 – 2 m (2.6 – 7 ft)
Multi Media – dual or trimedia (sand-coal-garnet)	Sand Effective size: 0.45 – 0.65 mm Uniformity coefficient: 1.4 – 1.5 Depth: 0.3 m (1 ft) Anthracite coal Effective size: 0.9 – 1.4 mm Uniformity coefficient: 1.4 – 1.5 Depth: 0.45 m (1.5 ft) Garnet Effective size: 0.25 – 0.3 mm Uniformity coefficient: 1.2 – 1.5 Depth: 0.0075 m (0.25 ft)
Granular Activated Carbon (GAC)	Effective size: 0.5 – 1 mm Uniformity coefficient: 1.5 – 2.5 Depth: 1.8 – 3.6 m (6 - 12 ft)

Considerations should include ensuring production of acceptable filtered water and also plant operational capabilities. Wash water troughs should be designed to ensure suitable discharge capacity and to enhance good filter washing. Filter backwash provisions should ensure sufficient rates for suitable filter media expansion. Auxiliary water or air wash systems are recommended. Filter to waste provisions should also be provided.

3.2.6.2 Pressure Filtration

Pressure filters are used at times for rapid filtration. The water to be filtered enters the filter under pressure and leaves at slightly reduced pressure because of the headloss encountered in the filter medium, underdrain and piping connections. In general, one of the best applications of pressure filters is the filtration of pumped, deep-well water containing iron and manganese. Use of pressure filters for surface water treatment should be limited to plants with a design capacity less than 3.5 L/S (46 gpm) and where good coagulation/flocculation and sedimentation facilities are available.

In general, filtration rates should not exceed 12.5 m/h (4.17 gpm/ft^2). For pressure filters, consideration should be given to:

- sufficient side wall shell height to accommodate desired media depths and bed expansion;
- filter shell corrosion protection;
- air release valves;
- an accessible manhole for inspection and repairs on all filters greater than 1 m diameter;
- measures to enable backwash water observations;
- provision for controlling flow rates for each filter; and
- provision of adequate sampling taps to monitor quality at appropriate points in the filter.

3.2.6.3 Direct Filtration

Direct filtration is a surface water treatment process that includes coagulation, flocculation and filtration. In certain cases, the flocculation unit is omitted and the process is referred to as *in-line filtration*, with flocculation occurring in the filter itself. Direct filtration should be only used where appropriate water quality treatment studies demonstrate successful application of the process and adequate monitoring and operational surveillance are available.

3.2.6.4 Slow Sand Filtration

Slow sand filters are operated at very low filtration rates and the grain size of the sand is smaller than that used in a rapid sand filter. A unique feature of slow sand filters, is the presence of a thin layer of medium on the surface of the filter bed known as ‘Schmutzdecke’. This layer composed of dirt and living and dead micro and macro-organisms from the water, becomes the dominant filter medium as the filter cycle progresses.

The general design criteria for the slow sand filter system are listed below:
- Filter bed area – 0.05 to 0.15 m^2 per capita per day.
- Number of filters – $n = 0.25\ Q^{0.5}$, where n is the number of filters and is greater than or equal to 2, and Q is the plant flow rate (m^3/h).
- Filtration rate – 0.04 to 0.42 m/h (0.01 to 0.14 gpm/ft^2).

In general slow sand filters should be limited to cases where the raw water quality is suitable for this type of filtration and documentation is available to demonstrate the potential effectiveness to produce acceptable water quality.

3.2.6.5 Other Filters

Filters such as vacuum diatomaceous earth or cartridge filters should be used only with high quality supplies and where the effectiveness can be demonstrated.

3.2.7 Taste and Odour Control

Taste and odour control capabilities should be available for all surface water treatment facilities.

Control provisions should include consideration of:
- source water quality variability and treatment;
- treatment flexibility; and
- operational and maintenance capabilities.

3.2.8 Activated Carbon Adsorption

The selection of activated carbon for adsorption should be based on the purposes and flexibility and operational requirements.

Addition of powdered activated carbon (PAC) at selective points in the treatment system may be advantageous for taste and odor control. The primary characteristic of PAC that differentiates it from granular activated carbon (GAC) is particle size. The main advantages of using PAC are the low capital investment costs and the ability to change the PAC dose as the water quality changes. The disadvantages include high operating costs, low total organic carbon (TOC) removal and sludge disposal problems.

Use of PAC in the treatment system include consideration of:
- contact time requirements;
- dosage and application point variability;
- wetting provisions; and
- dust control and chemical handling safety measures.

Granular Activated Carbon (GAC) is used as a substitute for filter medium or as an additional process in the conventional treatment process, for the removal of organic compounds including DPBs, those producing taste and odor and pesticides.

GAC can be classified by the following characteristics:
- flow direction – upflow or downflow;
- configuration – parallel or series; and
- driving force – gravity or pressure.

Water may be applied to GAC either upflow or downflow. Downflow columns are the most commonly used in drinking water treatment. GAC gravity contactors usually find their application in medium and large-scale water treatment systems. GAC contactors should be designed on the basis of contact time.
Additional factors that must be considered in the design of full-scale systems include:
- pretreatment;
- GAC particle size;
- hydraulic loading rate;
- backwashing;

- adsorption efficiency;
- biological activity and control of microbial growth; and
- replacement of the medium or regeneration frequency and method of regeneration.

3.2.9 Membrane Processes

Membrane processes mainly used in drinking water treatment are reverse osmosis (RO), nanofiltration (NF), electrodialysis (ED), ultrafiltration (UF) and microfiltration (MF). Membrane processes are used to separate impurities from water. The amount of purification depends on the type of membrane, the level of driving force and raw water characteristics.

Electrodialysis (ED) and electrodialysis reversal (EDR) processes are limited to treatment of ionic contaminants and are ineffective for pathogen and organic removal in most cases.

Membranes are often classified by their pore size. A reverse osmosis membrane rejects solutes as small as 0.0001 μm and nanofiltration membrane rejects solutes as small as 0.001 μm. Microfiltration and ultrafiltration membranes have a minimum solute rejection of 0.10 and 0.01 μm, respectively. The details about the membranes are summarized in Table 3.4. Cost is a major factor in the case of selection of a membrane process. Type of membrane, pressure, manufacturer's specification and guarantee are additional factors to be considered in the selection.

Table 3.5 Details of the Membranes Applicable to Drinking Water Treatment

Process	Pore size	Pressure	Removal Objects
Microfiltration (MF)	0.1 – 0.2 μm	0.7 – 1.4 kg/cm^2 (10 - 20 psig)	Particulate and microbial
Ultrafiltration (UF)	0.003 – 0.01 μm	0.7 – 7.8 kg/cm^2 (10 - 40 psig)	Molecular size compounds, Particulate and microbial
Nanofiltration (NF)	0.001 – 0.005 μm	5.3 – 10.6 kg/cm^2 (up to 150 psig)	Natural organic matter (NOM), including color, Ca and Mg.
Reverse osmosis (RO)	< 1 nm	> 14 kg/cm^2 (> 200 psig)	Ionized salt ions and colloidal matter.

Special considerations should be given to the disposal of the membrane concentrate. Discharging of membrane concentrate to a receiving body of water should only be done after careful considerations of each case from the broader water quality management point of view. Another disposal option is discharging the concentrate into the local wastewater collection system. Deep well injection is another disposal option but a costly method. Evaporation ponds are also a viable disposal option. Selection of a particular disposal method depends on the local environmental conditions, costs and ease of conveyance and disposal.

3.2.10 Fluoridation

Fluoride feeding equipment should be capable of maintaining feed rates within 5% of set rate. Where fluoridation is practiced, it is recommended the finished water contain 1.0 ± 0.2 mg/L fluoride and should not contain more than 1.5 mg/L fluoride.

3.2.11 Disinfection

Disinfection is the final component in water treatment train designed to further reduce and/or inactivate the number of pathogenic organisms in drinking water. Disinfectants are also used for other purposes such as, taste and odour control, oxidation of iron and manganese and as a coagulation and filtration aid. The potential formation of DPBs, such as trihalomethanes THMs), haloacetic acids, chlorate, chlorite, bromate, aldehydes and ketones should be considered when designing the disinfection system. The formation of DPBs depends on the type of disinfectant, the presence of organic material (e.g., TOC) and other environmental factors. The formation of DPBs can be minimized by removing the DPB precursors.

The factors to be considered in selecting a disinfection process are:

- raw water quality;
- the presence of surrogate organisms in the drinking water supply;
- the choice of using alternative disinfectants;
- the relationship between the concentration of the disinfectant residual (mg/L) and contact time (T);
- the formation of DBPs and their magnitude;
- safety problems associated with the disinfectants; and
- cost of disinfection systems.

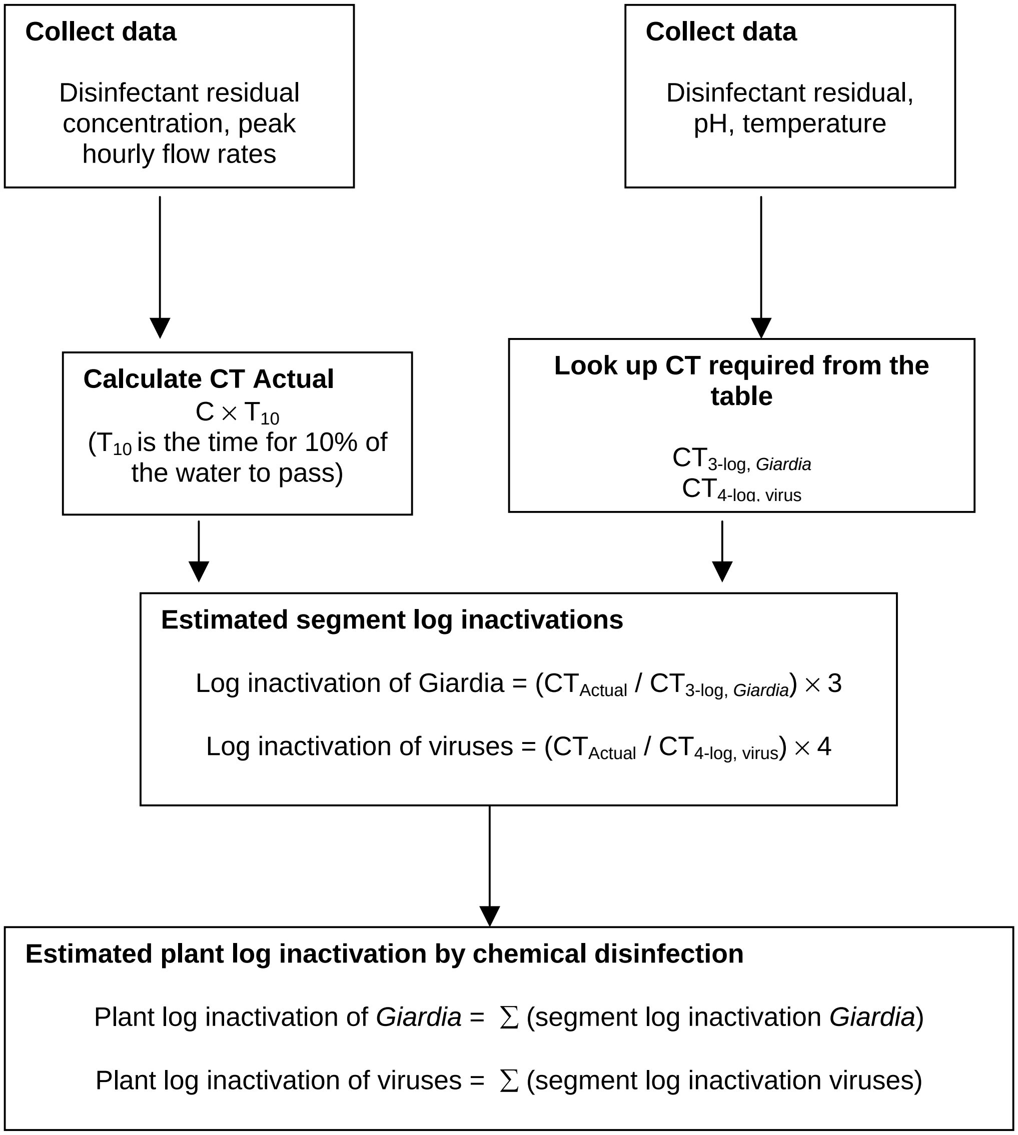
The factors that affect the disinfection efficiency are:

- oxidizable substances in the process water;
- particulate concentration;
- temperature and pH;
- contact time; and
- level of desired disinfectant residual, if applicable.

Chlorine is the most commonly used disinfectant in drinking water treatment. Chlorination equipment should be of adequate capacity to maintain a free chlorine residual throughout the system. Where feasible, and especially for small facilities, consideration should be given to he use of sodium hypochlorite for ease in operation. Use of gas chlorine should be in conformance with the Guidelines for Chlorine Gas Use in Water and Wastewater Treatment (1999; Saskatchewan Environment).

Other major disinfectants include chlorine dioxide, chloramines and ozone. Other materials that can act as disinfectants include potassium permanganate, iodine, bromine, hydrogen peroxide and ultraviolet (UV) light. One of the most important factors for determining the germicidal efficiency of a particular disinfectant and the adequacy of disinfection is the CT factor. The CT factor is defined as the residual disinfectant concentration (mg/L) multiplied by the contact time (T, min) between the point of disinfectant application and the point of residual measurement.

Figure 3.1 Disinfection profile methodology



For systems using filtration, compliance to a specified treatment level is ascertained by the type of filtration employed and CT values. The effective contact time should be determined by tracer studies.

The CT values corresponding to 3 log *Giardia* and 4 log viral inactivations are the basis for determining the estimated log inactivation achieved by the plant on any given day. Operational information required to use the CT tables include: disinfectant type, temperature, pH (for chlorine only) and residual disinfectant concentration. The CT value for a particular disinfectant corresponding to inactivation's of 3-logs of Giardia ($CT_{3\text{-log, } Giardia}$) and 4 logs of viruses ($CT_{4\text{-log, virus}}$) can be read from the tables which are shown in Appendix A. These

CT values can be used to determine the estimated log inactivation achieved by applying a disinfectant to water. The ability of a water treatment plant to inactivate protozoa and viruses can be determined by constructing a disinfection profile using the CT tables (Apendix A). The data to be used for the construction of disinfection profile must be representative of the entire treatment plant, from the initial point of disinfectant addition to the entrance to the distribution system.

The methodology of disinfection profile is shown in Figure 3.1.

Ultraviolet light (UV) is recognized as a disinfection alternative to other disinfectants in drinking water treatment. UV has three spectral bands: 1) 100 to 280 nm (short-wave); 2) 280 to 315 (middle-wave); and 3) 315 to 400 nm (long-wave). Typically, disinfection of UV is carried out by short-wave UV. A secondary disinfectant is required to maintain the necessary residual throughout the distribution system. The effectiveness of a UV disinfection system depends on the characteristics of the water, the intensity of UV radiation, the amount of time the microorganisms are exposed to the radiation and the reactor configuration. Medium-pressure lamps are generally used for large facilities. They have approximately 15 to 20 times the germicidal UV intensity of low-pressure lamps. However, these lamps operate at higher temperatures and with a higher energy consumption rate. UV dose is calculated by intensity times the exposure time in seconds and is expressed as mW.s/cm^2 (mJ/cm^2). The dose required to disinfect water varies with the quality of water, but generally in the range between 24 and 45 mW.s/cm^2 (mJ/cm^2). Protozoan parasites, particularly *Giardia* and *Cryptosporodium*, are considerably more resistant to UV inactivation than other microorganisms. Typically, protozoan parasites require a higher UV dose than that needed for other pathogenic organisms.

3.2.12 Instrumentations/Controls

Instrumentation and control systems should be selected on the basis of plant complexity, operating competency and operational needs, the need to control key functions to ensure smooth and continuous plant operation and the ability of the systems to be operated efficiently. Monitoring consideration should be given to:

- continuous monitoring and recording of finished water turbidity and chlorine residuals where feasible;
- raw water temperature, flow and turbidity;
- filter rate of flow, loss of head and effluent turbidity;
- washwater flow;
- clearwell or reservoir levels;
- treated water flow and pressure;
- process sensitive water quality variables;
- indicators, recorders and totalizers appropriate to the process; and
- alarm conditions and means for bringing alarms to the attention of responsible operating staff.

Selection of control systems should include considerations of:

- provision of manual backup systems for all automatic controls;
- maintenance and repair capability;
- the probable conditions that may be encountered and the need for consistent, continuous operation;
- the reliability of primary sensing devices; and
- the use of micro-electronic systems.

3.3 Groundwater

3.3.1 Processes

Groundwater works shall be designed so that the treated water meets turbidity and other water quality standards specified in the regulations. In general, groundwater treatment facilities should be adequately disinfected on a continuous basis to ensure greater than or equal to 99.99% (4 log) reduction of viruses. Many of the waterworks components are already discussed in previous chapters. Although many Saskatchewan groundwater supplies are characterized by a high hardness and/or high dissolved salt level, the use of central softening or demineralization has been uncommon and each application for these processes would have to be reviewed on an individual basis.

3.3.2 Pre-Filtration Processes

The selection, dosage ranges and application sequences for chemical pre-treatment should be based on appropriate treatment studies and assessment with consideration given to potential water quality variability, ease in operation, mixing enhancement and retention/reaction times.

Where either the raw water quality or the treatment process yields significant precipitate or settleable material, sedimentation should be incorporated prior to filtration. Sedimentation basin design should be based on the settleability characteristics and consider sludge removal features.

3.3.3 Filtration

In general, a minimum of two filters should be provided, with a design working capacity equal to the plant capacity and each capable of independent operation and backwash. In larger facilities with more than two filters, production capacity should equal the maximum day plant capacity with the largest filter removed from service.

Filtration rates should be based on the quality of the raw water, pre-treatment provided, filter media characteristics, operational surveillance available and plant quality control measures. In general, the filtration rates of 5 m/h (1.67 gpm/ft²) to 12.5 m/h (4.17 gpm/ft²) should be considered. Pressure filters should also be limited to 5 and 12.5 m/h (1.67 to 4.17 gpm/ft²).

Sufficient treated water backwash capability should be provided to develop the appropriate bed expansion consistent with the water temperature and media characteristics. Except for full depth anthracite filters, backwash rates in the 36 to 45 m/h (12-15 gpm/ft²) range should be available. Filter bottoms should be designed to provide uniform distribution of backwash water and the provision of support media should be based on the nature of the filter bottoms. Porous plate bottoms are not recommended for use with water containing high levels of iron and manganese or which have significant scale forming tendencies.

Filter media should be durable and should meet applicable American Water Works Association (AWWA) specifications. Rapid rate gravity filters should incorporate features noted in Section 3.2.6.1. Pressure filters should incorporate features noted in Section 3.2.6.2.

3.3.4 Manganese Greensand Filtration

Where manganese greensand is used, consideration for the continuous feed of potassium permanganate ahead of the filter should include retention time needs, use of other preoxidants and the raw water quality.

Media depths should be adequate and a minimum of 600 mm (24 inches) to permit good filtration and oxidation. A minimum 150 mm (6 inches) cap of anthracite media is recommended over manganese greensand. Auxiliary air wash facilities are recommended to assist proper backwashing. Manganese greensand filters should have sample taps at the top and mid-depth points in the media.

In some cases, manganese greensand filtration may be used for arsenic removal from groundwater. However, addition of iron at a suitable ratio to the influent arsenic is necessary to effectively remove arsenic.

3.3.5 Other Common Groundwater Treatment Processes

Sequestration of iron and manganese by polyphosphates or sodium silicates should be generally limited to waters that only slightly exceed maximum objective levels. Removal of iron and manganese by ion exchange should be limited to special cases only and where the raw water requires minimal treatment.

Treatment using substantial pH adjustment through the addition of acids or caustics should only be undertaken where proper control, neutralization mechanisms and safety features are available.

Filtration technologies such as iron oxide-coated sand filtration systems for arsenic (both arsenite and arsenate) removal may be applicable to small community groundwater supplies. However, demonstration testing at pilot-scale level is necessary. Membrane processes should incorporate features noted in Section 3.2.9.

4. Treated Water Storage

4.1 General

4.1.1 Type of Storage

Treated water storage may be clearwell and/or ground level storage at treatment plant or elevated or ground level storage in the distribution system. The type(s) of treated water storage should be selected on the basis of many factors such as serviceability requirements, size of service area, topography, costs, etc.

4.1.2 Location

New storage facilities should be located to enable reasonable access during all climatic conditions and designed that they can remain in operation during maximum anticipated flooding. As far as practically possible, areas of poor foundations should be avoided.

4.1.3 Protection

All treated water storage reservoirs should have suitable waterproof roofs or covers that exclude birds, animals, insects and excessive dust. Fencing, locks on access man ways and other necessary precautions should be provided to prevent trespassing, vandalism and sabotage.

4.1.4 Freezing

All treated water storage structures and their appurtenances, especially the riser pipes, overflows and vents should be designed to prevent freezing which will interfere with proper functioning. Elevated storage should be provided with facilities for heating and circulating the water.

4.1.5 Safety

The safety of employees should be considered in the design of a storage structure. As a minimum, such matters shall conform to pertinent *Occupational Health and Safety Regulations*. Ladders, ladder guards, balcony railings and safely located entrance hatches should be provided where applicable. Elevated tanks with riser pipes over 200 mm (8 inches) in diameter should have protective bars over the riser openings in the tank.

4.2 Capacities

4.2.1 Sizing

Storage facilities should have sufficient capacity, as determined by engineering studies, to meet domestic demands, plant operating requirementsand where fire protection is provided, fire flow demands.

4.2.2 Fire Protection

Compliance with the fire survey requirements of insurers, organizations (i.e. Insurers' Advisory Organization) in terms of fire flow should be encouraged. Contact the Fire Commissioners office for further details. Consideration may be given to small, relatively minor waterworks without fire protection.

4.2.3 Recommended Minimum Storage

For systems requiring fire protection, minimum storage capacity should be equal to twice the average daily consumption. For systems not providing fire protection, minimum storage should be equal to the average daily consumption. This recommended minimum storage may be reduced for non-municipal systems when the source and treatment facilities have sufficient capacity to meet peak demands of the system.

4.3 Design Features

4.3.1 General

Materials and designs used for finished water storage structures should provide stability, durability and water tightness as well as protect the quality of the stored water. Consideration should be given to ensure that construction products and/or materials will not adversely affect water quality.

Consideration should be given to miscellaneous design elements such as:

- providing positive water circulation in the reservoir;
- sizing and baffling when storage is used to provide contact time for chlorine;
- providing two cells if economically feasible and/or by-passes to allow flexibility and continuity of service during maintenance periods;
- pump wells in clearwell reservoirs to avoid excessive dead storage; and
- providing proper site drainage and protection against uplift forces.

Roofs, sidewalls and floors should be watertight with no openings except properly designed vents, man way entrances, overflows, risers, drains, etc.

4.3.2 Materials

Steel structures should follow current AWWA standards concerning steel tanks, standpipes, reservoirs and elevated tanks wherever they are applicable. Storage structures constructed of other materials should meet these guidelines and conform to applicable industry standards, such as AWWA, CSA, ASTM or CGSB.

4.3.3 Protective Coatings and/or Cathodic Protection
Proper protection should be given to metal surfaces by paints or other protective coatings, by cathodic protection or by both. After proper curing, the coating should not adversely affect water quality. Cathodic protection should be designed and installed by competent technical personnel.

4.3.4 Drains
It is recommended that drains on a water storage structure do not have a direct connection to a sewer or a storm drain. The design should allow draining the storage facility for cleaning and maintenance without causing loss of pressure in the distribution system.

4.3.5 Drainage of Roof
The roof of a storage reservoir should be well drained. Downspout pipes should not enter or pass through the reservoir. Parapets, or similar construction, which would tend to hold water and snow on the roof should be avoided, if possible. If parapets, etc. are used, special attention should be paid to waterproofing and drainage.

4.3.6 Entrances
Finished water storage reservoirs should be designed with reasonably convenient access to the interior for cleaning and maintenance. Manhole entrances above the waterline:

- should be framed at least 150 mm (6 inches), above the surface of the surrounding area. The grade surrounding exterior manholes should be sloped away from the manhole to prevent flooding by surface runoff;
- should be fitted with a solid watertight cover that overlaps the framed opening and extends down around the frame at least 50 mm (2 inches);
- should be hinged at one side; and
- should have a locking device.

Manhole entrances into a clearwell reservoir below a treatment facility should be framed at least 150 mm (6 inches) above the finished floor and shall be covered with a solid, durable lid so designed as to prevent entry of water.

4.3.7 Vents
Treated water storage structures should be vented separate from any overflows. Open construction between the sidewall and roof is not considered acceptable. Vents should prevent the entrance of surface water and rain water, exclude birds and animals and exclude insects and dust as much as practically possible.

Ground level structure vents should terminate in an inverted U construction with the opening 600 mm to 900 mm (24 to 36 inches) above the roof or sod and covered with twenty-four mesh non-corrodible screen installed within the pipe at a location least susceptible to vandalism.

4.3.8 Cleaning/Disinfection
Finished surfaces and floor slopes should be designed to facilitate cleaning and disinfection. Treated water storage reservoirs require cleaning and disinfection prior to being placed in service, in accordance with the latest applicable AWWA standard. Construction specifications should identify an appropriate method of disinfecting and bacteriological sampling/testing. Cleaning and disinfection should include the roof of the tank or reservoir, from which condensate may drop back into the water supply.

4.4 Hydropneumatic (Pressure) Tanks
4.4.1 Pressure Tank Storage
Pressure tank storage is acceptable for small water systems but is not to be considered for fire protection purposes. Pressure tanks should comply with pressure vessel codes and regulations.

4.4.2 Location
Due consideration should be given to proper location, protection from corrosion by elevating tanks above floor levels, adequate sizing, bypass piping and valving to facilitate maintenance, servicing access ports, drain, air blow-off means for adding air and pressure operated start-stop controls for the pumps.

5. Distribution

5.1 General

For the purposes of these guidelines, conventional municipal distribution systems, which provide fire protection, are referred to as municipal waterworks. Very small systems, which do not provide fire protection, are referred to as domestic waterworks.

Design and construction of water distribution systems should comply to all local or provincial bylaws and regulations. For distribution extensions, the past performance and records of the municipality should be reviewed to assure compatibility with existing systems.

Wherever possible, water demands and peaking factors based on usage records for the waterworks should be used for design of distribution systems. When such records do not exist or are unreliable, water demands and peaking factors derived from installations that are similar in terms of climate, locale, size and character of population, etc. may be used.

It should be ensured that there will be no physical connection between the distribution system and any pipes, pumps, hydrants or tanks whereby unsafe water or other contaminating materials may be discharged or drawn into the system.

In cases where water loading stations form part of the system, due consideration should be given to preventing contamination of either the public supply or treated water vessels being filled. In the design of water loading stations, attention should be given to assuring that there will be no backflow to the public water supply, that the piping arrangement will prevent contaminants being transferred from one hauling vessel to another and that hoses will not be contaminated by contact with the ground.

5.2 Pumping Facilities

5.2.1 General

Pumping stations should be accessible in all weather conditions and so located that the proposed site will meet requirements for sanitary protection of water quality, hydraulics of the system and protection against interruption of service by fire, flood, vandalism or any other hazards.

Pumping stations should be designed to provide adequate space for the installation of additional units if needed and for the safe servicing of all equipment. Consideration should be given to providing hoist-beams, crane-ways, floor openings, etc. for servicing and removal of heavy or bulky equipment.

For worker safety, ladders, ladder guards, balcony railings, etc. should be provided where needed and the pertinent *Occupational Health and Safety Regulations* should be adhered to.

Pump station buildings should be properly ventilated, heated and adequate lighting provided in accordance with all local and provincial regulations. Stations, which are staffed for extended periods, should be provided with treated water, lavatory and toilet facilities. Wastes should be handled so as to prevent contamination of a public water supply.

5.2.2 Pumps

At least two pumping units should be provided (in addition to any pumps required to provide fire flows). With any one pump out of service, the remaining pumps should be capable of serving the maximum daily pumping demand of the system.

Pumping units should have ample capacity to supply the peak demand and pressure conditions without dangerous overloading, be driven by prime movers able to operate against maximum head, have spare parts and tools available and be served by control equipment that has proper heater and overload protection for air temperature encountered.

Due consideration should be given to such factors as avoiding suction lift, if possible, or maintaining it within allowable limits; priming of pumps and protection of pump station headers against pressure surges.

Booster pumping stations should contain not less than two pumps with capacities such that peak demand can be satisfied with the largest pump out of service. Consideration should be given to the provision of standby power generation in the event of power outages.

5.3 Distribution Systems

5.3.1 Materials

Pipes, fittings, valves, fire hydrants and other appurtenances should conform to the latest standards issued by AWWA, CSA or CGSB. Anticipated water quality and bedding soil characteristics should be considered in selecting pipe materials, which will protect against both internal and external pipe corrosion.

Due consideration should be paid to the possible presence of sub-surface contaminants and the potential of such contaminants migrating through mains into the water supply. (For example, soil contaminated by hydrocarbons in the vicinity of existing or abandoned petroleum marketing installations has been known to impart taste and/or odour problems to water by migration through some plastic pipes.)

5.3.2 Placement

Dead-ends should be minimized by looping of all mains. Where dead-end mains cannot be avoided, they should be provided with a fire hydrant, blow-off or other acceptable measures to prevent problems associated with stagnation. For domestic waterworks, consideration may be given to the use of "yard hydrants" for flushing purposes. No flushing device should be directly connected to a sewer.

Adequate separation of water mains and sewers should be maintained with due consideration given to such matters as pipe materials, soil conditions, service and connections into the mains, etc. Water mains and sewer mains, under normal conditions, should not be installed in the same trench.

Precautions should be taken in the case of pressurized sewers (and/or sewage force mains) to prevent potential contamination of water supply mains. All water mains should be covered with sufficient earth cover or insulation below finished street/road grades to prevent freezing.

Water main bedding and backfill should be placed so that the pipe is adequately supported and protected. Fittings and appurtenances should be provided with reaction blocking to prevent movement.

5.3.3 Sizes, Pressures

All water mains, including those not designed to provide fire protection, should be sized to ensure adequate pressure and flow at the period of peak demand. Municipal distribution systems should be sized to meet fire flows and maximum daily demand occurring simultaneously.

The minimum size of mains for municipal waterworks (fire protection provided) should be 150 mm (6 inches). Sizing of mains for domestic waterworks (no fire protection) should be sized on the basis of hydraulic requirements with due regard to future maintenance requirements such as the potential need for "yard hydrants" to assist "swabbing" operations.

5.3.4 Fire Hydrants (Municipal Waterworks)

Fire hydrants should be located to provide adequate accessibility for fire fighting equipment, with due consideration given to type of equipment available, type and density of buildings. Generally, hydrant spacing may range from 110 m (350 feet) to 180 m (600 feet) depending on the type of area served.

Fire hydrants should have a bottom valve size of at least 125 mm (5 inches), one 115 mm (4 ½ inch) pumper nozzle and two 64 mm (2 1/2 inch) nozzles. Fire hydrant leads should be a minimum of 150 mm (6 inch) diameter. Valving of hydrant leads is recommended.

Fire hydrant drains should be plugged and the barrels pumped dry during freezing weather where the groundwater is permanently above the drain port. Where hydrant drains are not plugged, they should drain to gravel beds or to dry wells provided exclusively for that purpose. Hydrant drains should not be connected to or located within 3 m (10 feet) of sanitary sewers or storm drains.

Fire hydrants should only be installed on water mains capable of supplying fire flow requirements.

5.3.5 Valves, Appurtenances

Sufficient valves should be provided on water mains so that inconvenience and sanitary hazards will be minimized during repair operations. Generally, valves may range from 150 m (500 feet) to 180 m (650 feet) depending on the area served. Spacing of valves should take into consideration the nature of development and future expansion.

Valve positions should be recorded on plans of record ("as-constructed" drawings) or other such documentation to facilitate their location for repair operations or for adjustments during future paving work, etc.

5.3.6 Construction and Maintenance Practices

During installation, pipes and appurtenances should be as free as possible of all foreign material. Where a pipe contains dirt that may not be removed during normal flushing operations, the interior of the pipe should be thoroughly cleaned and swabbed as necessary with bactericidal solution.

When pipe laying is not in progress, open ends should be effectively plugged, sealed or covered to prevent the entry of rodents, foreign material or water into the pipe. Pipelines should be flushed after the pressure test has been made and prior to chlorination.

Pipelines in a new distribution system or in an extension to an existing system should be chlorinated so that a chlorine residual of 10 mg/L exists in all sections of the pipeline after 24 hours of contact time.

Where a system is repaired the repaired portion should be chlorinated in accordance with the above procedures or by maintaining a chlorine residual of 100 mg/L for a contact time of one hour. All valves and other appurtenances should be operated while a pipeline is being chlorinated.

After completion of the chlorination process, the chlorinated water in the pipeline should be thoroughly removed by flushing and the replacement water sampled and tested for bacterial quality before use.

Appendix A

Table 1: CT values ($CT_{99.9}$) for 99.9 percent inactivation of *Giardia lamblia* cysts by Free Chlorine at 0.5 ^{0}C or lower* (3-log inactivation)

Free residual (mg/L)	pH						
	≤ 6.0	**6.5**	**7.0**	**7.5**	**8.0**	**8.5**	**≤ 9.0**
≤ 0.4	137	163	195	237	277	329	390
0.6	141	168	200	239	286	342	407
0.8	145	172	205	246	295	354	422
1.0	148	176	210	253	304	365	437
1.2	152	180	215	259	313	376	451
1.4	155	184	221	266	321	387	464
1.6	157	189	226	273	329	397	477
1.8	162	193	231	279	338	407	489
2.0	165	197	236	286	346	417	500
2.2	169	201	242	297	353	426	511
2.4	172	205	247	298	361	435	522
2.6	175	209	252	304	368	444	533
2.8	178	213	257	310	375	452	543
3.0	181	217	261	316	382	460	552

Table 2: CT values (CT$_{99.9}$) for 99.9 percent inactivation of *Giardia lamblia* cysts by Free Chlorine at 5 ^{0}C* (3-log inactivation)

Free residual (mg/L)	pH						
	≤ 6.0	**6.5**	**7.0**	**7.5**	**8.0**	**8.5**	**≤ 9.0**
≤ 0.4	97	117	139	166	198	236	279
0.6	100	120	143	171	204	244	291
0.8	103	122	146	175	210	252	301
1.0	105	125	149	179	216	260	312
1.2	107	127	152	183	221	267	320
1.4	109	130	155	187	227	274	329
1.6	111	132	158	192	232	281	337
1.8	114	135	162	196	238	287	345
2.0	116	138	165	200	243	294	353
2.2	118	140	169	204	248	300	361
2.4	120	143	172	209	253	306	368
2.6	122	146	175	213	258	312	375
2.8	124	148	178	217	263	318	382
3.0	126	151	182	221	268	324	389

* These CT values achieve greater than a 99.99 percent inactivation of viruses. CT values between the indicated pH values may be determined by linear interpolation. CT values between the indicated temperatures of different tables may be determined by linear interpolation. If no interpolation is used, use the CT$_{99.9}$ value at the lower temperature and at the higher pH.

Table 3: CT values (CT$_{99.9}$) for 99.9 percent inactivation of *Giardia lamblia* cysts by Free Chlorine at 10 ^{0}C* (3-log inactivation)

Free residual (mg/L)	pH						
	≤ 6.0	**6.5**	**7.0**	**7.5**	**8.0**	**8.5**	**≤ 9.0**
≤ 0.4	73	88	104	125	149	177	209
0.6	75	90	107	128	153	183	218
0.8	78	92	110	131	158	189	226
1.0	79	94	112	134	162	195	234
1.2	80	95	114	137	166	200	240
1.4	82	98	116	140	170	206	247
1.6	83	99	119	144	174	211	253
1.8	86	101	122	147	179	215	259
2.0	87	104	124	150	182	221	265
2.2	89	105	127	153	186	225	271
2.4	90	107	129	157	190	230	276
2.6	92	110	131	160	194	234	281
2.8	93	111	134	163	197	239	287
3.0	95	113	137	166	201	243	292

Table 4: CT values ($CT_{99.9}$) for 99.9 percent inactivation of *Giardia lamblia* cysts by Free Chlorine at 15 ^{0}C* (3-log inactivation)

Free residual (mg/L)	pH						
	≤ 6.0	**6.5**	**7.0**	**7.5**	**8.0**	**8.5**	**≤ 9.0**
≤ 0.4	49	59	70	83	99	118	140
0.6	50	60	72	86	102	122	146
0.8	52	61	73	88	105	126	151
1.0	53	63	75	90	108	130	156
1.2	54	64	76	92	111	134	160
1.4	55	65	78	94	114	137	165
1.6	56	66	79	96	116	141	169
1.8	57	68	81	98	119	144	173
2.0	58	69	83	100	122	147	177
2.2	59	70	85	102	124	150	181
2.4	60	72	86	105	127	153	184
2.6	61	73	88	107	129	156	188
2.8	62	74	89	109	132	159	191
3.0	63	76	91	111	134	162	195

* These CT values achieve greater than a 99.99 percent inactivation of viruses. CT values between the indicated pH values may be determined by linear interpolation. CT values between the indicated temperatures of different tables may be determined by linear interpolation. If no interpolation is used, use the $CT_{99.9}$ value at the lower temperature and at the higher pH.

Table 5: CT values ($CT_{99.9}$) for 99.9 percent inactivation of *Giardia lamblia* cysts by Free Chlorine at 20 ^{0}C* (3-log inactivation)

Free residual (mg/L)	pH						
	≤ 6.0	**6.5**	**7.0**	**7.5**	**8.0**	**8.5**	**≤ 9.0**
≤ 0.4	36	44	52	62	74	89	105
0.6	38	45	54	64	77	92	109
0.8	39	46	55	66	79	95	113
1.0	39	47	56	67	81	98	117
1.2	40	48	57	69	83	100	120
1.4	41	49	58	70	85	103	123
1.6	42	50	59	72	87	105	126
1.8	43	51	61	74	89	108	129
2.0	44	52	62	75	91	110	132
2.2	44	53	63	77	93	113	135
2.4	45	54	65	78	95	115	138
2.6	46	55	66	80	97	117	141
2.8	47	56	67	81	99	119	143
3.0	47	57	68	83	101	122	146

Table 6: CT values ($CT_{99.9}$) for 99.9 percent inactivation of *Giardia lamblia* cysts by Free Chlorine at 25 ^{0}C* (3-log inactivation)

Free residual (mg/L)	PH						
	≤ 6.0	**6.5**	**7.0**	**7.5**	**8.0**	**8.5**	**≤ 9.0**
≤ 0.4	24	29	35	42	50	59	70
0.6	25	30	36	43	51	61	73
0.8	26	31	37	44	53	63	75
1.0	26	31	37	45	54	65	78
1.2	27	32	38	46	55	67	80
1.4	27	33	39	47	57	69	82
1.6	28	33	40	48	58	70	84
1.8	29	34	41	49	60	72	86
2.0	29	35	41	50	61	74	88
2.2	30	35	42	51	62	75	90
2.4	30	36	43	52	63	77	92
2.6	31	37	44	53	65	78	94
2.8	31	37	45	54	66	80	96
3.0	32	38	46	55	67	81	97

* These CT values achieve greater than a 99.99 percent inactivation of viruses. CT values between the indicated pH values may be determined by linear interpolation. CT values between the indicated temperatures of different tables may be determined by linear interpolation. If no interpolation is used, use the $CT_{99.9}$ value at the lower temperature and at the higher pH.

Table 7: CT values for inactivation of viruses by Free Chlorine, pH 6.0 – 9.0

Temperature (^{0}C)	Inactivation (log)	
	3	**4**
0.5	9.0	12.0
1	8.7	11.6
2	8.0	10.7
3	7.3	9.8
4	6.7	8.9
5	6.0	8.0
6	5.6	7.6
7	5.2	7.2
8	4.8	6.8
9	4.4	6.4
10	4.0	6.0
11	3.8	5.6
12	3.6	5.2
13	3.4	4.8
14	3.2	4.4
15	3.0	4.0
16	2.8	3.8
17	2.6	3.6
18	2.4	3.4
19	2.2	3.2
20	2.0	3.0
21	1.8	2.8
22	1.6	2.6
23	1.4	2.4
24	1.2	2.2
25	1.0	2.0

Table 8: CT values for inactivation of *Giardia* cysts by Chlorine dioxide, pH 6.0–9.0

Temperature (^{0}C)	**Inactivation (log)**	
	2.5	**3**
1	52.0	63.0
2	44.5	53.8
3	37.0	44.5
4	29.5	35.3
5	22.0	26.0
6	21.4	25.4
7	20.8	24.8
8	20.2	24.2
9	19.6	23.6
10	19.0	23.0
11	18.4	22.2
12	17.8	21.4
13	17.2	20.6
14	16.6	19.8
15	16.0	19.0
16	15.4	18.2
17	14.8	17.4
18	14.2	16.6
19	13.6	15.8
20	13.0	15.0
21	12.2	14.2
22	11.4	13.4
23	10.6	12.6
24	9.8	11.8
25	9.0	11.0

Table 9: CT values for Viruses Inactivation by Chlorine dioxide, pH 6.0 – 9.0

Temperature (^{0}C)	**Inactivation (log)**	
	3	**4**
1	25.6	50.1
2	23.5	45.9
3	21.4	41.8
4	19.2	37.6
5	17.1	33.4
6	16.2	31.7
7	15.4	30.1
8	14.5	28.4
9	13.7	26.8
10	12.8	25.1
11	12.0	23.4
12	11.1	21.7
13	10.3	20.1
14	9.4	18.4
15	8.6	16.7
16	8.2	15.9
17	7.7	15.0
18	7.3	14.2
19	6.8	13.3
20	6.4	12.5
21	6.0	11.7
22	5.6	10.9
23	5.1	10.0
24	4.7	9.2
25	4.3	8.4

Table 10: CT values for inactivation of *Giardia* cysts by Chloramine, pH 6.0 – 9.0

Temperature (^{0}C)	Inactivation (log)	
	2.5	**3**
1	3,170	3,800
2	2,835	3,400
3	2,500	3,000
4	2,165	2,600
5	1,830	2,200
6	1,772	2,130
7	1,714	2,060
8	1,656	1,990
9	1,598	1,920
10	1,540	1,850
11	1,482	1,780
12	1,424	1,710
13	1,366	1,640
14	1,308	1,570
15	1,250	1,500
16	1,183	1,420
17	1,116	1,340
18	1,049	1,260
19	982	1,180
20	915	1,100
21	857	1,030
22	799	960
23	741	890
24	683	820
25	625	750

Table 11: CT values for inactivation of viruses by Chloramine, pH 6.0 – 9.0

Temperature (^{0}C)	Inactivation (log)	
	3	**4**
1	2,063	2,883
2	1,903	2,659
3	1,743	2,436
4	1,583	2,212
5	1,423	1,988
6	1,352	1,889
7	1,281	1,789
8	1,209	1,690
9	1,138	1,590
10	1,067	1,491
11	996	1,392
12	925	1,292
13	854	1,193
14	783	1,093
15	712	994
16	676	944
17	641	895
18	605	845
19	570	796
20	534	746
21	498	696
22	463	646
23	427	597
24	392	547
25	356	497

Table 12: CT values for inactivation of *Giardia* cysts by Ozone

Temperature (^{0}C)	Inactivation (log)	
	2.5	3
1	2.40	2.90
2	2.20	2.65
3	2.00	2.40
4	1.80	2.15
5	1.60	1.90
6	1.52	1.81
7	1.44	1.71
8	1.36	1.62
9	1.28	1.52
10	1.20	1.43
11	1.12	1.33
12	1.04	1.24
13	0.95	1.14
14	0.87	1.05
15	0.79	0.95
16	0.75	0.90
17	0.71	0.86
18	0.68	0.81
19	0.64	0.77
20	0.60	0.72
21	0.56	0.67
22	0.52	0.62
23	0.48	0.58
24	0.44	0.53
25	0.40	0.48

Table 13: CT values for inactivation of viruses by Ozone

Temperature (^{0}C)	Inactivation (log)	
	3	4
1	1.40	1.80
2	1.28	1.65
3	1.15	1.50
4	1.03	1.35
5	0.90	1.20
6	0.88	1.16
7	0.86	1.12
8	0.84	1.08
9	0.82	1.04
10	0.80	1.00
11	0.74	0.92
12	0.68	0.84
13	0.62	0.76
14	0.56	0.68
15	0.50	0.60
16	0.48	0.58
17	0.46	0.56
18	0.44	0.54
19	0.42	0.52
20	0.40	0.50
21	0.37	0.46
22	0.34	0.42
23	0.31	0.38
24	0.28	0.34
25	0.25	0.30

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Glossary of Symbols and Abbreviations

Waterworks Abbreviations

ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
CGSB	Canadian General Standards Board
CSA	Canadian Standards Association
CT	the residual disinfectant concentration (mg/L) multiplied by the contact time (T, min) between the point of disinfectant application and the point of residual measurement.
DPBs	Disinfection By-Products
ED	Electrodialysis
EDR	Elctrodialysis Reversal
GAC	Granular Activated Carbon
MF	Microfiltration
NF	Nanofiltration
PAC	Powdered Activated Carbon
RO	Reverse osmosis
THMs	Trihalomethanes
TOC	Total Organic Carbon
UF	Ultrafiltration
UV	Ultravioloet
d	day
ft	feet
ft^2	square feet
ft/min -	feet per minute
fps	feet per second
G	flocculation energy gradient
gpd	gallons per day
gpm	gallons per minute
gpm/ft^2	gallons per minute per square foot
in	inch
L/s	litres per second
m	metre
m^2	square metre
m^3	cubic metre
m^3/d	cubic metre per day
mgd	million gallons per day
mg/L	milligrams per litre
m/h	metres per hour (m^3/h per m^2)
mm	millimetre
m/min	metres per minute
m/s	metres per second
sec^{-1}	per second