Atlantic Canada
Water Supply Guidelines
May 2022

ATLANTIC CANADA WATER & WASTEWATER ASSOCIATION

American Water Works Association Atlantic Canada Section

Water Environment Federation the water quality people

Purpose & Use of Guidelines

Purpose

The purpose of the *Atlantic Canada Water Supply Guidelines* (2022) (Guidelines) is to provide a guide for the development of drinking water supply projects in Atlantic Canada. These Guidelines are an update of the *Atlantic Canada Guidelines for the Supply, Treatment, Storage, Distribution and Operation of Drinking Water Supply Systems* (2004) from the Atlantic Canada Water and Wastewater Association. The update includes revisions to technical requirements and a section on the consideration of climate change factors for the design of climate resilient infrastructure. The *Atlantic Canada Wastewater Guidelines* (2022) were developed separately to provide a guide for the development of wastewater systems in Atlantic Canada.

These Guidelines are intended to be used in the evaluation of water supply, treatment, and distribution projects, and for the design and preparation of plans and specifications. These Guidelines suggest minimum requirements for items upon an evaluation of such plans and specifications may be made by Regulatory Authorities, and establish, as far as is practical, a best practice.

THESE GUIDELINES DO NOT ELIMINATE THE NECESSITY FOR DETAILED DESIGN. ENGINEERS WHO USE THESE GUIDELINES IN PREPARING REPORTS, DESIGN DRAWINGS, AND SPECIFICATIONS MUST RECOGNIZE THAT THE DESIGN ENGINEER RETAINS FULL RESPONSIBILITY FOR THEIR WORK.

Support

Support for the updates to these Guidelines was provided by Natural Resources Canada (NRCan) under the Building Regional Adaptation Capacity and Expertise (BRACE) program, a 5-year (2017-2022), $18.0M initiative under the Adaptation and Climate Resilience pillar of the Pan-Canadian Framework on Clean Growth and Climate Change. The purpose of the program is to increase the ability of communities, organizations, small and medium-sized enterprises, and practitioners to access, use, and apply knowledge and tools on climate change adaptation in their work.

Financial support from NRCan has been matched by in-kind contributions from Project Committee members and peers, starting in late 2018. Committee members include representatives from the provinces of Newfoundland and Labrador, New Brunswick, Nova Scotia, and Prince Edward Island, the City of Charlottetown, Halifax Water, and from the Atlantic Canada Water and Wastewater Association (ACWWA). A representative from the Atlantic First Nations Water Authority joined the Project Committee in late 2020.

The Project Committee included the following representatives:

- Water Supply Guidelines Lead: Wendy Krkosek, Halifax Water, B.A.Sc., Ph.D., P.Eng.
- Wastewater Guidelines Lead: Richard MacEwen, City of Charlottetown, M.Sc., FEC, P.Eng.
- ACWWA Executive Director: Clara Shea.
- New Brunswick Department of Environment and Local Government: Sylvie Morton, M.Sc.E., P.Eng.
- Newfoundland and Labrador Department of Environment and Climate Change: Deneen Spracklin, P.Eng.
- Nova Scotia Department of Environment and Climate Change: Denis Tufts, P.Eng.
- Prince Edward Island Department of Environment, Energy and Climate Action: Morley Foy, P.Eng.
- Atlantic First Nations Water Authority: John Lam, P.Eng.

The guidance and assistance from the above representatives and their peers are acknowledged and greatly appreciated.

Climate Change

Understanding climate change and its impacts on water supply (infrastructure is an important reality for utilities in Atlantic Canada. Utilities are anticipated to encounter both challenges and opportunities related to addressing the impacts of on-going climate change. It is anticipated that impacts from climate change will vary widely across Atlantic Canada due to the size and diversity of the region. There are significant regional economic and demographic differences where every System Owner has their own unique set of priorities and finite resources, including those which are available to build resiliency to the impacts of climate change. As such, when one combines these factors, it becomes evident that each region within Atlantic Canada will be impacted by climate change differently.

Given the regional differences in Atlantic Canada, there is limited value in presenting detailed site-specific climate change parameters, indices, and adaptation design processes in these Guidelines. Instead, these Guidelines aim to build the capacity of utilities and designers seeking to incorporate climate change information and adaptation strategies within infrastructure planning, design, and operations, using accessible climate science resources and methods which are both reputable and reliable. These Guidelines will focus on climate change adaptation instead of climate change mitigation. That said, where possible, these Guidelines will identify climate change mitigation opportunities such as reducing energy consumption and demand in water supply operations to limit human-induced gas emissions.

These Guidelines serve as a foundational introduction to climate change adaptation for water utilities in Atlantic Canada and highlight the linkages between a changing climate and the planning, design and operations of infrastructure managed by water and wastewater utilities. A new introductory Climate Change chapter (Chapter 2) aims to deliver a comprehensive overview for the strategies available to gather climate change information, to assess impacts and risks, and to implement effective adaptation planning. Throughout these Guidelines, reference will be made to climate change impacts, and what to consider in a climate change context when outlining the steps for planning, designing, and operating a water supply facility.

Limitations

Users of these Guidelines are advised that requirements for specific issues such as filtration, equipment redundancy, and disinfection are not uniform throughout Atlantic Canada, and that the appropriate regulations, standards, and guidelines should be consulted prior to, or during, an investigation to discuss specific key requirements.

Approval Process

These Guidelines were prepared for use in the design of infrastructure for water supply systems in Atlantic Canada. Every effort has been made to ensure that these Guidelines are consistent with current technology, environmental, and climate change considerations. The approval process outlined in these Guidelines is general in nature and is meant to be an overview only. System Owners are advised to familiarize themselves with the requirements of all legislation and policies dealing with water supply projects in the province where the work is to be undertaken.

The respective provincial legislation, standards, guidelines, policies, and/or contacts may be accessed as follows:

- New Brunswick Department of Environment and Local Government.
- Newfoundland and Labrador Department of Environment and Climate Change.
- Nova Scotia Department of Environment and Climate Change.
- Prince Edward Island Department of Environment, Energy and Climate Action.

Innovation

These Guidelines are not intended to limit innovation on the part of System Owners. Where the designer can show that alternate approaches can produce the desirable results, such approaches may be considered for approval. Emerging technologies and innovative solutions to technical challenges in the water supply and treatment field are continuously unfolding. Where these solutions adopt forms similar to aspects of existing technologies and guidelines, it is expected that consideration be given to apply the guideline principles where appropriate, such that new technologies build from these Guidelines and are based on sound practice and technical principles.

Definition of Terms

The terms used in these Guidelines reflect generally used definitions in the water industry. Users are referred to the latest edition of *The Water Dictionary* from the American Water Works Association (AWWA) for a comprehensive definition of water related terms.

Policy/Position Papers

There are a wide range of issues which must be dealt with in the upgrading of existing water systems or the design and commissioning of new systems. Not all issues are easily categorized and addressed in these Guidelines. In some cases, technical aspects of the issues are still emerging, while others may require greater discussion regarding the context in which they may be used or dealt with.

AWWA and the Canadian Water and Wastewater Association (CWWA) have developed policy/position papers that reflect the current state of knowledge, experience, and best practices on a variety of topics. Users of these Guidelines are encouraged to review AWWA and CWWA's policy/position papers at the following:

- AWWA: http://www.awwa.org.
- CWWA: http://www.cwwa.ca.

Reference Material

In developing these Guidelines, material from outside sources was reviewed, and guidelines appropriate for conditions in Atlantic Canada were adopted. In some cases, multiple sources are referenced in these Guidelines, pending responses from the industry.

Conflicts

Conflicting statements may have survived the review process. Should conflicting statements be found, readers are directed to contact the Regulatory Authority for the appropriate jurisdiction for clarification.

Comments

Comments on these Guidelines should be forwarded to contact@acwwa.ca.

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Acronyms

ACT	Accelerated Column Test
ACWWA	Atlantic Canada Water and Wastewater Association
ADF	Average Daily Flow
ANSI	American National Standards Institute
AOP	Advanced Oxidation Processes

ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
asu	Algal Standard Units
ATV	All-Terrain Vehicle
AWWA	American Water Works Association
BEP	Best Efficiency Point
BRACE	Building Regional Adaptation Capacity and Expertise
BTEX	Benzene, Toluene, Ethyl Benzene and Xylenes
CAN-EWLAT	Canadian Extreme Water Level Adaptation Tool
CCTV	Closed-Circuit Television
CFD	Computational Fluid Dynamic
CIPP	Cured-in-Place Pipe
CMAS	Complete-Mix Activated Sludge
COC	Contaminant of Concern
CP	Contingency Plan
CSA	Canadian Standards Association
CSMR	Chloride to Sulphate Mass Ratio
CT	Contact Time
CWWA	Canadian Water and Wastewater Association
DAF	Dissolved Air Flotation
DBP	Disinfection-By-Product
DBPfp	Disinfection By-Product Formation Potential
DFO	Department of Fisheries and Oceans
DI	Ductile Iron
DIC	Dissolved Inorganic Carbon
DMA	District Metered Areas
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
ELISA	Enzyme-Linked Immunosorbent Assay
EPA	Environmental Protection Agency
EQ	Exceptional Quality
ERP	Emergency Response Plan
FUS	Fire Underwriters Survey
GAC	Granular Activated Carbon
GCM	Global Climate Models
GHG	Greenhouse Gas
GIS	Geographic Information System Mapping
GUDI	Groundwater Under the Direct Influence of Surface Water
H&S	Health and Safety
HAA	Haloacetic Acid
HAB	Harmful Algal Bloom
HAZMAT	Hazardous Materials
HDPE	High-Density Polyethylene
HMI	Human Machine Interface
HVAC	Heating, Ventilation, and Air Conditioning
ICLR	Institute for Catastrophic Loss Reduction
ID	Internal Diameter
IDF	Intensity-Duration-Frequency
IEC	International Electrotechnical Commission
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization

LC-MS/MS	Liquid Chromatography-Tandem Mass Spectrometry
LPHO	Low Pressure-High Output
MAC	Maximum Acceptable Concentration
MF	Microfiltration
MP	Medium Pressure
MWCO	Molecular Weight Cut-Off
NDMA	N-nitrosodimethylamine
NF	Nanofiltration
NFPA	National Fire Protection Association
NMS	National Master Specification
NOM	Natural Organic Matter
NPSHa	Net Positive Suction Head Available
NPSHr	Net Positive Suction Head Required
NPV	Net-Present-Value
NRCan	Natural Resources Canada
NSF	National Science Foundation
NTU	Nephelometric Turbidity Unit
O&M	Operation and Maintenance
OCOP	Organochlorine Pesticides
ORP	Oxidation-Reduction Potential
OSG	Onsite Hypochlorite Generation
OUR	Oxygen Uptake Rate
P&ID	Process (or Piping) and Instrumentation Diagram
PAC	Powdered Activated Carbon
PCB	Polychlorinated Biphyenyls
PE	Population Equivalent
PLC	Programmable Logic Controller
PTA	Packed Tower Aeration
PVC	Polyvinyl Chloride
PVDF	Polyvinylidene Fluoride
QA/QC	Quality Assurance/Quality Control
RCM	Regional Climate Models
RCP	Representative Concentration Pathways
RED	Reduction Equivalent Dose
RO	Reverse Osmosis
RRGF	Rapid Rate Gravity Filtration
RSSCT	Rapid Small-Scale Column Test
RTD	Resistance Temperature Detector
RTU	Remote Telemetry Unit
SCADA	Supervisory Control and Data Acquisition
SCC	Standards Council of Canada
SDS	Safety Data Sheets
SDSM	Statistical DownScaling Mode
SFBW	Spent Filter Backwash Water
SIPP	Sprayed in Place Pipe
SOP	Standard Operating Procedure
SPEI	Standard Precipitation Evapotranspiration Index
SSP	Shared Socioeconomic Pathways
SWP	Source Water Protection
SWPA	Source Water Protection Area
SWPP	Source Water Protection Plan

$TBOD_5$	Total 5-day Biochemical Oxygen Demand
TCU	Total Colour Units
TDH	Total Dynamic Head
THM	Trihalomethane
TKN	Total Kjeldahl Nitrogen
TMP	Transmembrane Pressure
TN	Total Nitrogen
TOC	Total Organic Carbon
TOT	Time of Travel
TP	Total Phosphorus
TRC	Total Residual Chlorine
TSS	Total Suspended Solids
TWL	Top Water Level
UF	Ultrafiltration
USEPA	United States Environmental Protection Agency
UTM	Universal Transverse Mercator
UV	Ultraviolet
UVT	Ultraviolet Transmittance
VFD	Variable-Frequency Drive
VOC	Volatile Organic Compounds
WEF	Water Environment Federation
WHMIS	Workplace Hazardous Materials Information System
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant

Appendices

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Chapter 1 Approval Requirements & Procedures

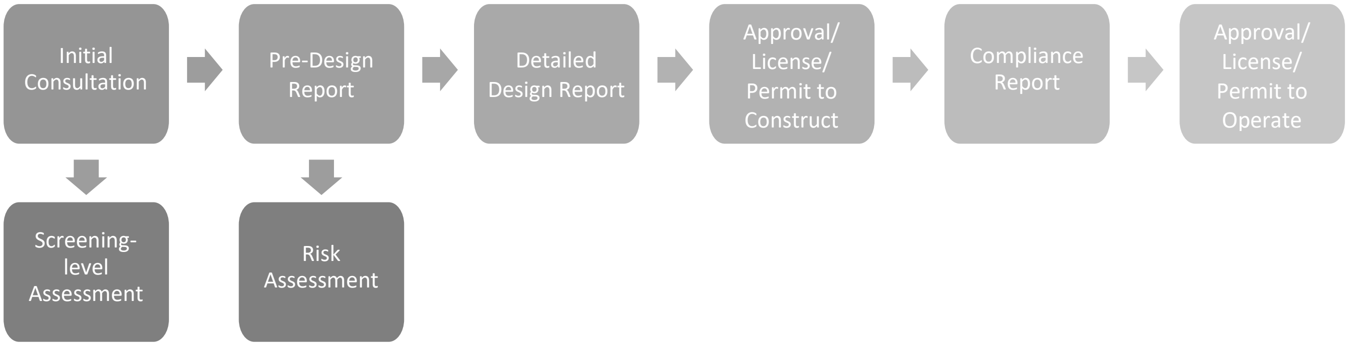
1.1 General Overview

The approval process for water supply, treatment and distribution varies from province to province, and can include multiple overlapping agencies. In all cases, the System Owner should seek early clarification from the respective province as to whether an approval for construction, modification, or operation will apply to the project before it advances. In some cases, an approval is needed for the vertical assets (e.g., Water Treatment Plant (WTP), storage reservoir, and pump station) but is not required for linear assets, such as extensions to local distribution piping. The application for approval should be submitted, reviewed, and approved prior to starting construction. The application should be signed by the System Owner in the format prescribed by the respective province.

Depending on the type of infrastructure to be constructed, there may be additional assessments, approvals, permits and/or authorizations from other provincial and/or federal authorities required before proceeding with construction. Determination of an overall regulatory roadmap of a given project is beyond the scope of these Guidelines. These Guidelines are intended to guide the design stages associated with public water supply infrastructure. In general, early consultation with the Regulatory Authorities is recommended in the project planning stages.

Climate change is creating evolving risks for water supply infrastructure and operations. Governments and Regulatory Authorities are increasingly requiring consideration of the impacts of climate change on built infrastructure within the planning stage (e.g., as a requirement for funding). These Guidelines outline considerations for the identification of current and future climate risks to support the incorporation of adaptation measures into design and operations of water supply systems.

The approval process can be a multi-step procedure and varies from province to province. Throughout the project, regular consultation and status review meetings should be continued through the concept, design, approval, and construction stages. The general approach for addressing a project's regulatory process is shown on the following chart and expanded upon in the following sections. Not all steps are required in each project, or in each province.



Within these Guidelines, climate change is addressed in two phases of the approval process. First, with a screening-level assessment at the pre-consultation phase, and second (if applicable), with a risk assessment at the pre-design phase (refer to Chapter 2 for further guidance). The purpose of the screening-level assessment is to consider potential impacts of climate change on the project, determine the System Owner's priorities regarding risk tolerance, and determine the need for a climate change risk assessment in the pre-design phase. If potential climate change impacts on the project are identified but cannot be directly addressed due to data gaps (such as a need for climate projections and a more thorough design review), then a risk assessment is recommended to be completed during the pre-design phase.

Depending on the nature of the project, the scope of submission to the Regulatory Authorities for each phase of approvals will vary in depth and complexity.

In some provinces, the Pre-design Report will be submitted to the Regulatory Authority, with a request for comments. Acceptance of a Pre-design Report (in any form) from a Regulatory Authority should not be considered as having received official approval to proceed with construction or modification of a project.

Where applicable, a processing fee form should be completed, and the appropriate fee submitted.

The formal approval application, with the plans, specifications, and supporting documentation should be submitted at least 90 days (or as specified by the Regulatory Authority) prior to the planned start of the construction or modification project. The plans, specifications, and supporting documentation should be stamped by a Professional Engineer that is licensed to practice in the province where the project is located. The application should be submitted to the Regulatory Authority and should be signed by the System Owner, or where authorization is provided, a person representing the System Owner.

The Regulatory Authority should review the application to determine if it conforms with policies, standards, or guidelines enforced by the department. During the review of the application, the Regulatory Authority may request additional information on the project. If the requested information is not received, the Regulatory Authority may declare the application incomplete, and advise the applicant of such.

In some provinces an Approval/License/Permit to Construct will be issued after the design application has been reviewed and found to be satisfactory for all requirements, including climate resilience. The proposed works should not be undertaken by the System Owner until the official approval has been issued by the Regulatory Authority. The System Owner should be aware of the expiration date associated with the approval. If the project is delayed, an extension may need to be filed with the Regulatory Authority.

In some provinces, a "Post-Construction Report/Certificate of Compliance/Completion Report" is required at the completion of the project.

After the submission of the closeout report, the Regulatory Authority may provide an Approval/License/Permit to Operate if all aspects of the project are acceptable.

The purpose of the approval is to clearly outline the operating and reporting requirements for the water supply system.

The expiry date of the approval and the terms for renewal would be indicated by the Regulatory Authority.

1.2 Pre-Consultation

System Owners planning a water supply project should consult with the Regulatory Authority to discuss project scope and to determine the regulatory requirements. Key outcomes of early consultation include:

- Identification of applicable laws, standards, and regulations that apply to the project.
- Identification of applicable permits, approvals, and authorizations required for the project.
- Identification of assessments, including those which address considerations for climate change. The respective Regulatory Authority should be contacted to determine specific requirements.
- Identification of key timelines associated with the review process.
- Identification of key stakeholders that should be involved in the process.
- Completion of a screening-level assessment to consider potential impacts of climate change on the project and determine the need for a risk assessment in the pre-design phase of the project (refer to Chapter 2 for further Guidance).

The screening-level assessment provides an opportunity to:

- Determine if the project requires an assessment and/or registration under the respective Environmental Assessment Act and additional regulatory requirements regarding climate change.
- Consider potential impacts of climate change on the project.
- Assess the System Owner's risk tolerance regarding climate change vulnerability and risk.
- Determine the need and/or scope of a risk assessment to be completed in the pre-design phase.

1.3 Pre-design Report

A Pre-design Report should be considered a good engineering practice even when not required by the Regulatory Authority.

A Pre-design evaluation will generally be required by the Regulatory Authority for large scale projects and/or projects involving the development or upgrade of the following:

- Water supply sources.
- Pump-house infrastructure.
- Water treatment plant.
- Transmission mains.
- Distribution system reservoirs, booster pumps, and pressure reducing valves.

The Pre-design Report should document the "problem statement" or the "problem to be solved", which may or may not be the same as the long-term goals.

The purpose of a Pre-design Report is to assess the existing infrastructure and operating conditions, identify and address system or asset vulnerabilities and risks, including potential impacts of climate change, and to determine options for upgrade, improvement, adaptation, or replacement.

Architectural, structural, mechanical, and electrical conceptual designs are typically not included in the Pre-Design evaluation; however, their estimated costs must be evaluated in terms of their impact on the overall project costs. Sketches may be included to describe treatment processes where applicable. Outline specifications of process units and special equipment may also be included.

A Pre-design evaluation for a proposed project is typically used by:

- System Owners for a project description and includes risk and adaptation strategy identification, findings, conclusions, cost estimates, financing requirements and recommendations.
- Designers, to establish the overall scope of design, including climate change considerations, and for the arrangement, capacity, and type of components to be designed.
- The Regulatory Authority for evaluation of environmental impacts, for examination of process operations, for verifying compliance with water treatment standards, for the issuance of a "Concept Approval", and to identify other regulatory triggers (e.g., those which require the inclusion of climate change considerations) prior to the initiation of detailed design.
- Investment groups and government funding agencies to evaluate the "quality" of the proposed project with reference to authorization and financing.
- News media for description of the project.

General practice is that a Pre-design Report may be considered valid for a period of up to 5 years unless new information has resulted in it being obsolete. This practice, however, may vary from project to project or within a given jurisdiction.

1.3.1 Contents of a Pre-design Report

The pre-design evaluation should, where applicable, include but not be limited to consideration of the following:

- Provide an overview of the existing infrastructure.
- Indicate the limitations of the existing infrastructure.
- Indicate existing water quality compared to existing provincial or federal water quality guidelines or standards.
- Conduct a risk assessment (scope of which is determined through the screening-level assessment) to evaluate system/asset vulnerability and risk to climate change and identify adaptation measures to implement into project design.
- Identify the long-term goals of the work being considered.
- Assess alternate options of resolving the limitations in an effort to meet the long-term goals which have been identified.
- Identify geotechnical issues.
- Provide estimated construction and operational costs.
- Provide a recommendation regarding feasible options.
- Provide a concept plan of the recommended option.
- Outline requirements for project implementation and approval by Regulatory Authorities.
- Identify all waste streams/emissions from project.
- Identify impacts of the environment on the project.
- Identify System Owner or private developers (name, address, telephone).
- Include a map of project site to show the following:
  - Property boundary and ownership for existing and future expansion.
  - Area of new development/area of existing development.
  - Flood zones including climate change considerations.
  - Environmentally sensitive areas (e.g., watercourse and wetland) including climate change considerations.
- Identify source capability to produce drinking water quantity and quality (with treatment) to meet provincial or federal water quality guidelines or standards.

- Identify treatment process options being evaluated, including disinfection systems.
- Determine service area.
- Determine equivalent service population.
- Summarize of water consumption data.
- Provide future population and water consumption projections.
- Identify maintenance and operation requirements.
- Identify adaptation/resiliency measures and options.
- Identify plans for monitoring of adaptation/resiliency measures.
- Any other requirements of the Regulatory Authority.
- Present summarized findings, conclusions, and recommendations for the System Owner's guidance.

1.3.2 Concept & Guidance for Plans & Specifications

The Pre-design Report should be complete so that detailed plans and specifications may be developed from it without substantial alteration of concept and basic considerations. In short, basic thinking, fundamentals and decisions are spelled out in the Pre-design Report and carried out in the detailed design plans and specifications.

1.3.3 General Format of Pre-design Report

The requirements for a Pre-design Report will vary with the scope of the project and the specific requirements of the client and/or Regulatory Authority. Projects involving the consideration of a new water source, water treatment, and large water transmission mains will typically provide detailed requirements for a Pre-design Report in a Request for Proposals.

The planning and pre-design phase of the project should be robust so that the ultimate system design is appropriate until the end the useful life. In the absence of detailed requirements for a Pre-design Report, the following should be considered, as applicable to the project, as a format for the Pre-design Report:

- Project background.
- Screening-level assessment and risk assessment (if applicable) addressing the impacts of climate change.
- Evaluation of water supply sources and water treatment options.
- Evaluation of transmission/distribution main options.
- Discussion of water supply sources, treatment, and transmission/distribution options.
- Discussion of probable capital/operations and maintenance costs of evaluated options.
- Recommended water supply source, water treatment process, and transmission/distribution.

Table 1.1 provides a checklist of components that typically should be included in a Pre-design Report. The requirements can be determined by the System Owner by indicating which components are applicable to the project and serve to determine the contents for a specific project to be submitted to the Regulatory Authority for review and approval. Specific tasks to be completed under each component are provided in Appendix A.

Table 1.1: Pre-design Report Requirements Checklist

	Yes / No / N/A
• Screening-level assessment and/or risk assessment.	
• Surface water supply source.	
– Existing and historical water quality.	
– Projected risks to water quality (including climate change considerations).	
• Groundwater supply source.	
– Existing and historical water quality.	
– Projected risks to water quality (including climate change considerations).	
• Water treatability.	
– Existing and historical water treatability.	
– Projected risks to water treatability (including climate change considerations).	
• Raw water storage reservoir.	
• Raw water transmission main.	
• Water treatment plant.	
• Treated water quality.	
• Treated water transmission main.	
• Acceptable pipe material.	
• Treated water storage.	
• Water distribution system.	
• Additional key components.	
– Water demand projections.	
– Design criteria.	
– Climate resiliency strategies to be incorporated into design.	
– Site selection of treatment plant.	
– Conceptual layout of treatment plant.	
– Ancillary equipment and infrastructure.	
– Route selection of transmission main.	
– Site selection of water storage reservoirs.	
– Cost estimate and financing.	
– Alternate treatment evaluation.	

1.4 Detailed Design

The System Owner must prepare and submit an application and, where applicable, a Detailed Design Report to the Regulatory Authority for approval. The application should be signed by the System Owner, or where authorization is provided, a person representing the System Owner.

Detailed design should include climate-resilient components as identified and prioritized through the risk assessment process completed in the pre-design phase of the project. The climate risks and climate adaptation strategies incorporated into design should be clearly stated in the Detailed Design Report. Reasoning should be provided for instances where risks have been identified and resiliency strategies were not incorporated into design (this may be presented within the risk assessment). Clear reasoning should be provided in the case that the conclusions of the screening-level assessment negated the completion of a risk assessment and climate resilient strategies were not incorporated into design (this may be presented the screening-level assessment). Refer to Chapter 2 for further guidance.

Applications for specific items within the project, such as stream crossings and withdrawal permits, may require approval from other jurisdictions.

An Approval/License/Permit to Construct cannot be issued until final, complete, detailed plans and specifications have been submitted to the Regulatory Authority, reviewed, and found to be satisfactory.

Detailed design documentation to be submitted with the application should include, but not be limited to:

- Design Report.
- Design plans.
- Specifications.
- Quantities and cost estimates.
- Other information as required by the Regulatory Authority.

1.4.1 General Format of a Detailed Design Report

The Detailed Design Report should contain all the up-to-date technical information on the project. It should make use of the data presented in the Pre-design Report but should be a stand-alone document that does not require the Regulatory Authority to refer to the Pre-design Report. Where multiple options may have been considered in the Pre-design Report, only the selected option is to be included in the Detailed Design Report.

The risk assessment, including all pertinent information (e.g., climate projections, data sources, evaluation methodology, results, identification/prioritization of adaptations strategies, etc.), should be included in the Detailed Design Report. The climate resiliency strategies incorporated into design should be clearly stated in the Detailed Design Report. For reporting purposes, only the risk assessment may be included in the Detailed Design Report if both a screening-level assessment and risk assessment were undertaken. If only a screening-level assessment was undertaken, then it should be included in the Detailed Design Report. Refer to Chapter 2 for further guidance.

Similar to the Pre-design Report requirements, the requirements for a Detailed Design Report will vary with the scope of the project and the specific requirements of the System Owner and Regulatory Authority. When it is determined that a specific project requires a Detailed Design Report, Table 1.2 provides a checklist of water supply system components that typically should be included in the report. The requirements can be determined by the System Owner by indicating which components are applicable to the project and serve to determine the contents for a specific project to be submitted to the Regulatory Authority for review and approval. Specific tasks to be completed under each component are provided in Appendix A.

Table 1.2: Detailed Design Report Requirements Checklist

	Yes / No / N/A
• General information.	
• Screening-level assessment and risk assessment.	
• Climate resiliency strategies incorporated into design.	
• Extent of water supply system.	
• Soil, groundwater, and geotechnical conditions.	
• Water demands.	
• Hydraulic evaluation of transmission mains and distribution system.	
• Sources of water supply.	
• Design criteria of WTP.	
• Automation.	
• Requirements for operations during construction.	

1.4.2 Plans

1.4.2.1 General

All plans should bear a title showing the project name, location, System Owner, the scale in appropriate units, the north point, date, and the engineer's name and be stamped by a Professional Engineer that is licensed to practice in province where the project is located.

The plans should be clear and legible. They should be drawn to scale which will permit all necessary information to be plainly shown. Datum used should be indicated. Locations and logs of test borings, where applicable, should be shown on the plans.

Detailed plans should consist of plan views, elevations, sections, and supplementary views that, together with the specifications and general layouts, provide the working information for the contract and construction of the works. The plans should also include dimensions and geodetic elevations of structures, the location and outline form of equipment, location and size of piping, water levels and ground elevations.

1.4.2.2 Technical Specifications

Complete technical specifications for the construction of impoundment structures, intakes, pumping stations, wells, WTPs, transmission mains, reservoirs, distribution system piping, valve chambers, and all appurtenances, should accompany the plans.

The specifications accompanying construction drawings should include, but not be limited to the following:

- All construction information not shown on the drawings which is necessary to inform the builder in detail of the design requirements as to the quality of materials and workmanship and fabrication of the project and the type, size, and strength.
- Operating characteristics and rating of equipment.
- The complete requirements for infrastructure equipment, including machinery, valves, piping and jointing of pipe, electrical apparatus, wiring, and appurtenances.
- Instructions for testing materials and equipment as necessary to meet design standards.
- Operating tests for the completed works and component units (it is suggested that these performance tests be conducted at design load conditions wherever practical).

1.4.2.3 Review of Design Submissions

The application and all supporting documentation should be submitted to the Regulatory Authority.

Where applicable, a processing fee form should be completed, and the appropriate fee submitted.

The formal approval application, with the plans, specifications, and supporting documentation, must be submitted prior to the planned start of the construction or modification project, and provide for the requisite number of days allowed for review by respective provincial agency. The plans, specifications and supporting documentation should be stamped by a Professional Engineer that is licensed to practice in the province where the project is located. The application should be signed by the System Owner, or where authorization is provided, a person representing the System Owner.

During the review of the application, the Regulatory Authority may request oral or additional written information on the project. If requested information is not received, the Regulatory Authority may declare the application incomplete, and advise the applicant of such.

1.5 Approval/License/Permit to Construct

An Approval/License/Permit to Construct should be issued by the Regulatory Authority after the design application has been reviewed and found to be satisfactory. **The proposed works should not be undertaken by the System Owner until the official approval has been issued.**

The approval will provide the System Owner with the authority to proceed with construction of the project.

Any changes in the approved works, or works other than those specified in the application, must be submitted in writing to the Regulatory Authority, and approved, in the form of an amendment to the approval prior to construction.

1.6 Post Construction Report/Certificate of Compliance

A Post Construction Report, although not required in all jurisdictions, should be provided at the completion of the project. This report may be called a Commissioning Report or Certificate of Compliance, depending on the jurisdiction. The report should contain all information regarding major changes, if any, from the approved plans or specification made during construction.

The report should contain all information regarding major changes from the approved plans or specification made during construction. Major changes include any deviations which affect capacity, flow, or operation of units. The report should also include results of all test-runs of the WTP to demonstrate that the plant can produce water meeting all applicable standards.

Information required includes, but is not limited to, the following:

- Equipment start-up tests and any other tests results produced during construction.
- Results of start-up of the plant confirming that treated water meets the water quality flow requirements.
- Confirmation that the plant and it’s components, watermains, and reservoirs are compliant to the latest edition of NSF/American National Standards Institute (ANSI)’s *NSF/ANSI 60: Drinking Water Treatment Chemicals - Health Effects*.

- Confirmation that a cross-connection survey has been performed and none have not been found.
- For groundwater sources, Groundwater Under the Direct Influence of Surface Water (GUDI) status and whether further assessment is required. For groundwater sources, GUDI status and whether further assessment is required.
- Confirmation that all components and chemicals are compliant to the latest edition of *NSF/ANSI 61: Drinking Water System Components - Health Effects*.
- Indication that as-built drawings, Operation and Maintenance (O&M) manuals, and any other relevant documentation have been provided to the System Owner/operator and/or other body if required by the Regulatory Authority.
- Confirmation that operator training and certification is consistent with provincial requirements.

If specific information cannot be confirmed when the report is prepared, a compliance plan outlining the time frame to comply should be submitted.

1.7 Approval/License/Permit to Operate

When applicable, the Regulatory Authority would provide an Approval/License/Permit to Operate or equivalent document, which will contain terms and conditions.

The purpose of the approval is to clearly outline the operating and reporting requirements for the water supply system.

The expiry date of the approval and the terms for renewal would be indicated by the Regulatory Authority.

1.8 Monitoring & Recording Requirements

Monitoring and recording requirements for the System Owner would be outlined, as applicable, by the Regulatory Authority in the Approval/License/Permit to Operate.

The monitoring program should be carried out in compliance with sampling and analysis requirements outlined in the approval.

Any monitoring carried out by a Regulatory Authority may not relieve the System Owner of their responsibility related to this function. The operator would be employed by the System Owner, therefore, the ultimate responsibility for compliance is from the System Owner.

1.9 Reporting Requirements

Reporting should be carried out in compliance with the requirements outlined in the regulatory approval documents or legislation as applicable.

1.10 Facility Classification & Operator Certification

Most provinces have adopted regulations that make facility classification and operator certification mandatory, while others strongly recommend operator certification. Where applicable, the regulations may require all water treatment and water distribution personnel to be certified and require that an operator with a certification level equivalent or greater to the facility classification be in direct responsible charge.

The Regulatory Authority should be consulted regarding specific requirements.

1.11 System Owner/Operator Responsibility

The System Owner of any water treatment or water distribution system should practice due diligence and should ensure that all monitoring and reporting is conducted in accordance with the requirements of the Approval/License/Permit to Operate.

In provinces that do not have mandatory facility classification and operator certification, System Owners are encouraged to voluntarily ensure that operators have attained the required certification status and are provided with on-going education and training.

1.12 Regulatory Authority Responsibility

The responsibilities of the Regulatory Authority should be as outlined in the latest respective provincial acts and other applicable regulations, policies, guidelines, and directives.

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Chapter 2 Incorporating Climate Change in the Design of Drinking Water Infrastructure

2.1 Introduction

In general, across Atlantic Canada, temperature and precipitation are increasing, sea-level is rising, extreme weather events are becoming more common, and these changes are projected to continue. Climate change is expected to have direct and indirect impacts on the supply, treatment, storage, distribution, design, and operation of drinking water systems. Projected climate changes and associated impacts will vary across the Atlantic Region due to geographic, economic, and demographic variability. Utilities are anticipated to encounter both challenges and opportunities with climate change. These challenges are often in the form of evolving vulnerabilities and risks to source water quality, infrastructure, and operations, whereas opportunities may be in the form of operational cost savings from increased system efficiency and reduced energy demands. Adaptation of existing and future drinking water infrastructure will help to maintain safe and reliable access to drinking water and minimize the social, environmental, and economic costs associated with severe weather and longer-term climate change trends.

Historically, infrastructure and water quality standards, best practices, and codes that incorporate climate-based risk considerations were established (either whole or in part) on historically measured values and the assumption of a relatively stationary climate. This stationary assumption is challenged by projected climate changes, which may translate to an increased risk of infrastructure failure, presentation of new hazards, and treatment challenges for System Owners. Proactive investments in resilient design and planning strategies (i.e., ones that considers a full range of climate projections and risks), can help to reduce future maintenance requirements, repair and/or replacement costs. For that reason, it is essential that best practices for built infrastructure, treatment, and operations consider both current and future climatic conditions to mitigate loss and ensure the safety of Canadians.

As introduced in Chapter 1, these Guidelines recommend that climate change be incorporated into two phases of the approval process:

1. First, at the pre-consultation phase with a screening-level assessment.
2. Second, at the pre-design phase with a risk assessment (scope of which is determined through the screening-level assessment).

2.2 Purpose

As described in the Introduction (Section 1.1) climate change is relevant not only for proposed systems (i.e., design, approvals, and construction), but also for existing systems (i.e., operations, maintenance, and retrofitting). For that reason, the purpose of this Chapter is to support teams endeavoring to develop risk assessments in support of adaptation planning for both existing and proposed drinking water infrastructure, source water quality changes, and operations/maintenance considerations. The information is presented at a level of detail that is appropriate for System Owners (e.g., managers, engineers, and operators) and Design Engineers. Teams involved in these assessments should have both asset and climate science expertise.

This Chapter is not prescriptive. Instead, it provides background concepts, illustrates complexities, and suggests factors to consider when choosing climate information and risk assessment methodologies. There is no list of climate interactions or indices provided, nor is their a step-by-step “how to” section on developing a risk assessment and adaptation plan, since these depend on the goals and scope of the assessment, geography, stakeholders, and availability of climate information. Instead, the purpose of the guide is to illustrate the steps and relevant questions, so that teams can tailor their process to the site-specific project needs. Similarly, instead of providing a go-to list of data portals, climate information is categorized into broader types that reflects the practical realities of where information is sourced, and examples are provided. Thus, the information in this Chapter is applicable for a range of assessment types, impacts, jurisdictions, and climates across the Atlantic Canadian region.

Lastly, this Chapter does not address climate change “mitigation”, which refers to the process of reducing Greenhouse Gas (GHG) emissions through action planning. As introduced above, this Chapter focuses on adaptation (building resilience to the impacts of climate change). It is, however, a best practice to consider whether climate adaptation plans can prioritize actions that also reduce life cycle GHG emissions.

2.3 Projected Climate Changes in Atlantic Canada

In this section, a brief summary of major climate changes in Atlantic Canada is presented. This information is general and should not be used directly in risk assessments which may require more site-specific context and projections.

It is noted that climate science is continuously evolving, and the projections presented herein are reflective of the best available information at the time of publication. The information is obtained from *Canada's Changing Climate Report* written by Bush, E. and Lemmen, D.S. and published by the Government of Canada, as well as the Intergovernmental Panel on Climate Change (IPCC) (2021).

2.3.1 Observed Climate Change in Atlantic Canada

- **Air Temperature:** Due to climate change, annual and seasonal average temperatures are projected to increase across the Atlantic region. More specifically, the following changes are anticipated:
  - There will be faster rates of change in the northern regions.
  - Increase in growing season length throughout Atlantic Canada.
  - The intensity and frequency of high temperature events are expected to increase while low temperature events are expected to decrease.
  - The freeze and thaw cycles are expected to vary decreasing the shoulder seasons.
  - Winter thaw events are expected to increase as a result of climate change.
- **Water Temperature:** Seasonal increases in surface water temperatures are expected in many areas, although this depends on local conditions. For example, in some locations, air temperatures may drive water temperatures, whereas other locations the water temperature may depend on groundwater inputs.
- **Seasonal Precipitation, Flow Patterns, and Drought:** Annual precipitation is generally expected to increase in the Atlantic region as a result of climate change. That said, in many locations the increase in annual precipitation will occur during the winter and spring. Except in parts of Labrador, more precipitation is expected to fall as rain rather than snow (although snowfall extremes may still occur). It is possible that

these changes lead to increased occurrence of rain on snow. During the summer and early fall, projections generally show more hot and dry conditions, potentially contributing to longer and more acute droughts, and low flows. It is also expected that regions across Atlantic Canada will experience earlier spring flows from snow melt.

- **Freezing Rain:** The weather systems that cause freezing rain are expected occur further northward with climate change. This means that certain parts of Atlantic Canada will see an increase in freezing rain, whereas others will see a decrease (e.g., some more southern regions and coasts).
- **Flooding:** According to the Institute for Catastrophic Loss Reduction (ICLR, 2012), flooding is the most frequent disaster in Atlantic Canada. Flooding can be caused by different drivers, such as high-intensity precipitation, a river or stream overtopping its banks, ice and debris jams, and extreme coastal water levels. In Atlantic Canada, flooding often occurs due to a combination of these processes. Climate change will lead to increased flooding in many areas, due to changes in high-intensity precipitation, snow melt, rain-on-snow, storm surge, and sea-level rise. It is noted that because flooding varies depending on local terrain and other factors, it cannot be assessed by projected changes to these climate variables alone.
- **Storm Activity:** Storm intensity and extreme weather events are expected to increase as a result of climate change (e.g., tropical storms, thunderstorms, windstorms, and nor'easters). This may lead to more intense precipitation that is combined with surge events, as well as high winds combined with freezing rain and/or blowing snow.
- **Sea Level Rise:** Sea levels have risen globally, as documented by long-term tide gauge records, such as the tide gauge installed in the Halifax Harbour and the tide gauge installed in Charlottetown. Relative sea-level change will significantly vary across Atlantic Canada, in part due to vertical land motion (James et al., 2014). Land subsidence in the south will increase local relative sea level rise, while land rebound in the north will buffer it.
- **Extreme Coastal Water Levels and Erosion:** Contributors to extreme sea levels include sea-level rise, an overall increase in storminess (storm surge), and increased wave action due to reduced ice cover. These changes may increase inundation and coastal erosion in some areas. The extent of impact is highly variable depending on the local coastline.
- **Wildfire and Other Disturbance Regimes:** The severity and frequency of natural disturbance regimes is expected to increase as a result of climate change, as a result of forest fires, blow downs/windthrow, precipitation damage, invasive species/pathogens/pests, disease, and drought.
- **Permafrost:** Southern Labrador is at the lower end of the permafrost distribution (with isolated, sporadic, and discontinuous permafrost), and Northern Labrador is within the zone of continuous permafrost. Climate change over the next century is expected to have the greatest effect on the more vulnerable permafrost at the southern boundary.

2.4 Climate Impacts

Direct and indirect impacts to the supply, treatment, storage, distribution, design, and operation of drinking water supply systems as a result of climate change are described generally within this section. The impacts of climate change on water systems may include:

- Structural damage and overland and/or coastal flood risk to buildings and infrastructure.
- Supply chain disruption.
- Power and communication outages.
- Water quality changes (source water, groundwater, and water distribution).
- Reduced allowable withdrawal and safe yield of source water.
- Structural performance and maintenance of dams.

- Operations of residuals management facilities.
- Breakage and deterioration of water transmission and distribution systems.

Climate impact examples are provided to serve as an illustration of potential considerations and are not wholly encompassing. The examples were generally referenced from:

- *Canada's Changing Climate Report* written by Bush, E. and Lemmen, D.S. and published by the Government of Canada.
- *Nova Scotia Climate Change: Water Impacts* from Nova Scotia Environment and Climate Change.
- *Climate Impacts on Water Quality* from the United States Environmental Protection Agency.
- *U.S. Climate Resilience Toolkit* from the United States Global Change Research Program.
- *Safety and Security* from the Water Environment Federation (WEF).
- *Groundwater & Climate Change* from the International Groundwater Resources Assessment Centre.

Climate impact examples:

- **Power Outages:** The frequency of power outages may increase with climate change due to projected increases in the severity and frequency of extreme events. Power outages may significantly impact a water supply system's ability to provide potable drinking water to downstream consumers.
- **Coastal Infrastructure:** Impacts of flooding and erosion on coastal infrastructure may increase with climate change. In Atlantic Canada, this may have implications for supply chain along coastal highways and through ship-based transportation.
- **Source Water Quality:** Climate change impacts on source water quality will be widely variable and dependent on local watershed and waterbody factors such as location, topography, geology, development, and small-scale ecosystem interactions, among others. In coastal locations, the salinity and pH of surface water and groundwater sources may change. Further, decreases in water quality from increased disturbances within watersheds may be a result of extreme weather. Increased incidence of wildfire may increase soil erosion and contaminate loading to surface waters, posing a threat to aquatic habitats and surface water quality. Lastly, increases in the intensity of precipitation events may increase runoff and contribute to loading of turbidity, nutrients and contaminates to source water supplies. This may impact water system operations by increasing filter loading rates requiring increased chemical dosing and backwashing rates.
- **Groundwater Quality:** Groundwater sources may be increasingly impacted by flood events that mobilize pathogens and lead to the release of chemical contaminants. Flooding of wastewater infrastructure (lagoons and lift stations), or direct overflows associated with sanitary and storm water infrastructure, could add significantly to the pathogen load of the floodwater. Inundation of fuel tanks and chemical storage areas could likewise release petroleum hydrocarbons and other species which may migrate to source waters. Coastally located aquifers may be impacted from saltwater intrusion resulting from sea level rise.
- **Source Water Quantity:** Changes in water availability across the Atlantic region are expected as a result of climate change. Potential increases in drought conditions, changes in precipitation patterns, increased storm intensity, and increased snowmelt and evaporation rates from rising surface and water temperatures may impact water availability. Periods of low flow and decreased water levels, resulting from seasonal increases in drought conditions and warmer temperatures, may result in decreased water quantity in some regions.
- **Groundwater Quantity:** Groundwater sources may be impacted by both low flow periods and increases in precipitation intensity, which may lead to decreased opportunity for recharge. Potential decreases in aquifer recharge may result in increased draw down rates, impacting allowable pumping rates and well performance. Depending on the depth and size of the aquifer, climate change impacts may not be evident for decades to centuries due to the generally slow rate of groundwater hydraulics. In terms of well

infrastructure, for users drawing water from a deep regional aquifer, changes may not become apparent over the normal operational lifetime of the well (i.e., 20 to 40 years). Shallower wells tend to show the fastest and most direct responses to changes in the groundwater recharge rate. During times of drought this can cause the water level in the well to approach the depth of the pump, with potential interruptions to the water supply. Dug wells and wells installed in unconfined sand and gravel aquifers are at greatest risk. Long-term decreases of the groundwater recharge rate may also contribute to over-pumping of the aquifer, reductions in baseflow to streams, dewatering of fracture systems, and subsidence of the aquifer material.

- **Warmer Water Temperatures:** Seasonally warmer water may increase instances of low oxygen levels or "hypoxia"; foster Harmful Algal Blooms (HABs); and alter the toxicity of some pollutants. Warmer surface water temperatures may also impact water treatment operations such as chemical dosing rates and design conditions such as intake depth. Warmer water temperatures in the summer months may intensify stratification throughout the water column in surface water bodies impacting the aquatic environment, turnover events, and the release of contaminants (e.g., iron, manganese, and phosphorus) from lake sediments. Warmer water temperatures further support the growth of algae and water borne pathogens.
- **Water Usage Patterns:** Warmer air temperatures, particularly during the summer months, may impact water usage patterns, resulting in increased demand on water supply systems.

It should be noted that the processes that influence water quality and quantity changes are highly complex and dependent on local factors (e.g., watershed, waterbody, and presence of control structures among other factors). Further, the impact of variations in source water quality on treated water quality is highly dependent on the specific WTP and cannot be considered independently. Nonetheless, these changes may impact approval and compliance criteria for water withdrawal and treated water quality targets.

2.5 Climate Information

This section summarizes important background concepts relating to climate projections. These ideas are key for understanding how climate information is used in climate change risk assessments.

2.5.1 Managing Uncertainty

Decision-makers are already equipped to deal with uncertainty. Weather variability and extreme weather unpredictability is a fact that engineers, planners, emergency service providers, and policymakers have learned to accept and respond to appropriately.

Since there is no one certain future for any given climate variable, the available information is best used by applying the full range of projections (from lowest to highest future value) in risk assessment. This is the recommended approach/best practice.

Regardless, the uncertainties associated with climate projections should be factored into, and not against, the use of future climate information. Climate projections and their uncertainties should be framed within the presentation of the data plots and graphs. This allows designers and decision-makers to familiarize themselves with the potential envelope of conditions to be considered.

2.5.2 Understanding Climate Models

A climate model is a computer representation of the climate system. Climate models divide the earth into 3D cells that are approximately 100 to 300 km wide and use equations to simulate atmospheric, oceanic, and other processes. There are over 30 Global Climate Models (GCMs) which are owned by leading scientific institutions around the world and require significant computational power to run.

2.5.3 Understanding the Use of Climate Models

Climate models are used to test how the climate system will behave under future changes. Without climate models, we would need to extrapolate measured historical trends, and this assumes that past processes remain unchanged in the future ("the stationarity assumption"). Considering the climate is a complex system, there can be step-changes and other non-linearities, so the stationarity assumption is often false. Climate models are used to better project the future climate by resolving some of these more complex processes. This is important background information when choosing types and sources of climate information for an assessment (e.g., complementing historical information with climate model projections; see Appendix B).

2.5.4 Emission Scenarios

Greenhouse gases such as carbon dioxide, nitrogen dioxide, and methane, trap the sun's heat within the atmosphere, causing the climate to warm. Emission scenarios are possible GHG patterns over the 21st century, which depend on population growth, future technology, policies, and conflict. Global climate models are driven by emission scenarios. The IPCC has established several industry-standard scenarios, called Representative Concentration Pathways (RCPs) or Shared Socioeconomic Pathways (SSPs).

2.5.5 Spatial Resolution & Downscaling

The spatial resolution of climate models is important for some processes to be properly modelled. The resolution of GCMs is too coarse to properly resolve certain processes. High-intensity precipitation, for example, is better represented at higher spatial resolutions.

Global climate model outputs can be focused onto smaller areas by using processes referred to as "statistical downscaling" or "dynamical downscaling". Statistical downscaling uses statistical relationships between local climate variables and large-scale predictors, which are then applied to model outputs to approximate local climate projections. Dynamic downscaling uses Regional Climate Models (RCMs), which are driven by outputs of GCMs. Representative concentration pathways are higher-resolution (smaller grid size, e.g., 10 to 50 km) and include more detailed information on regional conditions (e.g., mountains or water bodies), which increases accuracy. This is important background when choosing types and sources of climate information for an assessment (Appendix B).

2.5.6 Projection Horizons

Projection horizons are the discrete time periods over which climate projections are obtained. These are selected based on the remaining useful life of the program or asset being assessed (e.g., mechanical systems often use a lead-time of 30 years). It is also appropriate to use shorter-term projections to assess the capacity of a project/asset with a long-term planning horizon, as the project/asset will still experience changes over the short term.

Climate projections for atmospheric conditions are often obtained as a mean value over a 30-year period, which is compared to a mean over a 30-year baseline (e.g., 1981-2010). The 30-year periods are necessary in order to average natural climate variability that occurs on multi-decadal timescales. For example, climate projections for the 2050s are calculated as 2041-2070. This is important background when choosing types and sources of climate information for an assessment (Appendix B).

2.5.7 Climate Indices

The outputs of GCMs and RCMs include variables like temperature, precipitation, humidity, and wind. Indices are calculated from these variables to provide detailed and meaningful projections that can be used by decision-makers (e.g., indices can be threshold-based, minimum, maximum, extremes, or related to duration). Some indices require a combination of variables, such as humidex which involves both humidity and temperature.

2.5.8 Locally-Dependent Climate Changes

While some climate changes are expected to be relatively consistent over a region (e.g., temperature and sea-level rise), others depend more strongly on local processes. For example, changes in water quality depend on the characteristics of the watershed and waterbody (e.g., degree of impact from flushing events and disturbance, stratification, receiving water quality and dilution, etc.).

Flooding extents and depths also depend on the local terrain (e.g., watershed size and width of the riverbed), hydraulic structures (e.g., culverts), and other factors. This means that a given increase in precipitation intensity may result in an amplified increase in flooding in one location, while causing a minimum increase in flooding in another.

In other words, changes in these locally dependent climate changes cannot be projected without additional modelling or analysis. In the case of flooding, engineers use impact models (i.e., hydrologic, hydraulic, and hydrodynamic) to convert climate projections for precipitation intensity and extreme coastal water levels into projected changes in flood lines.

2.5.9 Model Ensembles

Climate models use approximations in their mathematical formulations. This is because models cannot capture the entire complexity of the climate system. The approximations are a practical solution to account for phenomena that occur at spatial scales smaller than their grid cells. This means that a given model can overestimate or underestimate the actual climate. Considering different models use different approximations, they give different solutions, each of these solutions representing one possible future. For that reason, the range of the models' projections covers the range of possibilities (to the extent that they can be modelled), so an ensemble of models should be used for climate projections.

This approach for managing climate projection uncertainty is called ensemble modelling. The results of ensembles are presented with graphs and plots that indicate the distribution of data so that an assessment can be made with respect to the spread and overall confidence of the modelled result. Typically, climate projections from model ensembles are reported with percentiles of the ensemble as an indication of the uncertainty (e.g., 10^{th}, 50^{th}, and 90^{th} percentiles). This is important background when choosing types and sources of climate information for an assessment (e.g., climate information based on ensembles and that allow for uncertainty characterization; see Appendix B).

2.5.10 Sources of Uncertainty

Although climate models are the best tools available to study projections, there are uncertainties in the models and associated observational datasets and statistical transformations. The amount of uncertainty depends on the variable being projected, the index, and the climate/geography (e.g., confidence in temperature projections may be greater than for other variables such as precipitation or winds. Return period precipitation extremes are harder to project than changes in total precipitation).

The relative importance of each source of uncertainty also depends on the timescale considered. Over the timescale of a few decades, natural variability (fluctuations of the climate system that occur even without any changes in GHG concentrations) dominates and can even blur or obscure the climate change signal. That said, over longer time horizons, predictions associated with each emission scenario diverge, lessening the relative significance of uncertainty associated with natural variability. The use of more than one emission scenario mitigates this uncertainty by presenting a range of possibilities. This is important background when choosing types and sources of climate information for an assessment (e.g., complementing historical information with climate model projections; see Appendix B).

2.5.11 Evolving Science

Climate science is fast-moving. Models continue to resolve a higher number of processes more accurately, and updated emissions scenarios, new modelling ensembles and better post-processing of climate projections are becoming available. For example, future generations of models will have better spatial resolution (made possible due to an increase in computing power). Nonetheless, some processes will remain difficult to represent in models, and others will still be smaller than the grid resolution (e.g., cloud microphysics). This is important background when choosing types and sources of climate information for an assessment (e.g., updated sources of information; see Appendix B).

2.5.12 Finding Climate Information

Climate information is available from different types of sources, which range from qualitative to quantitative. Examples are provided in this section.

The reader is referred to Appendix B for a detailed description of how the concepts presented in this Chapter (e.g., climate-asset interactions, scope of the risk assessment, and availability of climate information) apply to the selection of climate information.

2.5.12.1 Local, Operator, & Indigenous Knowledge

Knowledge and experience of the people living or working close to the geography or infrastructure being assessed can be an important source of climate information. For example, some phenomena are only known by residents of the area, such as local processes that have not been studied or modelled (e.g., microclimate in a valley). Local residents can help characterize recurring problems such as flooding. Infrastructure operators and people familiar with the site may highlight trends (e.g., changes to wind-driven movements of lake ice or algal blooms). Traditional Indigenous knowledge is a valuable source of information that is complementary to other approaches. Traditional Indigenous knowledge can be defined as a network of knowledges, beliefs, and traditions intended to preserve, communicate, and contextualize Indigenous relationships with culture and landscape over time.

Examples of obtaining local, operator and Indigenous knowledge include:
- Consultation of First Nation, Inuit, and Métis Communities and groups.
- Asking residents to validate flood maps at a public engagement session.
- Conducting a risk workshop with infrastructure operators.

2.5.12.2 Measured Data
There are many types of directly or indirectly measured data that can be used to characterize historical trends (e.g., data from climate station instruments, tide and river gauges, and satellites). In terms of characterizing future changes, extrapolating measured historical trends can be problematic because it assumes that changes do not speed up or slow down. Nonetheless, an understanding of past changes can complement knowledge of climate projections. Examples of measured data include:
- Historical ice charts from the *Canadian Ice Service archive* from the Government of Canada.
- Tide gauge records from the Department of Fisheries and Oceans Canada (DFO).
- Hourly wind speed measurements from Environment and Climate Change Canada stations.
- River monitoring (water levels and flow) information from the National Hydrometric Program (https://wateroffice.ec.gc.ca/index_e.html).

2.5.12.3 Climate Model Projections from Data Portals
Quantitative projections can be obtained from data portals. These are user-friendly and include pre-calculated indices (e.g., total annual precipitation, number of days > 30˚C, etc.). Several portals include ensembles of statistically downscaled GCMs, and projections can be extracted for one location or visualized on a map. Yearly precipitation extremes are available (e.g., annual maximum 1-day precipitation), although return-period indices (e.g., 1-in-100-year 1-day precipitation) are not available at present. Available indices are generally calculated from daily temperature and precipitation projections only, although ClimateData.ca now has an index also based on evapotranspiration (the Standard Precipitation Evapotranspiration Index (SPEI)). The data portals are increasingly more flexible, allowing for custom-made indices (e.g., on ClimateData.ca). Examples of data portals include:
- *Canadian Centre for Climate Services* from the Government of Canada.
- *The Climate Atlas* from the Prairie Climate Centre.
- *Climate Data and Information* from CLIMAtlantic.

2.5.12.4 Project-Specific Computation of Climate Indices
If data portals cannot provide the required post-processing of climate model projections, another approach is to download the projections and calculate what is required offline. For example, statistically downscaled ensembles of GCMs can be obtained in a gridded format and manipulated with coding expertise. This requires more time but means that the outputs can be tailored to the assessment. Some examples are:
- Computation of sector-specific indices (e.g., 2-day or 5-day precipitation).
- Computation of projections over a desired area (e.g., averaged over a watershed or municipality).
- Generation of certain figures and visualizations not available through data portals (e.g., monthly changes shown on the same plot).

2.5.12.5 Clausius-Clapeyron Equation
For projected changes in precipitation intensity, use of temperature scaling through the Clausius-Clapeyron equation has become the de-facto approach, until better approaches are established. This equation describes

the ability of warmer atmosphere to hold more water, simplified as a 7% increase in precipitation intensity per increase in °C. Some examples of where this approach is described are:

- *CSA PLUS 4013 Technical Guide- Development, Interpretation and use of rainfall intensity-duration-frequency (IDF) information: Guidelines for Canadian water resources practitioners* from the Canadian Standards Association (CSA).
- *Climate-resilient buildings and core public infrastructure 2020: an assessment of the impact of climate change on climatic design data in Canada* from Environment and Climate Change Canada.

2.5.12.6 Downscaling & Post-Processing Tools

Certain tools are available (online or as software) to aid in the generation of climate scenarios. These are different approaches to projecting future climate data for a given locality. Each has its own assumptions and limitations. Some examples are:

- *IDF-CC Tool* from the Western University Canada.
- *Statistical DownScaling Model – Decision Centric* from SDSM.
- *Canadian Extreme Water Level Adaptation Tool (CAN-EWLAT)* from the Bedford Institute of Oceanography.

2.5.12.7 Impact Models

As described in Section 2.5.8, some climate changes are more locally dependent. This includes changes in water quality and flooding. These variables are typically not directly available from climate models and are only indirectly impacted from precipitation and temperature changes.

Future changes in these variables are usually characterized from a physical or data-driven impact model that is forced with future climate data. Some examples include:

- Using a hydrological/hydraulic model to project riverine flooding.
- Using a sewer model to project combined sewer overflows.
- Using a wave model to project wave height.
- Using a water quality model to project lake acidification.
- Using a groundwater model to project low flow.
- Using a hydrodynamic model to project dilution in receiving water bodies.

This information usually comes from a standalone assessment.

2.5.12.8 Flood Lines & Hazard Mapping

Another source of information on future climate changes is hazard mapping. Here, "hazard" is used to refer to the projected climate change. Hazard mapping is particularly relevant for locally dependent changes, such as flooding. Other hazard maps can include combined sewer overflows or wave heights.

In the case of flooding, flood line mapping in Atlantic Canada is usually conducted by governing bodies such as provincial or municipal governments. The challenge is when available flood line mapping has not yet been updated to include the impacts of climate change (e.g., projected increase in precipitation intensity and sea-level rise), and flood modelling is outside the scope of the risk assessment.

In these cases, using the largest historical flood on record is not adequate, as this is rarely representative of future flooding likelihood. Likewise, use of a safety factor (e.g., adding 1.0 m for climate change) is not recommended, as the future change in flooding can be drastically different from this, and the safety factor provides false confidence in the analysis.

The recommendation is for existing flood line mapping to be used to characterize baseline flooding. Expert judgement should then be applied to estimate a likelihood score for future projection horizons, based on an understanding of projected climate changes and the local hydrology and hydraulics. The risk assessment should flag the flood line mapping gap as part of the recommendations.

2.5.12.9 Literature

Certain climate phenomena are not well captured by climate models. These include freezing rain and ice storms, extreme winds, hurricanes, and several others. Future changes in these phenomena need to be characterized from a process-based understanding (i.e., how the factors that affect these phenomena are changing), which is typically obtained from the literature (existing reports and peer-reviewed science articles). The literature can also be a source of both quantitative (snow, freezing rain, sea-level rise, etc.) and qualitative (hurricanes, fog, etc.) projections. Example sources of projections include:

- *Climate-Resilient Buildings and Core Public Infrastructure: an assessment of the impact of climate change on climatic design data in Canada* from Environment and Climate Change Canada.
- *CMIP5 drought projections in Canada based on the Standardized Precipitation Evapotranspiration Index* in by Tam et al. and published in the Canadian Water Resources Journal (p. 44(1), 90-107).
- *Changes in oceans surrounding Canada* (Chapter 7, p. 343-423) written by Greenan et al. and published by the Government of Canada.

2.6 Climate Change Risk Assessments

This section summarizes important background concepts relating to risk assessments that are key for understanding the context and applicability of a risk assessment for various applications.

2.6.1 Introductory Concepts

Introductory concepts for climate change risk assessments are summarized below:

- **What is a Risk Assessment?** Risk can be defined as the combination of the severity (or consequence) of impacts and probability (or likelihood) of a climatic event occurring. Risk assessment is one part of a larger decision-making process that helps manage the uncertainty from climate data, understand system capabilities and required functionality, consider evolving risk factors, and prioritize areas for adaptation. A risk assessment qualifies or quantifies the likelihood, vulnerability, and consequence of a particular climate interaction, to arrive at a prioritization of high-risk areas (e.g., infrastructure and operations). The purpose of the risk assessment is to evaluate both existing and evolving risks to aid in prioritizing adaptation actions. An adaptation plan can then be implemented in either the planning, design, or operational phase of an asset.
- **Who is Involved in a Risk Assessment?** A team consisting of a diverse group of participants with relevant specific subject matter expertise are best equipped to conduct a thorough and comprehensive risk assessment. The multidisciplinary team may be called upon at various stages of the design development and planning process to ensure a broad perspective and approach is being applied. Team members may consist of the facility operators (front-line to office staff), Regulatory Authorities, engineers, planners, climate scientists, and emergency management professionals, where applicable. Practitioners are cautioned that proper application of climate data can be a complex process which requires interpretation of data and characterization of uncertainty. Typically, engineers, planners, policy makers, and operators are trained to work with uncertainty. A team with climate projection expertise can interpret and filter the significant

volume of available climate information down to a critical set of projections to be considered in the decision-making process. It is recommended that personnel with climate science expertise be involved throughout the entirety of the risk assessment process to ensure data is interpreted and applied correctly to facilitate informed decisions making.

- **What is the Role of Risk Assessment in New Infrastructure Projects?** For proposed new projects, it is recommended that a climate change risk assessment (if needed) be incorporated at the pre-design phase of work to determine if/how adaptation efforts are to be undertaken throughout design, construction, and operation. This is consistent with the recommendation in Chapter 1 of these Guidelines that the Pre-design Report be completed such that detailed plans and specifications may be developed from it without substantial alteration of concept and basic considerations. The scope of the risk assessment is established through a "screening process" that is undertaken at the pre-consultation phase to determine the level of detail required for project planning purposes. The screening process should determine the scope and boundaries of the risk assessment based on the expected outcomes of the analysis and how the results will feed into the larger decision-making process. Risk assessment is sometimes required for a funding program.
- **What is the Role of Risk Assessment for Existing Systems?** For existing systems, a risk assessment can be completed at any time during the infrastructure life cycle. End of life, poorly maintained, poorly sited, or "under sized" infrastructure is likely to be more susceptible to the impacts of climate change. For that reason, a risk assessment may be prioritized for infrastructure that is at or near the end of its useful life and replacement is imminent; has not met performance expectations; has been negatively impacted by extreme weather in the past; has insufficient capacity for growth; is undergoing an update to planning (compliance, asset management, etc.) and/or is scheduled for capital improvements. Risk assessment is sometimes required for a funding program.
- **What Should a Risk Assessment Include?** The System Owner and practitioner may choose to scope the assessment relative to the importance, criticality or complexity of the asset or system (i.e., highly critical assets may warrant a more in-depth analysis), taking into consideration the current phase in the project's life cycle (i.e., from planning to operation and maintenance). Further, the risk assessment can be performed municipality-wide, at the asset-class level (e.g., horizontal vs. vertical assets), or on a single existing or proposed asset. Assessments will vary in the degree of precision required and can be executed qualitatively or quantitatively. The anticipated impact(s) or climate-asset interactions may be a driving factor in the precision level required. A risk "screening-process" can be undertaken during the pre-consultation phase of a large, proposed capital project to determine if climate change impacts are a concern, and if so, the scope and scale of the risk assessment required.

2.6.2 Screening-Level Assessment

The purpose of the screening-level assessment is to identify potential climate change impacts to the project, determine the System Owner's priorities regarding risk tolerance, and determine the need for a climate change risk assessment in the pre-design phase. If consideration for the impacts of climate change is found to be applicable to the project but cannot be directly addressed due to data gaps (such as a need for climate projections and a more thorough design review), then a risk assessment is recommended at the pre-design phase.

A screening-level assessment provides an opportunity to identify the general scope in which climate change considerations will be incorporated into the project and determine the need for or scope of a risk assessment. The screening-level assessment includes a high-level evaluation to identify asset-climate interactions and potential system/asset vulnerabilities to climate change over its design/service life.

A risk assessment should be undertaken if a regulatory requirement for incorporation of climate change considerations to the project is identified through the screening-level assessment. Further, if climate change vulnerability is identified through the screening-level assessment and the risk exceeds the System Owner's risk tolerance, then a risk assessment should be undertaken. The screening-level assessment should provide clear reasoning in the conclusion that a risk assessment does not need to be completed in the pre-design phase of the project.

2.6.3 Executing a Risk Assessment

An industry best practice is to select a risk assessment methodology that is consistent with the latest edition of *ISO 31000 Risk Management-Guidelines*. The selected risk assessment methodology should consider both historical and future climate. There are many different climate change risk assessments methodologies available that generally use either a "top-down" or "bottom-up" approach. The main difference between the two approaches is the sources of information that drive the assessment. In a simplified description, a "top-down" approach is driven by the climate projections. A "bottom-up" approach focuses on the system that is impacted (e.g., asset and ecological) by determining potential future vulnerabilities and/or failure scenarios. Climate projections are then analysed to determine if the previously determined failure scenarios are plausible. With the "bottom-up approach", information from large stakeholder teams is usually a dominant source for determining the scope of the analysis and characterizing risks.

Climate change risk assessment methodologies will typically include the following key components:

- **List of System Components:** A catalogue of the current capabilities, design, and function of the asset/system is developed. This background system review process may be completed in a workshop setting with experienced operators, engineers, and facility managers. Only systems that are impacted by climate change are included in the list. A climate-asset interaction summary matrix, with climate parameters in columns and system components in rows, can be a helpful presentation tool.
- **Use of Thresholds:** A threshold is defined as the limit past which an infrastructure asset or system component is critically vulnerable. Thresholds guide the types of outputs required from the climate assessment. Thresholds can be based on review of performance history, design criteria, modelling of system performance, identification of key performance indicators, or asset condition.
- **Climate Analysis:** A climate projections analysis for risk assessment includes a quantitative or qualitive measure of the probability (or likelihood) of a particular climate event occurring at the location of interest. Appendix B provides a detailed description of how the concepts presented in this Chapter (e.g., climate-asset interactions, scope of the risk assessment, and availability of climate information) apply to the selection of climate information for the climate projections analysis.
- **Vulnerability and Consequence Analysis:** The vulnerability and consequence assessment considers the degree to which the system is affected when exposed to changes in climate factors; where climate vulnerability is defined as the degree to which a system is affected by climate stressors, and consequence is defined as the outcome, should a given climate change occur. Consequence should be assessed independently from probability/likelihood. Depending on the risk assessment methodology used, vulnerability may be combined with consequence or may stand alone. Vulnerability can be measured in terms of the system's ability to withstand an anticipated consequence (e.g., backup power can mitigate the impacts of power outages and, therefore, reduce system vulnerability). There are several categories of consequences to consider such as asset damage, financial loss, loss of service, health and safety, and reputation, among others (*Asset Management & Climate Change: Planning for a Future of Uncertainty* by

Ali A, Singh A., et al.). The consequences for not meeting desired levels of service should be considered when determining severity.

- **Risk Assessment:** The risk analysis categorizes each climate-asset interaction according to the risk levels identified (i.e., quantitative or qualitative scoring). The risk scoring exercise is generally finalized in a workshop setting with a multidisciplinary team. The risk assessment results can be displayed visually in a risk matrix which categorizes risks from low to high. The risk matrix example below (from the *Climate Lens-General Guidance* written by Infrastructure Canada and published by the Government of Canada) presents a qualitative definition for likelihood and consequence. It is noted that that risk assessment is generally an iterative process as the practitioner often revisits certain conclusions or priority scoring based on relative risk comparisons and multidisciplinary discussions with project stakeholders in a workshop format. The outcome of the risk assessment is a ranking of climate interactions from low to high risk, which will inform the adaptation plan priorities.

Table 2.1: Risk Assessment Matrix

Consequences	Very high	Moderate risk	High risk	High risk	Extreme risk	Extreme risk
	High	Low risk	Moderate risk	High risk	High risk	Extreme risk
	Moderate	Low risk	Low risk	Moderate risk	High risk	High risk
	Low	Negligible risk	Low risk	Low Risk	Moderate risk	Moderate risk
	Very low	Negligible risk	Negligible risk	Low risk	Low risk	Low risk
		Very low	Low	Moderate	High	Very high
		Likelihood				

Extreme risk (red): Immediate controls required.
High risk (orange): High priority control measures required.
Moderate risk (yellow): Some controls required to reduce risks to lower levels.
Low risk (blue): Controls likely not required.
Negligible risk (green): Risk events do not require further consideration.

2.7 Climate Change Adaptation

Adaptation planning involves identifying priority options to improve resiliency to climate risks. Risks are first evaluated and ranked through the risk assessment process. Adaptation measures, sometimes referred to as risk treatment measures, are a set of actions designed to reduce the risk of negative impacts (and potential loss) to an acceptable level. Adaptation also includes taking advantage of opportunities presented with climate change. An adaptation plan is the collection of preferred risk treatment measures into a strategy document, which typically outlines the cost or level of effort associated with each measure, as well as the timelines and parties responsible for implementation. An adaptation plan can be implemented in either the planning, design, or operational phase of an infrastructure asset.

Adaptation measures are first identified for each unacceptable risk, which is either guided by the System Owner's risk tolerance or based on risk ranking from the risk assessment methodology (i.e., high risk categories may require risk treatment measures). There are many potential adaptation measures that can be explored, some of which may include:

- Developing Emergency Response Plans (ERPs) or Contingency Plans (CPs).
- Adjusting operating practices.

- Upgrading infrastructure.
- Creating new practices or processes.
- Monitoring performance overtime and revaluating as needed.
- Implementing an advanced warning system.
- Adapting engineering design parameters or safety factors.
- Altering maintenance plans.
- Relocating or raising the asset beyond the future flood limits.
- Completing a more detailed analysis to address data gaps.

A “do nothing” or a “business as usual approach” is also an option, however, this may not be appropriate for high-risk interactions.

Once a list of potential adaptation measures is finalized, the preferred adaptation strategies are selected, for example by taking into consideration the System Owner’s strategic goals, stakeholder expectations, and business level/service/operational targets. One tool for selecting the preferred adaptation measure, or assessing the overall feasibility, is a cost-benefit analysis. This analysis quantifies the costs of the risk treatment measure against the measure’s benefits, which may include improved safety, reduced service disruptions, or decreased environmental contamination. Lifecycle cost-benefit analysis is used to determine the set of investments with the lowest Net-Present-Value (NPV). To quantify the feasibility of the proposed risk treatment measures, the latest edition of the *Climate Lens-General Guidance written* by Infrastructure Canada and published by the Government of Canada provides a methodology for calculating the loss avoided and return on investment of the proposed adaptation measure.

No-or low-regret adaptation measures are those that have a proven cost-benefit regardless of climate change, or under all future climate scenarios. For climate interactions with a lower risk profile in the short-term, practitioners may opt to monitor the asset performance over time and adjust the adaptation plan accordingly as the risk profile increases, or as new technologies and information becomes available. Alternatively, if action must be taken in the short term, leaving available space for flexibility will allow the system to be expanded or built upon at a later time.

Selected adaptation measures should address the risk directly and not transfer downstream to another System Owner or asset(s). Considerations for adaptation measures with multiple benefits, such as those that reduce GHG emissions, consider the application of natural infrastructure, or improve environmental and social conditions are preferred.

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Chapter 3 Source Water Development

3.1 Surface Water

3.1.1 Quantity Assessment

There are a variety of methods that can be used to estimate surface water yields. Mass flow curves can be generated from streamflow records. Alternatively, a record can be simulated using long-term precipitation data. Where data exists, both methods should be used, and a comparison made between them.

The impacts of climate change on water availability will be widely variable and dependent on factors such as location, topography, geology, and urban development. Future development and climate change (e.g., increasing temperatures and changes in precipitation patterns) may impact future yield. It is recommended that practitioners include climate change considerations when determining the long-term viability of a water source. This may be done by evaluating both the current and the future yield, including climate change considerations, to assess the vulnerability of a water source over its service life. Refer to Chapter 2 for further guidance.

For selection of surface water yield (current or future) for approval application, Practitioners may either:

- Adopt the existing yield and reassess the long-term yield during each approval process to ensure regulatory requirements are being met and evaluate changes in water availability. In this case, it is recommended that the approval process require an assessment of the yield in accordance with the criteria below, once every 5 years.
- Adopt the more conservative yield (lowest safe yield) following comparison of the current and future yield, including climate change considerations. This methodology will ensure a more robust long-term water source over the service life of the asset.

Yield assessments should consider the following criteria:

- Where streamflow data exists, mass flow curves should be used to estimate the minimum perennial yield on record, and future minimum yield including climate change considerations.
- A minimum drought return period should be determined based on the site setting and include climate change considerations (e.g., potential increases in the frequency of drought conditions due to increasing temperatures and changes to precipitation patterns).
- Drought conditions should be considered in the calculation of safe yield, including selection and discussion of an appropriate return period.
- A minimum drought duration of 60 days or greater should be determined on a site-specific basis and include climate change considerations (e.g., potential increases in the duration of drought conditions due to increasing temperatures and changes to precipitation patterns).
- Where precipitation data is used to calculate yield, the runoff characteristics should adequately reflect the average conditions of the watershed and include considerations for future development and climate change considerations (e.g., potential changes to precipitation patterns such as the frequency and intensity of rainfall events).
- Future projections for precipitation should account for climate change (e.g., potential changes in the frequency and intensity of rainfall events) when calculating yield (e.g., safe yield).

- All available storage should be considered in all yield calculations.
- The yield should be adequate to meet the maximum and future water demand based on the most extreme drought on record, while not significantly affecting the ecology of the water course downstream of the intake.
- The yield should be adequate to compensate for all losses such as silting, evaporation, seepage, and including considerations for climate change (e.g., potential increases in evaporation rates resulting from projected temperature increases).
- The yield should be adequate to provide ample water for other legal users of the source.

3.1.2 Water Treatability

All drinking water should meet drinking water standards and/or the latest edition of the *Guidelines for Canadian Drinking Water Quality - Summary Table* from Health Canada for the parameters identified by respective provincial Regulatory Authorities.

Surface water and GUDI, where applicable, will require treatment to meet drinking water standards and guidelines. The pre-design investigation should evaluate the treatability of the water using one or both of laboratory scale tests and pilot scale tests. Water quality considerations are an important factor in the overall efficacy and efficiency of a treatment system, impacting system performance and operations such as retention times, chemical dosing rates, filter run times and backwashing operations.

Climate change may impact future water quality. Practitioners should consider potential future changes to water quality, including climate change, when undergoing treatability investigations, (e.g., during the pre-design laboratory or pilot scale testing phases). This will ensure a robust treatment system which provides resiliency to the impacts of climate change on water quality. Climate change impacts on source water quality will be widely variable and dependent on factors such as location, source water, topography, geology, urban development, and small-scale ecosystem interactions. The impact of climate change on water quality should be considered in Source Water Protection (SWP) programs.

The following examples of possible climate change impacts on water quality are provided in order to guide the considerations of practitioners, (i.e., climate factors and interactions when investigating risks to future water quality):

- **Temperature:** Projections for increasing temperatures may result in seasonal increases in surface water temperatures. Warmer water holds less Dissolved Oxygen (DO) making instances of low oxygen levels or “hypoxia” more likely, fosters HABs, alters the toxicity of some pollutants, and impacts stratification and turnover events which may upwell lake sediments and contaminants.
- **Precipitation:** Increases in the frequency of watershed disturbances and intensity of precipitation events (leading to increased runoff) may result in increased sediment, nutrient, and contaminate loading to source water supplies.
- **Flooding:** Potential increases in flood risk from climate change impacts (e.g., sea level rise and heavy precipitation events) which may facilitate increased transport and loading of contaminates to source water supplies.

3.1.2.1 Laboratory Scale Testing Program

As a minimum, a pre-design investigation of an existing or new water supply should include a water quality sampling and treatability testing program in an effort to determine the relative performance of potential processes. The laboratory scale testing program should evaluate the potential impacts on treatment (if any) resulting from changes in water quality (e.g., potential changes in water quality from the impacts of climate change).

Large volume (50 L) samples should be collected from the source. Lab treatability tests conducted to establish the chemical, physical, and biological requirements to produce treated water that meets provincial, federal and or industry drinking water guidelines or standards. The findings of the laboratory treatability testing program can be used to estimate appropriate design parameters of the process equipment, to assist in the concept design of the WTP, and in the determination of a budget cost for the facility.

3.1.2.2 Pilot Scale Treatment Program

A pilot scale treatment program should be conducted where laboratory testing results indicate that several process options are available for the treatment of the water, or where good background performance data does not exist for a specific process train which appears acceptable in a particular water supply. The pilot scale testing program should evaluate the potential impacts on treatment resulting from changes in water quality (e.g., potential changes in water quality from the impacts of climate change).

The pilot scale testing results should be used to confirm that the process can treat the water, and that the operational requirements and costs are acceptable. Piloting should be conducted over a sufficient period of time to enable all seasonal raw water quality fluctuations to be experienced, or to enable an acceptable degree of confidence that the process is capable of dealing with the fluctuations in water quality that are anticipated.

Information regarding, but not necessarily limited to, the following should be collected during a pilot study:

1. Average day, maximum day, and peak design flowrates.
2. Influent and pilot plant effluent quality including:
   - Colour.
   - Turbidity.
   - Temperature.
   - pH.
   - Iron.
   - Manganese.
   - Natural Organic Matter (NOM).
   - Chlorine demand.
   - Trihalomethane (THM) formation potential.
   - Microbiological characteristics.
   - Any other such site-specific water quality data that may be deemed pertinent to the study (e.g., particle counts for membrane pilot studies or other parameters of concern identified in previous treatment studies).
3. Chemical requirements:
   - Chemical types.
   - Dosages.
   - Costs.
4. Coagulation/flocculation requirements:
   - Mixing intensity.
   - Flocculation time.

5. Clarification requirements:
   - Retention times.
   - Surface overflow rate.
   - Plate/tube design criteria.
   - Weir loading rates.
   - Recycle rates, air concentrations and bubble diameters (if applicable).
   - Sludge flows and concentrations.
6. Filtration requirements:
   - Filtration rates and/or flux rates.
   - Headloss development and filter run times.
   - Media types and specifications.
   - Membrane materials (if applicable).
   - Backwash and requirements including:
     - Air scour.
     - Flowrate
     - Backwash water quality.
   - Reject characteristics including flowrates and quality (if applicable).
   - Scraping frequency and filter ripening periods (e.g., slow sand filtration).
7. Disinfection systems:
   - Chlorine demand.
   - Contact Times (CT).
   - Residuals.
   - Disinfection By-Product Formation Potential (DBPfp).
   - Intensity (Ultraviolet (UV) systems only).
   - Inactivation.
8. Aeration systems:
   - Air loading and/or flowrates.
   - Mixing requirements.
   - Pressure requirements.
   - Removal efficiencies.
9. Residuals handling and treatment:
   - Characterization of residual streams including:
     - Sources.
     - Flows.
     - Solids content.
     - Chemical, physical, and microbiological quality.
   - Treatment requirements including:
     - Equalization.
     - Chemical addition.
     - Effluent quality.
     - Clarification requirements.
   - Recycling feasibility.

3.1.3 Required Intake Facility

The minimum required intake facility for a surface water supply includes, but is not limited to, the following:

- A reservoir or impoundment that provides a water supply of adequate quantity and quality, including climate change considerations (i.e., potential impacts to yield and water quality).
- An intake structure with a screen that meets DFO intake velocity requirements.
- An intake that is set at an optimum depth to draw water of highest quality, including climate change considerations (e.g., selection of intake depth which accounts for potential increasing seasonal surface water temperatures, and low water levels during periods of drought).
- An intake that will not be vulnerable to drought conditions, including the impacts of climate change (e.g., decreasing intake depth to account for potential increases in the frequency and duration of drought conditions contributing to low flow and water level conditions).
- Consideration of redundancy.
- A method by which to clean the screen and/or the intake.
- Located sufficient distance from shore to avoid shore wash influence/build-up of debris.

3.1.4 Impoundments & Reservoirs

Impoundments and reservoirs should meet the following general requirements:

- Should be of sufficient volume to sustain, if possible, the 1-in-50-year yield without significant drawdown (the volume should be confirmed by bathymetric survey at least once in 20 years).
- Should have fish ladders or fish passages where stipulated by the Regulatory Authority having jurisdiction.
- The hydraulic structure should be designed in accordance with the latest edition of the *Dam Safety Guidelines* from the Canadian Dam Association, or the Regulatory Authority having jurisdiction.
- The site should be made as secure as is reasonably possible using fencing, signage, and patrolling/policing, if necessary.

3.2 Groundwater Supply

Provincial regulations determine the siting and construction requirements for water wells. Specific requirements concerning the casing and annular seal, setbacks, driller and assessor qualifications, exploratory permits, and yield assessment should be consulted prior to any intrusive work. Additional guidance documents on aquifer testing and yield assessment are provided by each province.

The well field should be capable of supplying the maximum day demand with one well out of service. Two (2) wells capable of pumping simultaneously will offer operational advantages, but in settings where this is not possible, wells may be twinned at the same site. The goal of the redundant supply is to ensure a consistent rate of flow and water quality, regardless of which well is pumped. To maintain consistency, all active wells in the system should be used regularly, if possible, on an equal basis. Less active wells should be flushed or operated for a minimum of 2 hours at least once every 7 days.

Groundwater sources may be impacted by low flow periods during increased drought conditions and increases in evapotranspiration and precipitation intensity which may lead to decreased recharge. Potential decreases in aquifer recharge may result in increased drawdown impacting allowable pumping rates and well performance. Coastally located groundwater supplies may be impacted from saltwater intrusion (e.g., increased salinity) facilitated by sea level rise and shifting of the freshwater-saltwater interface.

The impacts of climate change on groundwater supply sources will vary widely depending on factors such as location, geology, and the type, size, and depth of the aquifer. Depending on the depth and size of the aquifer, climate change impacts may not be discernible for decades due to the generally slow rate of groundwater recharge. For example, drilled wells drawing water from deep, regional aquifers may not experience the impacts of climate change over the normal operational lifetime of the well (i.e., 20 to 40 years). Substantial changes to hydraulic head in larger aquifers would most likely be required before interference with a municipal well may be of concern. As recharge and travel times are quicker for surficial aquifers, any reductions to aquifer recharge or hydraulic head would be experienced first within dug wells or wells installed in shallower sand and gravel aquifers. Depending on the availability of a productive bedrock unit underlying surficial materials, some dug well users may be able to replace dug wells with a new, deeper drilled well.

3.2.1 Location

The availability of municipally owned land or proximity to the distribution system should not be the only criteria used in selection of test drilling locations. Emphasis should be placed on hydrogeology and suitability for long term management of source water.

A well siting study should be completed prior to exploratory drilling. The well siting study should consider:

- Topography and drainage, including climate change considerations (e.g., sea level rise and increased intensity of precipitation events may increase flood risk).
- Geology mapping.
- Existing water well records.
- Aquifer hydraulic properties and distribution.
- Beneficial confining units.
- Baseline/background groundwater quality.
- Proximity and potential connection to surface water.
- Expected groundwater flow directions and groundwater flow divides.
- Proximity to the coastline and elevation (in low lying areas), including climate change considerations (e.g., the potential for sea level rise to impact flood risk and the position of the freshwater-saltwater interface).
- Land uses in source water zones, including the impacts of climate change on the footprint of urban infrastructure and potential contaminant sources (e.g., potential for increased flood risk).
- Distance from existing production wells.
- Cost of transmission.

Avoidance of potential contaminant sources and interference with other well users are important considerations when locating new supply wells.

Municipal wells should be hydraulically up-gradient and/or have sufficient setbacks from potential contaminant sources. Required separation distances are based on the Time of Travel (TOT) to the well, and the persistence of the contaminant source. Further guidance on SWPs is provided in Section 3.3.

Land uses of concern, include:

- Agricultural sources (runoff from pastures or feed lots, fertilized fields, manure storage areas and intensive pesticide use areas).
- Landfills or waste management facilities.

- Cemeteries.
- Bulk storage of liquids (service stations, dry cleaners, bulk plants, heating oil).
- Roads and highways (road salt runoff, accidental chemical releases).
- Mines and quarries (stored mine water, acid mine drainage, heavy metals from tailings, mine dewatering activities).
- Residential communities individually serviced that could expand.
- Wastewater treatment plants.
- Industrial activities (manufacturing or processing facilities).

Required setbacks are legislated as a part of water well regulations in each province (e.g., wastewater pipelines, on-site wastewater disposal systems, petroleum storage tanks, roads, and waste management facilities).

Proximity to streams and lakes can affect a well's vulnerability to pathogens. The degree of interaction between well field pumping and stream base flows must be addressed through well location, casing length, monitoring of groundwater and stream flow responses, and water quality monitoring. Wells that must be located close to surface water require an assessment of GUDI. Best practices for well site selection include a screening-level GUDI assessment of any new groundwater supply; in some jurisdictions this assessment is a requirement. Pending the results of the screening-level assessment, additional steps may be required. Updated and expanded guidance on assessments for groundwater at risk of containing pathogens are available in other jurisdictions

The location of production wells may also consider the long-term sustainable yield of the host aquifer. A watershed scale water-balance approach (including climate change considerations) or groundwater modeling approach should be applied that considers climate including climate change, and groundwater and surface water interaction over the anticipated lifetime of the well field. In situations where large quantities of groundwater are required, it may be necessary to locate new wells within a different catchment area to avoid exceeding the aquifer recharge rate. If new wells are being added to an existing well field, potential locations should consider interference between new and existing wells. Such effects can have impacts on well performance and long-term operating costs of existing, new and/or future wells.

Identification of a suitable municipal well field location should consider the need for additional wells, based upon growth in water supply demand. Future land use and long term well head protection should also be a factor in selection of a suitable location.

In addition to the hydrogeological considerations of well or well field location, a public participation process may be needed to identify the public's concerns, identify existing land uses and potential hazards, and to assure surrounding well users that their supplies will not be compromised.

3.2.2 Exploration Program

A groundwater supply exploration program will help to confirm the quantity and quality of groundwater available within a target area. The program scope will be determined by previous testing work within the area, potential supply source and water supply requirements.

Test drilling should be supervised by a qualified hydrogeologist to ensure that all available geological and hydrogeological information is properly documented. In bedrock, water well drilling equipment will be used for test drilling. The minimum test hole diameter should be 150 mm in areas that have not been previously investigated, to allow for pumping tests. Depending on the well setting and goals of the investigation, test holes with a minimum diameter of 200 mm may be more appropriate, as larger diameter pumps are often required to test at municipal-scale pumping rates. If a 150 mm diameter test well is used, it can be re-drilled as a larger diameter municipal production well.

For screened wells within unconsolidated materials, geotechnical rigs offer some advantages in collecting representative samples of the aquifer material. Air rotary water well rigs may offer other methods to improve sample collection (e.g., cyclone). Provided that the samples obtained are deemed representative of the formation, they may be used to design the well screen. In such cases, and once the screen design is complete, water well drilling equipment will be used to install the screened test well.

During construction of each exploration well, a detailed log should be made to show the following:
- Borehole lithology and stratigraphy.
- Location of water-bearing zones.
- Cumulative air-lifted well yield.

Upon completion of each exploration well, the well should be developed by the driller for a minimum 2-hour period with an air lift “blow” test to estimate total yield. A preliminary water quality sample may be taken and analyzed for the full suite of health and aesthetic related parameters to confirm the presence of suitable water quality. If the well has not been developed, turbidity can affect the analytical results of unfiltered samples. Filtered samples may be more appropriate for turbid samples collected at this early stage of exploration.

The completion of exploratory wells will allow for the assessment of aquifer characteristics, and will ultimately allow for proper production well design, spacing of wells and pump selection. The well driller should take precautions to prevent a well from flowing out of control, particularly in areas that have a history of flowing wells.

3.2.3 Well & Aquifer Hydraulic Testing

Well and/or aquifer hydraulic testing requirements vary by province, and the respective Regulatory Authority should be contacted to determine the system-specific requirements. Hydraulic testing generally consists of the following three components:
- Step-testing, to establish the well’s preliminary yield and drawdown efficiency (minimum of three 1-hour steps).
- Constant-rate testing for at least 24 hours, or as specified by the Regulatory Authority (completed production wells generally require a 72-hour test).
- Recovery monitoring until well recovers to 95% of the static water level, or as specified by the Regulatory Authority, after completion of the constant-rate test.

All hydraulic testing should be supervised by a qualified hydrogeologist to ensure the testing is properly conducted and that all necessary data is obtained. In most cases one or more observation wells must be monitored during hydraulic testing, in addition to the pumped well. The pumping rate should be measured and maintained using an in-line totalizing flow meter. The following parameters must be monitored and recorded:
- Water level.
- Calculated drawdown.

- Flow meter reading (volume).
- Calculated pumping rate between readings.

If possible, the temperature, pH, and specific conductance (electrolytic conductivity) of the discharged water should be measured at regular intervals using a hand-held meter.

Hydraulic testing documentation should include:
- Well owner and location details for all wells involved, including civic address, site location map, and site plan.
- Pumping test contractor or sub-consultant details.
- Well identification and construction details (depth, diameter, casing stick up), top of casing elevation Meters Above Sea Level (mASL).
- Well construction log and provincial Regulatory Authority well log number.
- Pumping test set-up details (pump size, pump elevation, riser pipe size, flowrate control, static water levels, pumping discharge location).
- Type of test (step, constant rate, recovery).
- Number of observation wells, location (Universal Transverse Mercator (UTM) coordinates) and construction details.
- Data source (pumping well, observation well, stream station).
- Date and time of day when pumping started and ended.
- Static water levels for pumping well and all available observations wells.
- Separation distances between pumping well and all observation wells.
- Plots of time-drawdown and time recovery data.
- Water chemistry sampling and laboratory chain of custody forms.
- Log of field observations including metering data to show flowrate adjustments and field measurements of discharge water quality.

Water quality samples should be collected during the constant-rate test at the following intervals:
- Within the first hour.
- Mid-point.
- At the end of the test.

A typical sampling protocol is outlined in Table 3.1. A comprehensive set of analyses should be completed on the 72-hour sample to screen for a broader list of possible contaminants, including bacteria. Bacteria testing should be included in all three samples if GUDI conditions are known or suspected. Official sampling protocols should be obtained from the Regulatory Authority.

Table 3.1: Typical Sampling Protocol - Groundwater Quality Parameters

	Sample 1 (First Hour)	Sample 2 (Mid-point)	Sample 3 (End of test)
Recommended Analytical Parameter Group (The number of parameters within some analytical parameter groups may vary slightly between laboratories).	Major ions, trace metals, chemical-physical parameters[1] TSS[8]	Major ions, trace metals, chemical-physical parameters[1] TSS[8]	Major ions, trace metals, chemical-physical parameters[1] TSS[8] EPA 624[2] Total coliform/*E. coli*[3] The following tests may be included if warranted, based on the well field setting: EPA 625[4] Pesticides (OCOP)[5] Gross Alpha, Beta & Gamma[6, 7]

Notes:

1. Parameter lists vary by lab but should include parameters with drinking water guideline limits (i.e., sodium, chloride, sulphate, nitrate, antimony, arsenic, barium, boron, cadmium, chromium, copper, iron, lead, manganese, selenium, strontium, uranium, zinc.) Analysis of all parameters with guideline values may be required by some jurisdictions.
2. EPA 624: a series of 35 Volatile Organic Compounds (VOCs), including BTEX (Benzene, Toluene, Ethyl Benzene and Xylenes) parameters: indicators of petroleum hydrocarbon contamination).
3. Bacteria analyses must include the bacteria count, not just presence/absence.
4. EPA 625: a series of 54 semi-VOCs.
5. Organochlorine Pesticides (OCOP) Pesticides: a series of 19 organochlorine and 48 organophosphate pesticides.
6. Gross alpha, beta and gamma used as indicators, if elevated, a series of 17 radionuclides is analyzed.
7. Lead: 210 may be required instead.
8. TSS: Total Suspended Solids.

Hydraulic test results including all time-drawdown, time-recovery, and water quality monitoring data, should be clearly documented on appropriate forms, and analyzed by a qualified hydrogeologist.

Analysis of hydraulic response data should be completed using recognized standard procedures (e.g., Theis, Theis-Recovery, Cooper-Jacob, Hantush-Jacob, Hantush-Bierschenk Well Loss), as found in standard reference texts. These procedures may be either applied using manual or electronic methods. Depending on the scope and scale of the pumping test, the analysis should determine:

- Transmissivity and storage coefficient of the aquifer (from observation well data).
- Calculated long-term sustainable pumping rate for the production well(s) (i.e., Q20 or equivalent).
- Potential range of operational pumping levels for intended well or well field pumping scenario.
- Recommended pump setting.
- Estimate drawdown interference between production wells.
- Estimate drawdown interference between the well field and the nearest domestic wells.
- Estimate zone of influence for each production well using observation well data.
- Estimate sustainable aquifer yield using observation well and water balance approaches.
- Interpret water quality data with respect to drinking water standards and guidelines.

- Discuss disinfection requirements.
- List parameters which may require treatment.

The recommended pumping rate, along with projected time-drawdown data, should be used in pump selection and setting specifications. If appropriate, additional long-term testing may also be included as part of the well commissioning process.

Hydraulic testing data and analysis, including water quality results, should be submitted to the Regulatory Authority and System Owner.

The results of well drilling and hydraulic testing are typically submitted to the provincial Regulatory Authority, as a part of an approval process. Regulation of groundwater supplies may include a withdrawal permit and associated monitoring/reporting requirements.

3.2.4 Groundwater Quality

Groundwater quality is monitored at various stages throughout well field development work. Groundwater quality data:

- Are compared to the latest edition of the *Guidelines for Canadian Drinking Water Quality - Summary Table* from Health Canada and any additional guidelines as stipulated by the local Regulatory Authority.
- Show the suitability of the raw water source for use in municipal drinking water supply.
- Provide indications of well vulnerability to pathogens, and associated disinfection requirements.
- Show parameters that require treatment (if any).
- Show any changes that may occur as a result of pumping.
- Provide evidence of contaminant sources that were not identifiable as part of the well siting study.

The Regulatory Authority should be consulted for advice on use of other criteria where there is a presence of chemical parameters for which no *Guidelines for Canadian Drinking Water Quality - Summary Table* from Health Canada values exist.

If the *Guidelines for Canadian Drinking Water Quality - Summary Table* from Health Canada values are exceeded, the hydrogeologist should indicate if this represents one or more of the following:

- A pre-existing condition within the aquifer related to:
  - The aquifer material (e.g., gypsum, arsenic, iron, manganese, and uranium).
  - Drawdown effects (e.g., hardness, dissolved solids, and redox changes).
  - Groundwater-surface water interactions (e.g., stream, lake, wetland, or seawater intrusion).
- Point-source contaminant sources (e.g., service station, dry cleaning store, and landfill).
- Non-point source contaminant sources (e.g., agriculture and road salting).

The results of this assessment should be included in the hydraulic testing report.

All quality testing associated with a groundwater supply should be performed by a laboratory accredited to the latest edition of *ISO/IEC 17025 Testing and Calibration Laboratories* by the Standards Council of Canada (SCC), the Canadian Association for Laboratory Accreditation Inc. (CALA), or accreditation to the latest edition of the *ISO/IEC 17025 Testing and Calibration Laboratories* from the International Organization for Standardization from another body that is recognized to grant such accreditation per the latest edition of the *ISO/IEC 17011*

Conformity assessment - Requirements for accreditation bodies accrediting conformity assessment bodies criteria for the individual parameters tested. Consult with the provincial Regulatory Authority to determine further requirements (e.g., provincial registration, acknowledgment, and memorandum of understanding).

3.2.5 Disinfection & Treatment

All raw municipal groundwater sources require chemical disinfection to ensure that viruses and bacteria are inactivated. Hypochlorite is a common disinfectant, providing pathogen inactivation both at the source and within the distribution system. Known or suspected GUDI sources may require additional disinfection, such as UV irradiation, which provides inactivation of protozoa (e.g., *Giardia* and *Cryptosporidium*). If the source water turbidity is elevated, chemically assisted Microfiltration (MF) may be needed. Barring system-specific exceptions, groundwater should be disinfected as outlined in Section 5.5.

Non-pathogenic parameters may require treatment systems. Systems to remove parameters such as hardness, iron, manganese, arsenic, uranium, or radiological substances, must be selected on a case-by-case basis. Common technologies include softening (ion exchange), greensand filtration, Reverse Osmosis (RO), and anion or cation exchange resins. Additional water quality sampling may be required before the treatment process can be designed. Where multiple wells are proposed, blending characteristics of the water should be considered.

3.2.6 Well Construction

Provincial well construction regulations require that water wells are constructed by a water well driller or well digger who is licensed in the province of jurisdiction.

Wells addressed by these Guidelines include wells drilled in bedrock and wells screened in unconsolidated materials. Other groundwater sources such as dug wells, sand points and springs, may be considered by local jurisdictions based on project detail and local conditions. Dug wells, sand points, and springs commonly draw groundwater under the direct influence of surface water and may require treatment in compliance with surface water (i.e., GUDI wells) standards.

All well construction work should be properly supervised by qualified personnel. A log of each well should be prepared following regulatory requirements, showing the borehole lithology and stratigraphy, and well construction details (e.g., casing, open borehole or screen, slot-size, etc.). A copy of each well log should be provided to the Regulatory Authority and to the System Owner.

At a minimum, well construction must satisfy provincial regulations. Additional guidance may be found in the latest edition of *A100-97: AWWA Standard for Water Wells*, and the latest edition of *NGWA 01-14 Water Well Construction Standard* from the National Groundwater Association (NGWA).

Figure 3.1 provides an example of open-borehole well construction, and Figure 3.2 provides an example of screened well construction.

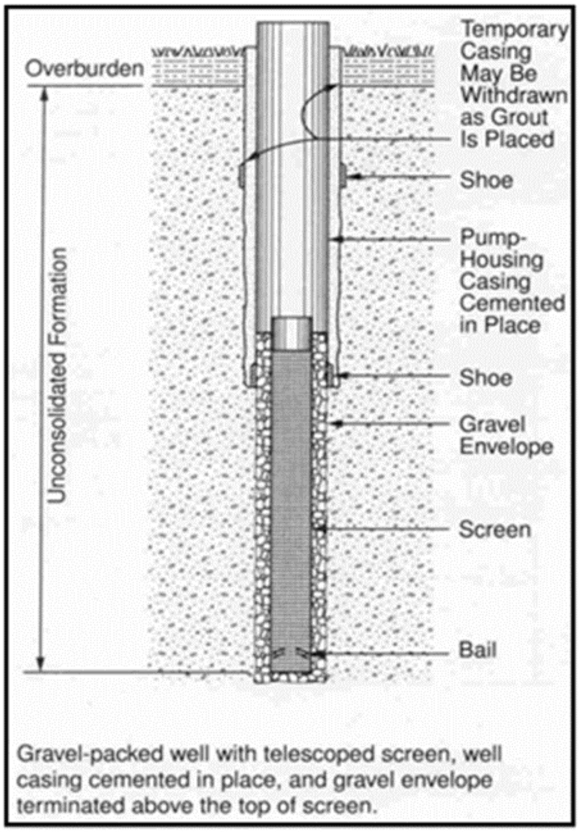

Figure 3.1: Example of Screened Well Construction

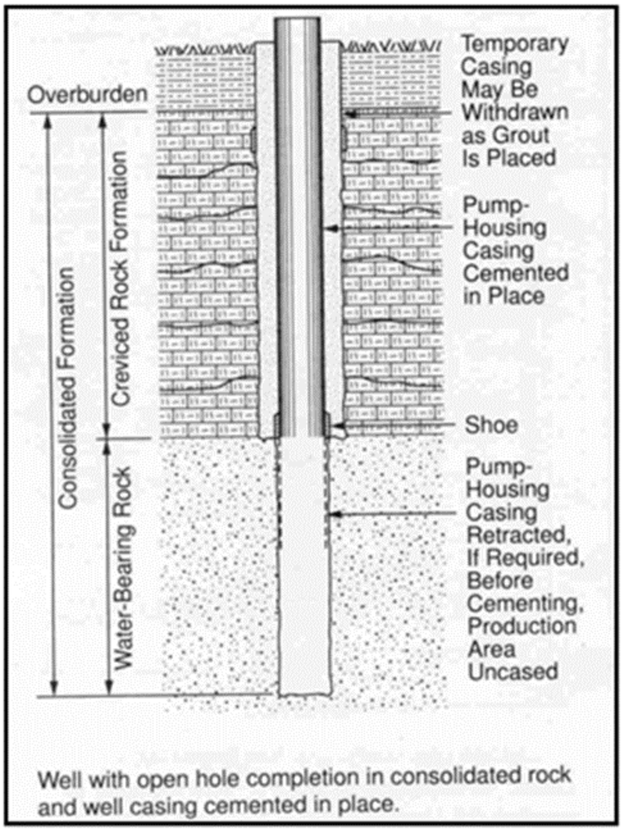

Figure 3.2: Example of Open-Borehole Well Construction

*Both Figure 3.1 and Figure 3.2 are from *A100-97: AWWA Standard for Water Wells* from the AWWA.

All wells will be straight and meet plumbness requirements, as specified by AWWA. Toxic fluids should not be used in the construction of wells. Use of any additives other than water, during well construction must be approved by the Regulatory Authority.

3.2.6.1 Casing

Casing provides the first level of protection to the water supply system from potential contaminants originating at the ground surface.

Permanent steel or nonferrous casing pipe should meet AWWA or American Society for Testing and Materials (ASTM) specifications, or Regulatory Authority requirements.

New casing should be used for all municipal wells. Used casing pipe may only be used for exploration well or monitor well construction with approval of the Regulatory Authority. Temporary casing, if used during well construction, should be removed prior to well completion.

The well and casing diameters should be based on the intended use (production or observation well), anticipated flowrates, pumping equipment specifications, well head completion appurtenances, and screen-liner requirements. Typical well completion diameters for municipal wells should be 200 mm, 250 mm, and 300 mm.

The minimum casing diameter should be 200 mm to provide sufficient size for pumps and monitoring devices, and contingency for possible future liner installation.

Minimum casing lengths are specified in provincial water well regulations. A new casing shoe should be used in construction of all municipal wells, unless directed otherwise by the hydrogeologist (e.g., temporary casings and outer grouted casings).

3.2.6.2 Stabilization Liners & Screens

Permanent steel or nonferrous stabilizing liners may be required in bedrock where the borehole or water bearing formation is not stable. Stabilizer liners should consist of one of the following:

- Steel or Polyvinyl Chloride (PVC) pipe one nominal diameter smaller than the casing diameter with slotted zones across major water-bearing zones.
- Continuously slotted pipe or stainless-steel wire-wrapped screen.
- Gravel filter-pack stabilization with a pipe and screen liner with sand or gravel filling an annular space between the liner and the borehole walls.

Design, installation, and hydraulic development of stabilization liners will be directed by a qualified hydrogeologist.

3.2.6.3 Grouting

Placement of an annular seal is a requirement in jurisdictions of Atlantic Canada. Grouting is recommended in AWWA and NGWA specifications. Grout is placed to ensure that the annular space is sealed, and that the potential for a short-circuit pathway between the ground surface and the well intake is minimized.

Grout should generally consist of 25 to 30% by volume bentonite clay, unless otherwise requested or approved by the Regulatory Authority. In selected circumstances (e.g., low water table), a concrete surface seal may be preferred. Grout should be introduced under pressure from the bottom upward in a continuous operation to ensure a complete seal. Grout should be installed using a pump, using the tremie method for larger wells, or by positive displacement method for smaller wells. Grout should extend from the bottom of the casing to a point immediately below the pitless adapter connection. A minimum borehole annulus of 50 mm is recommended.

3.2.6.4 Well Screens

All screened wells must be properly designed, based upon AWWA or other specifications, as approved by the Regulatory Authority. Only new, manufactured wire-wound V-notch stainless steel screens should be used.

Screen slot sizes should be designed based on grain size gradation data and depending on whether the filter pack is to be developed in-place or constructed. The diameter, length and slot size(s) should be designed to maximize pumping efficiency based on the aquifer hydraulic properties and the required well yield. Slot sizes should be checked using entrance velocity calculations to minimize deterioration of the screen.

Either pipe-sized or telescopic types of screens may be used in screened well construction. For telescopic screens, an elastomeric seal (i.e., a ‘Figure-K’ packer) should be installed and extended at least 1.5 m into the overlying permanent casing. No lead packers should be used. All telescopic screens should be equipped with a bail-bottom.

Constructed filter pack materials will be new, clean-washed material. Material size should be specified based upon grain size analysis of samples from the formation in which the screened well is installed. A minimum annular space of 50 mm will be used around the screen for installation of the filter pack.

3.2.6.5 Well Development

All wells should be sufficiently developed by surging or bailing to optimize yield and water quality, and to render the borehole as hydraulically efficient as is practical. Development will meet AWWA specifications, or as directed by the hydrogeologist.

3.2.6.6 Disinfection

Upon completion, all wells should be disinfected with a chlorine solution to remove microbial pathogens that may have been introduced during well construction. The Regulatory Authority should be contacted regarding chlorination procedures and the requirements for the disposal of chlorinated water. Effective disinfection requires that a conductor pipe is used to pump the solution to the bottom of the well.

3.2.6.7 Decommissioning

An open or unused well is a potential liability to any well field. Unless used for monitoring, all test holes, wells or partially completed wells should be properly decommissioned in accordance with the requirements of the Regulatory Authority.

All pumps, wire, and piping will be removed from the borehole. Prior to sealing, the well depth should be confirmed to check for obstructions or partial formation collapse. If obstructions are encountered, they should be removed prior to decommissioning.

Cement grout or bentonite should be used as sealing materials. Placement should be from bottom upward, by methods that avoid segregation or dilution of material. Decommissioning may involve alternate placement of grout and clean silica aggregate in a manner that simulates the natural formation stratigraphy and prevents vertical movement of groundwater along the borehole between water-bearing formations or fractures. Well decommissioning should be supervised by qualified personnel and follow provincial guidelines where present.

If the casing is to be left in place, the grout should extend across the bottom of the casing.

Decommissioning procedures should be documented and provided to the Regulatory Authority for review and approval.

3.2.7 Pump Hydraulics

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

- Well and/or casing diameter.
- Recommended pumping rate for sustainable well operation.
- Calculated or observed water level from pumping test(s).
- Total Dynamic Head (TDH) and vertical lift requirements.
- Friction/head losses.

- Service pressure.
- Long-term power requirements.

Wells should be equipped with either submersible or vertical turbine line shaft pumps.

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

3.2.8 Wellhead Requirements

Wellheads should be completed above grade. The design of the wellhead should be based on the following:

- Presence of existing facilities (e.g., treatment, monitoring, and telemetry).
- Design of associated distribution control and/or treatment plants.
- Water level conditions or artesian pressure.
- Well maintenance and/or servicing requirements.
- Wellhead flow metering.
- Capacity for manual water level monitoring.
- Capacity for water sample collection at the well head.
- Well instrumentation requirements (e.g., water level tube, down-hole pressure/water level transducers for Supervisory Control and Data Acquisition (SCADA) monitoring, and telemetry).
- Provincial well construction regulatory requirements.
- Height of well head in regard to flood plain elevation and projected water depths

All well heads must be clearly accessible for routine pump servicing and well rehabilitation by heavy equipment.

A pitless adapter well head completion is preferred and is recommended in cases where high water table or flooding risk occurs. Design will allow for a properly constructed, watertight and vermin-proof casing vent.

Provision should be made for manual monitoring of water levels within a separate access tube (i.e., minimum 25 mm Internal Diameter (ID)) attached to the pump riser assembly in each production well. A separate tube should also be used for installation of down-hole pressure (water level) transducers for SCADA monitoring.

3.2.8.1 Discharge Piping

Discharge or riser piping should meet the latest edition of AWWA or ASTM specifications for water supply pipes.

Discharge piping should be designed to minimize friction losses, and be equipped with the following:

- Check valve.
- Shut-off valve.
- Pressure gauge.
- Total or accumulating flow meter.
- In-line water sampling tap located where positive pressure is maintained.

Flow regulation control valves should be provided to permit routine specific capacity pumping tests and flow control at each well.

Discharge piping will be provided with a means of pumping the well to waste. This is an important precaution to be applied when a well has been “rested” for a period of time, to prevent release of sediment and discolouration into the distribution lines.

Discharge piping should be protected against entrance of contaminants. The production well top of casing elevation will be above the flood level for the relevant return period, including climate change considerations (refer to Chapter 2 for further guidance).

Where above-ground discharge is provided, control values should be located above the pump house floor. Exposed piping, valves and appurtenances should be protected against freezing and physical damage.

3.2.8.2 Pitless Well Head Completion

Shop-fabricated pitless adapter units constructed of materials and weighing at least equivalent or comparable to the well casing, should be used for wellhead completions.

Pitless adapter units should be of watertight construction to prevent entrance of contaminants and should be installed at an elevation that is above the 1-in-100-year flood level, including climate change considerations (refer to Chapter 2 for further guidance). Pitless units should make provision for an access tube within which water levels can be independently measured.

3.2.9 Monitoring

Although detailed well head and aquifer protection planning is not included in these Guidelines, it is recommended that a well field completion include a provision for routine surveillance of water levels and water quality in both the pumping well and the host aquifer. The Regulatory Authority should be contacted for their requirements.

Continuous and consistent monitoring of well performance and yield would typically provide the earliest and best indications of changes to groundwater sources resulting from ongoing climate change. This would require accurate and detailed records of pumping rates, schedules, and water levels in the well(s). Efforts to reassess the aquifer yield would need to account for declines in well performance associated with aging screens, pumps, and system infrastructure. Assessments of aquifer yield may also be updated through aquifer testing, water budget calculations, and/or numerical modelling.

3.2.9.1 Observation Wells

Provision should be made for an appropriate number of observation or monitoring wells. The intent of such wells is to allow appropriate monitoring of production well performance, to confirm the extent of the cone of influence and drawdown interference between wells, and to detect potential migration of contaminants toward the well.

Design of observation wells will be generally similar to the criteria used for the production wells. Wells drilled during the exploration program can be used or renovated for use as observation wells. At a minimum, all monitoring wells should have 12 m of casing, completed with above-grade water-tight, vermin-proof caps. All well heads must be above the flood level for the relevant return period, including climate change considerations (refer to Chapter 2 for further guidance). Depending on the well field setting, the use of 25 mm or 50 mm PVC monitoring wells may also be appropriate.

The required number and location of observation wells should be based on hydraulic testing results. Ideally, one observation well should be located within 10 m of each production well to assess production well efficiencies and long-term well performance.

At least one monitoring well should be located at the mid-point of all production wells, for surveillance of long term and seasonal water level responses within the aquifer. This monitoring well should be equipped with an automated logging pressure transducer.

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

3.2.9.2 Commissioning

Commissioning of new wells should take place following connection to the distribution system and installation of all well appurtenances. Operation and performance of all well system components should be checked against the system design.

During commissioning, further yield and time-drawdown data may be collected, to support calculated sustained yields and predicted pumping levels, and/or to confirm groundwater quality results. The groundwater quality results should be demonstrated to the Regulatory Authority. These results may be used to finalize the operational groundwater monitoring plan.

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

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

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

3.3 Source Water Protection

The protection of source water is an essential component of water supply development. Each province provides specific guidance on the protection of a raw water source that provides public drinking water. Source water protection planning is intended to strike an appropriate balance between individual interests and land uses, and the preservation and protection of water to be used as a public drinking water supply. Procedures vary for surface water and groundwater sources. Source water protection forms the first step of the multi-barrier approach:

- Protect the source using a Source Water Protection Plan (SWPP).
- Provide a certified operator.
- Provide treatment and/or disinfection.
- Monitor raw and treated water quality.

- Reporting and regulations.
- Provide operator continuing education.

Typical components of a SWPP include:

- An inventory and characterization of the source, including delineation of the source water area.
- An inventory of all land uses within the source water area to identify potential sources of contamination.
- Assessment of risk that various land uses may pose to the water supply.
- Implementation of strategies to reduce risk.
- Monitoring of the source water area.
- Stakeholder outreach and education.
- Delineation and mapping of the Source Water Protection Area (SWPA).
  - For surface water supplies the SWPA is commonly based on the watershed boundary.
  - For groundwater supplies the SWPA is delineated using time-of-travel capture zones.
  - Other common terms for groundwater SWPAs are well head protection areas or well field protection areas.
- A risk analysis and property-specific risk tables.
- A monitoring plan.
- Education and outreach to landowners and the public (including signage).
- Inspection and enforcement (in select cases).
- An ERP/CP for chemical spills or releases of pathogens to the environment.

In some jurisdictions SWPPs are administered by a SWP Committee, composed of System Owners, operators, municipal staff, Regulatory Authorities, planners, community stakeholders, landowners, and technical specialists. The committee would conduct regular meetings to discuss monitoring data and activity within the SWPA. In other cases, an SWPA may be registered within a provincial act, specifying the boundaries of the SWPA, any applicable subdivisions or zones, and permissible land uses or restrictions within each zone. Strategies for SWP should consider the potential for the System Owner or governing body to acquire key parcels of land where feasible. Strategies for SWP and identification of water supply risks should consider the impacts of climate change (refer to Chapter 2 for further guidance).

3.3.1 Delineation of Surface Water Protection Areas

The area contributing to a surface water source includes all tributaries and water bodies within the same watershed, basin, or catchment area for the water body. A watershed boundary is typically defined in relation to a specific outlet or discharge point, includes all upstream areas, and does not cross streams or water bodies except at the outlet. The Regulatory Authority should be consulted for acceptable methods of delineation. In many cases watershed mapping is available or is performed by government specialists.

Methods for delineation may include manual analysis of topographic mapping or Geographic Information System Mapping (GIS) analysis of digital elevation data. The appropriate scale for topographic mapping is no greater than 1:50,000, with a preference for more detailed mapping if available (e.g., 1:10,000). A SWPA may be based directly on the watershed boundary, or it may be modified to account for property mapping and/or potential contaminant sources located near the watershed boundary. The regulating body will determine if seasonal brooks, ditches, and small wetlands should be excluded from this process on a case-by-case basis.

In some jurisdictions the SWPA may be subdivided into zones, such as the water course itself, a watercourse buffer, and the entirety of the watershed. Restrictions would be most restrictive within the watercourse, at an intermediate level within the buffer, and lower in the outlying areas of the watershed. Restrictions may apply to activities such as watercraft and swimming, water crossings, new developments, camping, modification of dwellings, on-site wastewater disposal, tree harvesting, agricultural activity, and industrial and commercial land uses.

Delineation of the SWPA should include an inventory of the following:

- Watershed area.
- Water surface area.
- Applicable buffer area.
- Municipal, provincial, federal, and private ownership allocations (if applicable).
- Roads and highways.
- Dwellings.
- Current and past land usage.

3.3.2 Delineation of Groundwater Protection Areas

Groundwater SWPAs are based on capture zones that are delineated using TOT calculations. The outer boundary of a SWPA is associated with the longest considered travel time for contaminants of concern. Typical travel times are on the order of 20 years from the outer edge of the zone to the well head. SWPAs are often delineated aerially in two dimensions, and do not account for vertical travel time through the unsaturated zone and any saturated aquitards. The additional travel time that would be required for vertical travel through these zones introduces further degrees of safety for the well field. Source water protection zones may incorporate other factors such as land-use and aquifer vulnerability. Climate change should be considered when defining SWP zones and assessing the aquifer vulnerability. Potential influences may include, but are not limited to, the recharge rate and the potential for flooding. If numerical modelling is used the sensitivity analysis should include varying recharge rates.

Capture zones for larger municipal supplies are often delineated using 3D numerical models. For smaller public supplies, and in less complex settings, a 2D-analytic approach may be adequate. Analytic solutions to delineate a 2D SWPA are formulated based on the equations of radial flow to a well in the presence of a 1D ambient groundwater flow field. Both the pumping rate and the ambient flow field can influence the size and shape of the SWPA.

3.3.3 Risk Analysis

The level of risk to drinking water varies according to the Contaminant of Concern (COC) and increases in areas closer to the well or intake, where travel times are shorter. Some contaminants are more persistent or are transported in the environment more readily, and others are attenuated due to their unique properties. Some contaminants pose an immediate threat to life and health (pathogens), some are a threat based on long-term exposure (e.g., BTEX), and some merely render the water non-potable (e.g., salt).

Source water protection planning must balance the need to protect drinking water with pre-existing land uses and the interests of landowners. Although the most conservative approach would be to allow only water production within a SWPA, this is seldom practical. A risk-based and prioritized approach provides a way to manage the interests of stakeholders.

Risk-based management means that the most dangerous substances are restricted in zones closest to the well or intake. Land uses associated with COCs that pose a lower health risk, and those which are less likely to reach the well or intake, are generally manageable in the outer zones of a SWPA. Risk tables may be developed in order to assist the SWP Committee in assessing risk and preparing and administering a SWPP.

3.3.4 Monitoring Plan

The monitoring plan should provide a detailed schedule for data collection and reporting of:

- Daily volume pumped from individual sources.
- Daily maximum and minimum water levels.
- Water quality sampling at the source.
- Water quality sampling from upstream areas or observation wells.
- Inspection of the SWPA, including condition of the watershed (e.g., noting the occurrence of disturbances within the SWPA such as hurricanes, blowdown events, flooding, forest fires, insects and pests, and major watercourse alterations).
- The occurrence of incidences, or identified vulnerabilities/risks to water systems assets, which may worsen from the impacts of climate change (refer to Chapter 2 for further guidance).

Water quality samples are collected to provide an early warning of potential COCs that could be drawn into a water supply. Water quality samples may include both surface water and groundwater sampling stations.

If potential contaminants were to be detected by sampling, aspects of the ERP/CP would be invoked. In most cases (as for organochlorines and VOCs), any detectable concentration of COCs would be a trigger for further action. Where background ions and trace metals are concerned, on-going awareness of background levels and trends is essential.

Activity within a SWPA should be assessed on a semi-annual basis, most likely concurrent to water sampling activities. The inspection should include a windshield survey of all areas accessible by vehicle. If All-Terrain Vehicle (ATV) and snowmobile routes are not accessible by vehicle these should be checked on foot. The purpose of the inspection is to ensure that there are no unauthorized uses of the SWPA either by recreational users and/or residents. Inspections may focus on, but are not necessarily limited to identifying the following:

- Storage and spreading of manure.
- Unauthorized use of motor vehicles.
- Engine cleaning and refueling.
- Dumping.
- Road salting.
- Condition of on-site wastewater disposal systems.
- Condition of fuel oil storage tanks.
- Unauthorized fires/burning.

Inspections provide an ideal opportunity for on-going public education of any landowners and recreational users encountered during inspections. The results of the inspection process should be documented through annual reporting.

3.3.5 Emergency Response Plan/Contingency Plan

An ERP/CP describes procedures to mitigate emergencies within the SWPA and to ensure a rapid, systematic, and effective response to any event which may pose a threat to source water. Response procedures represent the final barrier that safeguards source water against unexpected threats that cannot be precluded through planning and land use controls. Responsibility for management of an emergency falls primarily on a System Owner representative, often a supervising municipal engineer.

Elements of an ERP/CP may include:

- Notification.
- Assessment.
- Communications.
- Response (e.g., containment).
- Post emergency activities (e.g., remediation and confirmatory monitoring).
- Documentation.
- Public relations.

If an emergency involves a chemical spill, the local Fire Department's Hazardous Materials (HAZMAT) team will generally act as the first responder.

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Chapter 4 Design of Water Treatment Plants

4.1 Design Basis

4.1.1 Design Flows

Water treatment plants should be designed such that major process equipment and plants are capable of supplying the maximum day demand for the 20 to 25-year projected design flows, plus an additional amount that will be sufficient to accommodate plant losses/process wastewater generation (e.g., filter backwashing) and potential impacts from climate change. The impacts of climate change on water usage patterns may vary significantly depending on the population and type of user serviced in the distribution system. Seasonal water demand may increase due to a demand for potable water from adjacent or nearby communities where the impacts of climate change are felt more acutely (e.g., nearby population of rural residents with private shallow well supplies impacted by low flow periods or drought conditions). Maximum day demand is the maximum amount of water supplied to the system on any given day within a calendar year. Climate change may increase daily demands through changes in usage patterns such as increased requirements for agriculture, drinking, and recreation during hotter months.

Minor process equipment such as piping, valves and chemical feed systems should be designed to accommodate future design flow, within the life expectancy of the components. Water treatment plants should be designed to facilitate future expansion, if necessary. In each case, the designer may consider modularity and expandability as an option to the provision of surplus capacity.

4.1.2 Target Contaminants & Process Selection

Typically, the target contaminants will be identified based on historical water quality data (if available) and should include considerations for the impacts of climate change on the source water quality. The process selection will be conducted in a Pre-design Report and should take into consideration the ability to meet all water quality requirements in the *Guidelines for Canadian Drinking Water Quality - Summary Table* from Health Canada or water quality requirements as adopted by the provincial Regulatory Authorities, by treating source water with a worst-case water quality scenario approach. The impacts of climate change on source water quality (e.g., changes in contaminants from changes in hydrology, disturbance events, and waterbody temperature) should be considered when determining a worst-case water quality scenario (refer to Chapter 2 for further guidance).

The designer should confirm the Pre-design Report findings prior to design of a new WTP. Process design criteria should also be identified in a Pre-design Report. If these critical pieces of information have not been evaluated in a Pre-design Report, then such a report should be completed prior to undertaking detailed design. See Section 1.3 for a further description of Pre-design Report recommendations.

Process (or Piping) and Instrumentation Diagrams (P&IDs) should be developed for all WTPs and should be provided in the detailed design drawings. Copies should be made available at the plant for use by operations and managerial staff. Process (or piping) and instrumentation diagrams should include all major and minor processes along with all ancillary process equipment.

4.1.3 General Redundancy Requirements

Water treatment plants should be designed in a multi-train system to enable the facility to be operated in the event that any single piece of critical process equipment fails or needs to be taken offline for servicing. Equipment which may be considered critical includes any individual component without which the treatment plant would not be able to produce the design treated water flows and quality. Examples of critical equipment for which redundancy is likely required includes raw and treated water pumps, filters, and disinfection units. Where critical equipment is installed with more than one capacity rating, the test for redundancy should consider the scenario with the largest single component out of service.

4.2 Site Selection

4.2.1 General

New WTPs should be located such that the selected site maximizes the use of existing infrastructure. In some cases, a new WTP may not be located in the vicinity of an existing facility as other sites may be more cost-effective or more attractive from a long-term system development standpoint. Considerations in planning the location of a new WTP should include:

- Proximity to existing infrastructure.
- Climate change infrastructure resilience.
- Hydraulic grade lines.
- Separation distances and future site expansion.
- Topography and geotechnical investigations.
- Land ownership.
- Site-related life-cycle costs.

4.2.2 Proximity to Existing Infrastructure

The locations of existing infrastructure services are critical in determining the location of a WTP. The WTP should be located close enough to maximize the use of these facilities. In the end, the best location will be one that maximizes the use of existing infrastructure while minimizing the costs associated with implementing a WTP at a particular site location. Such existing infrastructure may include, but not necessarily be limited to, the following:

- Proximity of raw water supply.
- Proximity to existing transmission mains: locating a WTP as close as possible to existing transmission mains will result in lower transmission main extension costs.
- Proximity to sanitary services: in some instances, existing sanitary services will be close enough to permit discharge of plant wastes to the wastewater system, which may eliminate the requirement for on-site waste treatment/disposal systems.
- Proximity to three phase power service: it is advantageous to minimize the amount of power service extensions required.
- Proximity to public access routes: locating a WTP near public access routes enables efficient and safe chemical and/or equipment delivery, as well as facilitating construction.

4.2.3 Climate Change Infrastructure Resilience

Infrastructure resilience to climate change should be specifically addressed as it relates to the selection of the WTP location. This may entail ensuring the facility is constructed at a minimum elevation which exceeds flood risk including the climate change considerations and that access routes and centralized power supply to the facility does not require transport through flood areas. Another climate change consideration is to minimize the impact of extreme weather on facility infrastructure and operations (e.g., potential increases in the frequency and intensity of disturbances should be considered as they may increase the risk of access routes becoming blocked or restricted).

4.2.4 Separation Distances & Future Site Expansion

When possible, WTPs should be located a sufficient distance from the nearest neighboring dwelling to allow for possible future facility expansion and to minimize the impacts of the facility on neighboring developments. Allowing sufficient distance from coastal hazard zones should also be incorporated to reduce the risks associated with coastal erosion, sea water rise, storm surge etc. as identified in Chapter 2. Maximizing separation from sites of known or suspected industrial contamination should be considered, particularly where subsurface water storage tanks are being constructed. Maximizing separation from other public or private developments will also reduce the risk of vandalism or sabotage provided there is restricted access to the facility (fences/gates/locks).

4.2.5 Hydraulic Grade Lines

The design of new WTPs should take into consideration the existing and proposed hydraulic grade lines to determine if raw or finished water pumping will be required. The use of gravity flow can often result in lower capital and operating costs but may restrict the siting of the treatment facility and may not be suitable for use with some treatment processes. Such factors should be carefully considered to determine the best possible hydraulic and siting configuration such that the water quality and flow capacity objectives of the facility are fully met.

4.2.6 Topography & Geotechnical Investigations

Water treatment plants should be in areas where the topography is best suited to the facility construction. Topographical surveys should be conducted on the site prior to design of a facility to confirm that the site will be conducive to development.

Site drainage should also be considered in site selection. Water treatment plants should be located in locations that exhibit relatively good drainage patterns and dry soil conditions, while considering that these patterns/conditions may be affected by climate change (e.g., potential increases in total annual precipitation). Such locations prevent the possibility of untreated groundwater and/or surface water intrusion into underground conveyance structures.

Prior to final site selection, a geotechnical survey should be conducted on the proposed site. The survey may include a series of test pits and/or boreholes for the purposes of determining the following:

- Soil types, moisture contents and densities.
- Soil load-bearing capacities.
- Depth to water table.
- Depth to bedrock.
- Assessment for possible contamination.

The number and type of test pits and/or boreholes will vary between sites but should generally cover the entire area to be developed. Test pits and/or boreholes should be located during topographic surveys.

4.2.7 Land Ownership

Land availability is often limited in the locations that are best suited to development and, therefore, negotiations for purchase are often time consuming. It is recommended that land negotiations begin as early as possible. Geotechnical investigations should be conducted prior to land procurement if and when possible, to ensure the suitability of the site for development. Practical issues may prevent more substantial investigation beyond a desktop review of available information and/or visual observations of site and soil conditions by a qualified person.

4.2.8 Site-Related Life-Cycle Costs

In addition to capital costs, operating costs can also greatly impact the selection of a site for a new WTP. Operating costs differences between sites may include, but not necessarily be limited to, the following:

- Raw and finished water pumping costs (in terms of both energy and maintenance related costs).
- Power extension requirements.
- Waste treatment and disposal costs.
- Site maintenance costs.

Once all site-related capital and operating costs have been identified, a life-cycle cost analysis should be completed. There are many ways to compare costs on a life-cycle basis, however, perhaps the most common method is to perform a NPV analysis. A NPV analysis considers both capital and operating costs and calculates the total costs to construct and operate a facility, in current dollars, for a predetermined amount of time. In a NPV analysis, the life expectancy of major equipment is used for the period of analysis and is typically 20 or 25 years for a mechanical facility. An appropriate interest rate should also be selected.

4.3 Layouts

4.3.1 Site Layout

The design should consider the following:

- Functional aspects of the plant layout.
- Provisions for future plant expansion.
- Provisions for expansion of plant waste treatment and disposal facilities.
- Access roads, driveways, and walkways.
- Site grading and site drainage.
- Chemical delivery and storage.
- Security-related issues (e.g., fence lines).
- Climate change resiliency (refer to Chapter 2 for further guidance).

Examples of design considerations to increase climate change resiliency include:

- The potential for increased flood risk, impacts of large storm events, and watershed disturbances should be considered as they may increase the risk of access routes becoming blocked or restricted.
- Site grading and site drainage should consider potential increases in the frequency and intensity of precipitation events and increased runoff.

4.3.2 Building/Plant Layout

The design of the facility should meet all applicable code requirements for the following:

- Operator health and safety.
- Ventilation.
- Fire protection.
- Structural design (post-disaster rating).
- Lighting and heating.
- Foundation drainage.
- Dehumidification (if required).

Additional items that should be considered in plant and building layouts, include the following:

- Equipment accessibility for operation, servicing, and removal.
- Flexibility of operation.
- Convenience and ease of maintenance.
- Backup power requirements.
- Separation of chemical storage and feeding.
- Manual overrides for automated controls.
- Location of process/equipment controls should be within line of sight of process/equipment.
- Allowing open tanks/filter areas to be kept in dark (i.e., without windows or skylights) to minimize algal growth.
- Location of electrical equipment in cool, dry places.
- Provision for cooling and dehumidification to account for humidity and hot temperatures worsened by the impacts of climate change.
- Redundancy and servicing requirements.
- Spare parts room.
- Provision for removal of equipment.
- Drainage of process areas and process piping and conduits.
- Safety provisions including alarms, railings, etc.
- Potential for cross-connections.

Some chemical feed and/or process areas may have specific requirements. Refer to Section 4.5 and Chapter 5 for recommendations.

4.3.3 Provisions for Future Expansion

Provisions for future plant expansions should consider:

- Building siting and topography.
- Oversizing of plant piping and conveyance facilities to provide for future projected flow requirements.
- Use of blind flanges for future process expansion connections.
- Allocation of additional space in facility superstructures.
- Building envelope access points for installation of future equipment.
- Sizing of Heating, Ventilation, and Air Conditioning (HVAC) and electrical systems.
- Provision of wall castings for future piping penetrations.

4.3.4 Engineered Lifting & Anchor Points

Consideration should be made for engineered anchor points in any facility which may require tie-off of lifting or fall arrest devices where confined space or fall hazards are present. This may include above openings, hatches, ladders, on roofs, in tanks, etc. Designers should attempt to mitigate the need for operators to engage fall arrest and confined space protocols by eliminating these areas wherever possible during facility design (e.g., where equipment is located on rooftops, provide guardrails around equipment to eliminate the need for the use of fall arrest procedures when accessing equipment for repair/maintenance). Lifting devices (cranes, monorails, hoists, etc.) should be provided where required for the removal of equipment and should be treated with a capacity exceeding the heaviest equipment intended for removal.

For all engineered lifting and anchor points, building code, and safety regulations must be incorporated into the design in accordance with the requirements of the Regulatory Authority having jurisdiction.

4.4 Stand-by Power

Dedicated stand-by power should be provided such that treated water may continue to be supplied to meet the average daily demand during power outages. This may become of increasing concern due to the impacts of climate change, in regions where power outages are controlled by the occurrence of storms and large wind events. Alternatives to permanent stand-by power may be considered with proper justification by the Regulatory Authority having jurisdiction (e.g., provision of infrastructure for connection of portable generator).

4.5 Chemical Feed Facilities

4.5.1 General

4.5.1.1 Plans & Specifications

Plans and specifications should include:

- Description of feed equipment, including minimum and maximum feed ranges.
- Location of feeders, piping layouts and points of application.
- Storage and handling facilities.
- Specifications for chemicals to be used, including latest edition of the *NSF/ANSI 60: Drinking Water Treatment Chemicals - Health Effects* for use in potable water treatment.
- Operating and control procedures including proposed application rates.
- Descriptions of testing equipment and procedures.
- Consideration for the impacts of climate change (e.g., resiliency of storage and handling facilities).

4.5.1.2 Chemical Application

Chemicals should be applied to the water at such points and by such means as to:

- Ensure adequate preparation of chemical (if required).
- Deliver the chemical to the point of use in the system.
- Ensure satisfactory mixing of chemicals in the process water.
- Provide maximum flexibility of operation through various points of chemical application.
- Prevent backflow or back-siphonage between multiple feed points.
- Provide maximum safety to operators.
- Ensure maximum safety to consumer.
- Ensure maximum efficiency of treatment.

4.5.2 Chemical Feed System Design

Chemical feed systems should be located as close to the point of application as possible to minimize feed runs without compromising delivery access, proper containment, safety, and cross contamination control.

4.5.2.1 Equipment Design

General equipment design should be such that:

- Feeders will be able to supply, at all times, the necessary amounts of chemicals at an accurate rate throughout the feed range.
- Materials that are in contact are resistant to the corrosiveness of the chemical solution.
- Chemicals that are incompatible are not stored or handled together.
- All chemicals are transported from the feeder to the point of application in separate conduits.
- Chemical feeders are as near as practical to the feed point.
- Chemicals are fed by gravity where possible.
- Corrosive chemicals are introduced in such a manner as to minimize the potential for cross contamination.
- Chemical feeders and pumps should operate at no less than 20% of feed range unless two fully independent adjustment mechanisms (such as pulse rate and stroke length) are provided, in which case the pumps/feeders should operate at no less than 10% of the feed range.

4.5.2.2 Number of Chemical Feed Systems

Where chemical feed is necessary for the protection of public health, the following is recommended:

- Consideration should be given to redundancy and/or spare parts (redundancy requirements are discussed in Section 4.1.3).
- Where redundancy is provided, the stand-by unit(s) should be of sufficient capacity to replace the duty unit(s).
- Where booster pumps are utilized, a redundant pump should be provided.

Separate feeders should be provided for each chemical applied. Spare parts should be available for all equipment components subject to wear and damage.

4.5.2.3 Control of Chemical Feed Systems

Features of the control of chemical feed systems should consider the following:

- Feeders may be manually or automatically controlled.
- Automatic controls should be designed with manual overrides.
- Chemical feed rates should be proportional to metered plant flowrates.
- Provisions should be made for measuring quantities of chemicals supplied.
- Coagulant and coagulant aid addition may be controlled, where water quality conditions warrant, by turbidity, streaming current detectors, pH, or some other sensed parameter, in addition to plant flow.
- Chemical disinfectants should be automatically controlled by monitoring residual disinfectant concentrations in addition to plant flow with appropriate alarms and other procedures to prevent inadequately disinfected water from entering the distribution system.
- Weigh scales should be provided for plants utilizing chlorine gas cylinders and should be capable of ±5% degree of accuracy and precision.
- Weigh scales are recommended for fluoride solution feed systems.

4.5.2.4 Dry Chemical Feeders

Dry chemical feeders should:

- Measure chemicals volumetrically or gravimetrically.
- Provide adequate solution water and agitation of the chemical.
- Provide gravity feed from solution containers.
- Provide a dust enclosure and/or collection system.

4.5.2.5 Positive Displacement Metering Pumps

Positive displacement metering pumps should:

- Be used to feed liquid chemicals and selected carefully when used to feed chemical slurries which can result in accelerated wear to wetted components and create accumulation and blockages in positive displacement pumps, particularly those with integral check valves where buildup of dry chemical can result in loss of pump functionality.
- Be capable of operating at the required maximum flowrates against the maximum pressure at the point of injection.
- Be outfitted with calibration columns and pressure relief valves.
- A minimum of one duty and one stand-by chemical feed pump should be provided for all chemical feed systems that are pumped where the chemical is critical to the treatment process.

4.5.2.6 Siphon Control

Liquid chemical feeders should be such that chemical solutions cannot be siphoned into the process water, by any of the following:

- Ensuring injection occurs at a point of positive pressure.
- Providing vacuum relief.
- Providing a suitable air gap.

4.5.2.7 Cross-Connection Control

Cross-connection control should be provided to ensure that:

- The service water lines discharging to the solution tanks are properly protected from backflow.
- No direct connection exists between any component of the treatment process tankage and the wastewater system. Provide an air gap between a receiving waste drain and process tank drain/overflow piping.

4.5.2.8 Make-up Water Supply

Make-up water for chemical feed systems and dilution should be:

- Ample in quantity and adequate in pressure.
- Controlled automatically or manually to provide a specific volume of make-up water to maintain a target batch solution strength.
- Fully treated and extracted from a source of finished water obtained from a location sufficiently downstream of any chemical feed point.
- Meet the requirements of the facility water supply as specified in Section 4.6.5.
- Be protected from backflow and cross-connections as specified in Sections 4.5.2.6 and 4.5.2.7, respectively.

4.5.2.9 Chemical Storage Requirements

General chemical storage requirements are as follows:

- Space is to be provided for convenient and efficient handling of chemicals.
- Appropriate heating, humidity control and ventilation for specific chemicals to be stored.
- Adequate delivery loading/unloading areas are to be provided.
- Storage tanks and pipelines should not be used for different chemicals.
- Chemicals should be delivered in unopened or covered containers until transferred into an approved storage unit.
- Safety Data Sheets (SDSs) for all chemicals utilized should be kept on-site.

Storage requirements for liquid chemicals are as follows:

- Liquid delivered in either “bulk” or “drum” form is to have a minimum 30 days of chemical storage. Sixty (60) days is recommended for essential systems.
- Inventory planning should include consideration of winter restrictions and spring road weight restrictions.
- Bulk and drum systems both require their own handling and storage areas within the plant.
- Bulk systems require containment systems capable of holding up to 150% of the maximum stored volume.
- Fill connections and piping to be manufactured of material of suitable chemical resistance for proposed treatment chemical.
- Storage tanks should have a level indicator.
- Fill piping should be minimum 50 mm diameter.
- Bulk liquid storage to provide a minimum 150% of tanker truck shipping capacity.

4.5.2.10 Batch Tanks

Batch tanks are used to dissolve dry chemicals into a solution and agitate the solution to maintain consistency and prevent sedimentation. Requirements for batch tanks are as follows:

- A means of maintaining uniform strength of solution should be provided.
- Continuous agitation should be provided for chemical solutions likely to precipitate.
- Liquid level indicators should be provided.
- A minimum of one solution tank should be provided (two is recommended for redundancy purposes).
- Solution/batch tanks should be covered, including access ports.
- Subsurface solution tanks should not be used. If they are absolutely necessary, they should:
  - Be free from sources of possible contamination.
  - Ensure positive drainage for groundwaters, accumulated water, chemical spills, and overflows.
- Overflow pipes should be turned downward, have screened ends, and have a free fall discharge and should be installed in a visible location to identify and contain overflows.
- Acid storage tanks should be vented to an exterior building vent through separate vent pipes that are located far enough from the air intakes (air condition, ventilation, etc.) to prevent contamination of indoor air.
- Each tank should have a drain valve protected against backflow.
- Solution tanks should be located within protective curbing so that chemicals from equipment failure, spillage, or accidental drainage cannot enter the water in conduits, treatment, or storage basins.
- Construction should be of a material suitable for resistance of corrosion for the chemical being conveyed.
- Tankage is to be labeled as per Section 4.11.

4.5.2.11 Day Tanks

Chemicals that are delivered to the facility in liquid form and are not likely to precipitate, or chemical solutions that have been mechanically mixed in batch tanks, may be transferred to a day tank which is the supply for liquid metering pumps. Requirements for day tanks are as follows:

- Day tanks are to meet the requirements of Section 4.5.2.10.
- A minimum of one day tank should be provided for each chemical feed system.
- Day tanks should hold between 24 and 72 hours of chemical supply. For facilities that may not be manned on weekends, consideration should be given to providing 72 hours storage. Some chemicals may become unstable after hydration, and manufacturer's written recommendations should be followed in these situations.
- Day tanks should be outfitted with an accurately calibrated liquid level measuring device.
- Tip racks and hand/mechanical transfer pumps may be used (mechanical transfer pump systems should be outfitted with a liquid level limit switch and an overflow).
- Construction should be of a material suitable for resistance of corrosion for the chemical being conveyed.
- Agitation should be provided if required to maintain chemical slurries in suspension.
- Tankage should be labeled as per Section 4.11.

Materials/equipment in contact with the chemicals should be suited to the chemical, but not necessarily National Science Foundation (NSF) approved. Designer should refer to the manufacturer to determine suitability if no reference can be established.

4.5.2.12 Solution Transport

Solution transport piping should be:

- As short as possible.
- Easily accessible through the entire length.
- Constructed of a material suitable for resistance of corrosion for the chemical being conveyed.
- Protected against freezing.
- Capable of being cleaned and/or flushed.
- Designed with consideration given to scale-forming or depositing properties of the solution being conveyed.
- Should be sloped upward from the chemical source to the feeder when conveying gases.
- Clearly colour coded as per Section 4.11.

4.5.2.13 Handling

The following is recommended with respect to chemical handling facilities:

- Carts, elevators, etc., should be provided to facilitate lifting/moving of chemicals and chemical containers.
- Provisions should be made for disposing of waste bags, drums, etc., such that dust emissions and product spillage are minimized.
- Provision such as the following should be made for the proper transfer of dry chemicals from shipping containers to storage bins or hoppers to prevent dust accumulation:
  - Vacuum pneumatic equipment.
  - Closed conveyor systems.
  - Enclosures for emptying containers.
  - Exhaust fans and dust filters.
- Floor surfaces should be smooth and impervious, non-slip, and well drained with 2.5% minimum slope.
- Floor drains should be discharged to an appropriate waste receiving/disposal system.

- Vents from chemical feed areas are to be separate from tank vents and are to vent to the facility exterior and should be above grade and remote from air intakes, doorways, or other openings.
- Provision should be made for measuring quantities of chemicals used to prepare feed solutions.

4.5.3 Chemicals

4.5.3.1 General

Chemicals should meet the latest editions of *NSF/ANSI 60: Drinking Water Treatment Chemicals - Health Effects* where these chemicals are available for the application.

Chemical shipping containers should be fully labeled, including:
- Chemical name.
- Purity.
- Concentration.
- Hazardous material warning label.
- Supplier name and address, phone number, and website.
- Date of delivery.

Safety data sheets should be provided with chemicals delivered (facility should have SDSs on hand for chemicals in use, and delivery vehicle should have SDSs for chemicals in transport). Provisions should be considered for assay of chemicals delivered.

4.5.3.2 Chlorine Gas

Chlorine gas feed and storage should be enclosed and separated from other operating areas. Some Regulatory Authorities may have specific guidelines for storage, feed, and handling of chlorine, and these should be followed, in addition to the following.

Full and empty cylinders of chlorine gas should be isolated from operating areas, restrained in position to prevent upset, stored in rooms separate from ammonia storage and in areas not in direct sunlight or exposed to excessive heat. The chlorine room should be:
- Provided with a shatter resistant inspection window installed in an interior wall.
- Constructed in such a manner that all openings between the chlorine room and the remainder of the plant are sealed.
- Provided with doors equipped with panic hardware, assuring ready means of exit and opening outwards only to the building exterior.
- Each room should be a gas-tight room, equipped with a ventilation fan with the capacity to provide one complete air change per minute.
- The ventilation fan should draw air near the floor and as far as practically possible from the air inlet location, with the fan discharge located so as to not contaminate any incoming air supplies.
- Air inlets should be through louvers near ceiling level.
- Louvers for chlorine room air intake and exhaust should facilitate airtight closure.
- Separate switches for the lights and fan should be located outside of the chlorine room and at the inspection window.
- Outside switches should be protected from vandalism.
- A signal light indicating fan operation should be located at each set of switches.
- Vents from feeders and storage should discharge to the outside atmosphere.

- The chlorine room location should be on the prevailing downwind side of the facility, away from entrances, windows, louvers, walkways, etc.
- Floor drains are not recommended, however, if necessary, they should discharge to the exterior of the building and should not be connected to any other drainage system. The outlet should be clearly marked, and a warning light or audible alarm provided to indicate the presence of chlorine in the outdoor environment.
- Equipment for the neutralization of chlorine upon automatic detection of chlorine should be provided.
- Chlorine rooms should be heated to approximately 15°C and should be protected from excessive heat.
- Pressurized chlorine gas piping should not convey chlorine gas beyond the limits of the chorine room.
- Should contain a chlorine gas monitoring system.
- Should contain warning lights or signals in case of emergency.
- A balance located in front of the inspection window should be provided.

4.5.3.3 Acids & Caustics

Acids and caustics should be kept in covered, corrosion resistant shipping containers or storage units. Acids and caustics should not be handled or stored in open vessels. Acids and caustics should be conveyed in undiluted form to the chemical point of treatment or day tank.

4.5.3.4 Sodium Chlorite for Chlorine Dioxide Generation

Due to the explosive nature of sodium chlorite, proposals, plans, and specifications for its use should be approved by the Regulatory Authority having jurisdiction.

Provisions for proper handling and storage of sodium chlorite is recommended and is outlined as follows:

- Sodium chlorite should be stored:
  - In a separate room, preferably detached from the main treatment plant building.
  - Away from organic materials.
  - In non-combustible structures or, water should be provided to keep the area cool enough to prevent heat-induced explosive decomposition of the chlorite.
- Measures should be taken to prevent spillage and emergency spill procedures should be in place.
- Storage drums should be thoroughly flushed prior to recycling or disposal.
- Positive displacement feeders should be provided.
- Piping for conveying sodium chlorite and chlorine dioxide solutions should be suitable for conveying these compounds and should be oriented to prevent the formation of gas pockets.
- Chemical feeders may be installed in chlorine rooms, provided sufficient space is available.
- Injection or termination of conveyance piping should be at a point of positive pressure.
- Check valves should be provided to prevent backflow of chlorine into the sodium chlorite piping.

4.6 Plant Facilities

4.6.1 Maintenance & Storage Facilities

Adequate facilities should be included for shop space, storage, wash bays, and/or maintenance and storage.

4.6.2 Offices & Control Areas

An operations/control area should be provided in a separate room. This area should include a personal computer, a Human Machine Interface (HMI), a fax machine, or printer/scanner as required, and a landline telephone. All plants should be designed with a user-friendly HMI system to facilitate plant operation and online monitoring. Equipment status, water levels, pressures and chemical feed rates should all be displayed via an HMI. All automated systems should be designed with manual overrides. Additional offices may be required for plant staff. Security cameras and Closed-Circuit Television (CCTV) monitors, if provided, should also be in this area.

4.6.3 Washroom Facilities

Washrooms with showers are recommended for plants where 24-hour staffing is provided. Additional facilities should be considered where the number of plant staff warrant; smaller facilities may require only one gender-neutral washroom. Designers should consult local building and/or plumbing codes for the minimum facilities required.

4.6.4 Lunchrooms

A lunchroom should be provided and should be separate from all control and laboratory areas. The lunchroom may also be used as a meeting room/training room depending on the size of the facility.

4.6.5 Facility Water Supply

The facility water supply service and the plant finished water sample tap should be supplied from a source of treated water at a point where the last chemical has been added and thoroughly mixed, and the disinfectant CT has been achieved.

4.7 Laboratory Facilities

4.7.1 General

Each public water supply should have its own equipment and/or facilities for routine laboratory testing. Laboratory equipment selection will be water quality and process specific. Portable and/or bench top units must be acceptable to the Regulatory Authority for the field measurement of any parameter being used for regulatory compliance or reporting. All materials and methods used are to meet current industry standards and should meet the approval of the Regulatory Authority having jurisdiction. A certified operator should be provided to perform all in-house laboratory testing.

4.7.2 Testing Equipment

As determined by the size, complexity, treatment process, parameters of concern and regulatory requirements, the following laboratory equipment may be required:

- All WTPs should provide the means necessary for obtaining water quality samples from select locations in both the WTP and the distribution system.
- All WTPs should have the following laboratory equipment:
  - Nephelometric turbidity meter.
  - pH meter.
  - Free and total chlorine residual analyzers.
  - Dissolved oxygen meter.
  - Spectrophotometer.
  - Titration equipment.

- Glassware appropriate for preparing reagents and analysis (e.g., pipettes, beakers, volumetric flasks, graduated cylinders, and Erlenmeyer flasks).
  - Deionized or distilled water.
  - Thermometer.
  - Bacteria incubator.
  - Fume hood.
  - Analytical balance to 0.1 mg accuracy.
- Surface WTPs utilizing coagulation and flocculation should have pipetting and bench-scale jar testing equipment. The equipment should be suitable for scale-up to that process which is used in the full-scale plant when possible.
- Iron and/or manganese removal plants should have equipment capable of measuring iron and manganese to lower detection limits below that of the latest edition of the *Guidelines for Canadian Drinking Water Quality - Summary Table* from Health Canada Maximum Acceptable Concentrations (MACs)/Aesthetic Objectives.
- Fluoridated water supplies should have equipment capable of measuring fluoride to a lower detection limit below that of the treatment standard.
- Systems which utilize polyphosphates and/or orthophosphates should have equipment capable of measuring phosphates from 0.1 to 20 mg/L.

Prior to the selection and procurement of laboratory equipment, the Regulatory Authority should confirm regulatory requirements for in-house water quality testing (if any) for the facility and confirm the acceptability of the laboratory equipment proposed to meet these requirements. Some jurisdictions may require quarterly confirmation of analytical results from an accredited laboratory, for appropriate Quality Assurance/Quality Control (QA/QC) for continuous online instrumentation.

4.7.3 Physical Facilities

All WTPs should have sufficient bench space, cabinetry/storage, ventilation, lighting, and sinks.

An eyewash station should be provided and should be located such that operators have easy access to the station. Eyewash stations not connected to a potable water system should have a minimum 15-minute flush capacity. Saline solutions should not be used. Permanent eyewash stations should be flushed regularly. Eyewash and showers should be located in areas of permanent chemical storage, feed and dosing and in particular where the SDSs for chemicals in use include the use of eyewash/showers. Eyewash and shower systems should be designed to provide sufficient flow, volume, and temperature water and in accordance with the requirements of the Regulatory Authority.

Air conditioning is recommended for all personnel areas.

4.8 Monitoring

All WTPs should have a reasonably accurate means of measuring raw water, treated water, and wastewater flow on a continuous and totalized recorded basis. All water systems should have a means of metering, displaying, and recording the flow of water to the distribution system.

4.8.1 Sample Taps & Locations

Sample taps should be provided so that water samples can be obtained from each water supply source and from appropriate locations from each unit treatment process. Taps used for obtaining microbiological samples should be of the smooth-nosed type without exterior threads, should not be of the mixing type, and should not have an aerator, screen, or other such appurtenance.

Wastewater treatment and disposal systems should have sufficient sampling points to ensure that discharge requirements can be maintained.

4.8.2 Online Water Quality Monitoring Equipment

WTPs should provide continuous online monitoring for the following parameters:

- Raw and treated water turbidity.
- Raw and treated water pH.
- Raw and treated water temperature.
- Total and free chlorine in treated plant process wastewater effluent discharge.
- Disinfectant residual at the primary disinfection CT control point where chemical disinfectant is used for primary disinfection.
- Ultraviolet dose or intensity as required to determine UV log reduction credits where UV irradiation is used for primary disinfection.
- Disinfection residual in treated water leaving the facility.

Where online disinfectant residual monitoring is in use to ensure adequate residual at the disinfection CT control point, or UV dose where UV is used for primary disinfection, this feedback should be configured to allow alarming/notification and/or shut-down of the treatment facility, as required. Where advanced monitoring and control systems are in place (i.e., Programmable Logic Controllers (PLC)/Remote Telemetry Unit (RTU)/SCADA) along with chemical-based primary disinfection, a continuous calculation of the CT ratio (CT achieved divided by CT required) may be provided to allow for more accurate monitoring and more appropriate response (i.e., warnings, alarm notifications and/or automatic shut-downs). Depending on the UV systems in use, adequate UV dose may be calculated based on online UV light intensity and transmittance, or by intensity only where a minimum Ultraviolet Transmittance (UVT) has been established for the facility.

Refer to Chapter 5 for UV disinfection design guidelines.

In addition to the above, surface WTPs should also monitor the following:

- Clarified (pre-filter) and individual post-filter effluent turbidities (including filter-to-waste effluent).
- Flocculation tank pH.
- Raw and treated water colour.
- Visual assessment of source water during warmer months for occurrence of algae blooms.

There may be a frequency in the occurrence of algae blooms in source waters across Atlantic Canada as result of increasing temperatures and the potential for increased nutrient loading and periods of low flow resulting from the impacts of climate change. Algae blooms and the potential for cyanobacteria and cyanotoxins in source waters can pose a serious risk to human health. If algae is observed in the source water, or has historically been observed in the source water, a regular sampling and analysis program for algae should be implemented through the WTP. Monitoring programs should be designed to provide information which can be used to trend source water quality over time, specifically water quality parameters which may be impacted by climate change (e.g., potential increases in surface water temperature, decreases in water levels, and changes to flow patterns). If algae has not been observed in the source water historically or encountered in the treatment system, visual assessments of the water source should be completed at minimum on a regular basis during the warmer months. Refer to Section 5.11 for more detailed information on algae blooms and cyanobacteria/cyanotoxins.

Membrane filtration systems, in addition to the above, may monitor pre- and post-membrane particle counts or pre-and post-membrane conductivity as an online measurement of filtration performance. Additional online monitoring instrumentation should be considered and is encouraged where conditions warrant. Advanced monitoring for parameters such as online Total Organic Carbon (TOC), UV254, streaming current, DBPfp, etc. may be desirable for more in-depth water quality monitoring and process control.

4.9 Operations & Safety

4.9.1 Operation & Maintenance Manuals

An O&M manual including a parts list and parts order form, operator safety procedures, and operational troubleshooting section should be provided for all equipment and operations pertinent to the facility.

Standard Operating Procedures (SOPs) provide a summary description of:

- Maintenance tasks to be performed.
- Person(s) performing the work.
- Necessary tools.
- Consumable materials.
- Equipment including Health and Safety (H&S) equipment and rental equipment.

These documents should be considered "living documents" and must be reviewed and updated regularly to ensure that procedures and plans in place are relevant and are developed/added in response to new activities.

Contingency plans are intended to provide guidance in response to abnormal events affecting (or potentially affecting) the water supply, treatment process, treatment facility, or finished water quality.

Each facility should also have an ERP.

For more detailed information, refer to Chapter 9.

4.9.2 Safety & Hazardous Materials

All WTPs should be adequately equipped to meet requirements of current Occupational Health and Safety legislation in the jurisdiction of the facility. All WTP staff should be adequately trained in emergency first aid, confined spaces (if applicable), and Workplace Hazardous Materials Information System (WHMIS). All SDSs should be made available at the locations in which the potentially hazardous material is used. A safety program is recommended for implementation at all WTPs.

In addition to the above, the following operator safety measures are to be employed:

- Provision should be made for ventilation of chlorine feed and storage rooms as per Section 4.5.3.2.
- Respiratory protective equipment meeting the latest edition of *CSA Z94.4 Selection, use and care of respirators* should be made available where chlorine gas is handled, should use compressed air, should have a minimum 30-minute capacity, but should not be stored in the location where chlorine gas is handled.
- Chlorine leak detection should be provided as follows:
  - Concentrated ammonium hydroxide (56% ammonia solution) should be available for chlorine leak detection.
  - Where tonne containers are used, a leak repair kit is required.
  - Continuous leak detection equipment is required.
  - Continuous leak detection equipment should be equipped with both audible and visual alarms.
- An adequate supply of protective equipment should be provided and should consist of:
  - One pair of rubber gloves (minimum).
  - One dust respirator certified for toxic dusts.
  - Protective clothing.
  - Goggles or face mask.
  - Other protective equipment as necessary.
- Emergency eyewash stations or deluge showers should be provided in areas where strong acids or alkalis are used or stored or are otherwise required by the Regulatory Authority.
- Standard operating procedures should be developed, and CPs should be documented.

4.10 Facility Construction

4.10.1 Basic Materials of Construction

Concrete tankage should be cast-in-place, steel reinforced concrete tankage, conforming to current CSA and ASTM standards. Concrete and some other materials commonly used in WTPs in direct contact with drinking water (pre- or post-treatment) are acceptable without *NSF/ANSI 61* certification, however, chemical admixtures and concrete coatings used for tanks in contact with water should be.

4.10.1.1 Prefabricated Tankage

Painted or epoxy coated steel should be the standard. Stainless steel is recommended for applications where the pH of the liquid in the tankage is less than 5.0. Marine-grade aluminum is also an acceptable tankage material.

4.10.1.2 Superstructure

In general, all WTPs should be housed within a building or superstructure. The superstructure should be designed to have a minimum service life of 50 years and should be designed to meet all current national and local building, plumbing and electrical codes as well as considering climate change. All electrical controls should be located above grade, in areas not subject to flooding or impacts of climate change. Building superstructures should be designed in accordance with “Post Disaster” importance category requirements. Precast or concrete brick and block superstructures are generally preferred over metal or wooden superstructures. In areas where high winds are expected, access doors should be located leeward of prevailing wind direction, or protection/reinforcement of doors should be provided.

Where components of the facility are to be located outside a building, the designer must consider the effects of extreme weather, including the climate change considerations, such as heavy and accumulative snowfall/snowdrifts, high winds, extended cold temperatures, freeze/thaw cycles, droughts, high groundwater levels, overland flooding risk, etc. on all outdoor components (valves, piping, tanks, instrumentation, mixers, etc.) and on the process itself (water, chemical feed lines, etc.), depending on the site specific design.

4.10.1.3 Access Hatches, Ladders, Catwalks, & Stairways

Access hatches, ladders, catwalks, and stairways should be provided between all floors, and in any pits or compartments which should be entered. They should have handrails on both sides and treads of non-slip material. Stairs should be the standard between superstructure levels with ladders and access hatches being the standard in chambers/pits/compartments, and catwalks should be the standard between and/or above process tankage. Stairs should have risers not exceeding 225 mm. Where cross-contamination is a possibility, catwalks should be of the fill type, with a toe plate. Access to filtered/finished water tanks and reservoirs should be restricted to watertight access hatches or similar provisions for infrequent entry to minimize the risk of contamination of treated water supplies.

4.10.2 Valves & Piping Materials

Valves and piping materials should be designed taking the quality of liquid to be conveyed into consideration. Acceptable process piping/valve materials include PVC, Polyethylene, Ductile Iron (DI), carbon steel and stainless steel. Special consideration is to be given the low and high pH liquids. Insulation should be provided where temperatures below 4°C are anticipated, or a humid environment where condensation on cold pipe surfaces would be expected. It is noted that humidity may increase in some areas throughout Atlantic Canada as a result of increased temperatures driven by climate change.

All piping and valves in contact with the process water, which is intended for distribution for potable use, including raw water, should be certified to the latest edition of *NSF/ANSI 61: Drinking Water System Components - Health Effects*.

4.11 Labelling & Colour Coding

To facilitate identification of process piping in WTPs, it is recommended that all piping be labeled. Due to the large number of small diameter chemical feed pipes, it is also recommended that all chemical feed piping be colour-coded. Directional arrows should be provided if flow is unidirectional. Labels and colour coding should adhere to the colour scheme shown in Table 4.1.

Table 4.1: Labels & Colour-Coding Guidelines

Process Water Piping	
Raw	Olive green
Settled or clarified	Aqua
Finished or treated	Dark blue
Chemical Feed Piping	
Primary coagulant (i.e., alum)	Orange
Ammonia	White
Carbon slurry	Black
Caustic	Yellow with green band
Chlorine (gas and solution)	Yellow
Fluoride	Light blue with red band
Lime slurry	Light green
Ozone	Yellow with orange band
Phosphate compounds	Light green with red band
Polymers and coagulant aids	Orange with green band
Potassium permanganate ($KmnO_4$)	Violet
Soda ash	Light green with orange band
Sulfuric acid	Yellow with red band
Sulfur dioxide	Light green with yellow band
Waste Piping	
Backwash waste	Light brown
Sludge	Dark brown
Wastewater	Dark grey
Other Piping	
Compressed air	Dark green
Gas	Red
Other	Light grey

All process piping is to be labeled and, where piping is not necessarily indicated in above, colour coding is to match that of the nearest unit process. All labels to be spaced a maximum of 1.5 m and to be easily visible. In cases where two colours do not provide enough contrast to easily differentiate the two, a 150 mm band of contrasting colour should be on one of the pipes at 750 mm intervals.

4.11.1 Commissioning & Testing

Commissioning and testing are to be carried out as per the requirements of the Regulatory Authority. It is recommended that the future WTP operator(s) be present during construction and commissioning and that the operators receive instruction on equipment and processes during facility start-up.

Tanks and piping that is to be operated under pressure should be hydrostatically tested in accordance with the system in place, generally hydrostatic testing should be completed at 1.5 times working pressure but no greater than the pressure rating of any component which cannot be removed/isolated during testing. Components such as pressure or water quality instrumentation which has a pressure rating less than 1.5 times the working pressure should be isolated and/or removed from the test section, and subsequently checked for leakage at normal operating pressure.

All tanks, pipes and equipment which convey or store potable water should be disinfected in accordance with AWWA procedures as well as the designer's plans and specifications.

4.11.2 Security

All WTPs should be made reasonably secure by means of chain-link fencing and gates to prevent public access onto the site. Building security is also imperative and locks should be provided on all doors, windows, and access hatches. Remote mounted cameras and security systems are also recommended. Access to process tankage and water storage basins should be highly restricted. An electronic building security system equipped with door and window contacts and connected to an alarm callout/dialer/internet notifier should be provided at minimum.

4.12 Remote Operation of Water Treatment Plants

Consideration should be given to remote monitoring capabilities as well as remote operation capabilities. Remote alarms should be provided for critical plant equipment failures as well as individual filter turbidity, finished water turbidity and chlorine residual concentrations/UV dose. Remote operation of the WTP using a SCADA system should be considered. The SCADA system should:

- Be capable of monitoring and recording online instrumentation data.
- Be capable of adjusting set-points of critical functions and key parameters within the plant.
- Be designed with adjustable alarms for monitoring of critical plant functions and key process parameters and/or equipment status.
- Be capable of remotely notifying the appropriate individual when the problems arise, in addition to the nature of the problem.
- Be provided with off-site controls for adjusting of critical plant functions.
- Only be provided in-conjunction with an available off-site operator with an adequate response time.

4.13 Other Considerations

Consideration should be given to the design requirements and recommendations of all other provincial and federal Regulatory Authorities for such items as safety requirements, handicapped accessibility, plumbing and electrical codes, etc. Consideration should also be given to design standards for specific process requirements, which although beyond the scope of these Guidelines, may impact the overall design of the facility.

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Chapter 5 Design of Water Treatment Processes

5.1 Screening

Screens should be used upstream of all other treatment units in surface WTPs.

Fine screens used at an end-of-pipe intake, where water is being extracted from fish-bearing waters, must conform to the latest edition of the *Freshwater Intake End-of-Pipe Fish Screen Guideline* from Fisheries and Oceans Canada. If the intake is from a fish-bearing water source and fine screens are only provided at the facility (i.e., not at the end of intake pipe), the screen design and flow velocity maximums must adhere to the DFO guidelines, and additional provisions may be required to allow fish to escape the intake structure. The local Regulatory Authority may require review and approval of the intake and screening design.

Fine screens used at the inlet of a surface WTP should meet the following requirements:

- Provide a screen opening between 150% to 200% of the conveyance channel.
- Provide a head loss no greater than 1.5 m.
- Have a mesh between 6.0 and 9.0 mm.
- Have a velocity of the net screen openings not greater than 0.6 m/s at maximum design flow and minimum submergence (lower requirements may be imposed by Regulatory Authorities for certain species of fish).
- Be hydraulically cleaned.
- Be easily accessible.

Coarse screens (bar and/or trash racks) may be required upstream of fine screens. Coarse screens should be constructed using 13 to 19 mm bars inclined at 30° from vertical, providing 25 to 75 mm openings.

5.2 Coagulation/Flocculation Process

5.2.1 General Description

Coagulation refers to the combined processes of rapid mixing and chemical precipitation of dissolved and particulate matter from water through “particle destabilization”. Coagulation can be accomplished using inorganic salts (positively charged metal ions such as aluminum and iron) or cationic polymers.

Enhanced coagulation refers to the process in which sufficiently high concentration of coagulant are added to optimize the removal of NOM with the goal of reducing or eliminating Disinfection By-Product (DBP) formation. Enhanced coagulation is now ubiquitous in conventional water treatment, as turbidity removal alone is no longer the primary focus of surface WTPs.

Flocculation is the process following coagulation which uses gentle stirring to bring suspended particles together so they will form larger aggregate particles, called flocs. Organic polymers are often utilized at this stage to provide bridging of floc particles, which tends to form even larger floc agglomerates which can be more easily removed in subsequent treatment steps (clarification and/or filtration).

5.2.2 Rapid Mixing

Rapid mixing should be provided for all systems which utilize chemical addition in the form of coagulation and flocculation in the treatment process. Rapid mixing should mean the rapid dispersion of chemicals throughout the water to be treated by agitation. Agitation may be provided through mechanical in-line mixers, static mixers, or paddle-type mechanical agitators. Alternative approaches to coagulation/flocculation chemical addition blending and mixing which do not include rapid mixing should be demonstrated by applicable references to existing installations or by pilot testing.

5.2.2.1 Chemical Injection

Chemicals injected to rapid mix units should be injected at a point closest to the inlet of the rapid mix unit. Flocculent aids should not be injected into the rapid mixing unit unless an additional rapid mixing unit for the flocculent aid is provided. Coagulant and coagulant/flocculant aid selection and addition sequencing should be derived from jar and/or pilot testing. Rapid mixing should not exceed 2 minutes. The nozzle velocity of a chemical injector into a rapid mix unit should not exceed 3.0 m/s.

In-line static mixers are considered suitable for rapid mixing of primary coagulants. Primary coagulants should not be mixed using in-line devices such as pumps, weirs, valves, etc., as they do not provide controlled mixing.

5.2.2.2 In-line Static Mixers

In-line static mixers are typically used for charge neutralization coagulation and should be designed to conform to all three of the following standards:

- Mixing intensity or velocity gradient (G-value) = 700 to 1,500 s^{-1}.
- Retention time (t) = 0.5 to 1.0 s.
- Gt = 500 to 1,500.

5.2.2.3 In-line Mechanical Mixers

In-line mechanical mixers are typically used for charge neutralization coagulation and should be designed to conform to all three of the following standards:

- Mixing intensity or velocity gradient (G-value) = 3,000 to 5,000 s^{-1}.
- Retention time (t) = 0.5 to 1.0 s.
- Gt = 2,000 to 3,000.

5.2.2.4 Paddle-Type Rapid Mixer

Paddle type mixers are typically used for sweep and enhanced coagulation and should be designed to conform to the following standards:

- Mixing intensity or velocity gradient (G-value) = 600 to 1,000 s^{-1}.
- Retention time (t) = 10 to 60 s.
- Gt = 6,000 to 25,000.

5.2.3 Flocculation

5.2.3.1 Flocculation Basins

All flocculation basins should:

- Be located within a properly designed building.
- Be designed to minimize hydraulic short-circuiting.

- Be designed to prevent destruction of floc agglomerates.
- Utilize a minimum of 2-stage flocculation to permit a tapered velocity gradient. Sometimes 3-stage flocculation may be more appropriate depending on the downstream treatment processes utilized.
- Utilize mechanical or hydraulic flocculation.
- Have a flow-through velocity not less than 0.15 m/s and not greater than 0.45 m/s.
- Have interconnecting piping and conduits designed to provide a velocity not less than 0.15 m/s and not greater than 0.45 m/s.
- Minimize turbulence at bends and other changes in direction.
- Be designed to minimize hydraulic losses.
- Be outfitted with either a drain or a sump for sludge removal.
- Not be greater than 5.0 m in liquid depth.
- Have a freeboard of at least 0.3 m.
- Be equipped with drainage connections.
- Not be of the diffused air or water jet mixing type for conventional WTPs.
- Be as close together as possible.

5.2.3.2 Flocculators

Mechanical, paddle-type flocculators should:

- Be designed to provide a mixing intensity (G) of 10 to 80 s^{-1} depending on number of flocculation stages).
- Be designed to provide a total Gt of 20,000 to 110,000.
- Have a maximum peripheral speed of 1.0 m/s.
- Have variable speed motors consisting of a minimum of three settings.
- Be manufactured from corrosion resistant materials.
- Have a minimum water depth of 3.3 m.
- Have variable speed motors to allow optimization of flocculation mixing intensity.

Hydraulic flocculators should:

- Only be utilized in systems where the anticipated flow variations are small.
- Have a maximum liquid velocity of 1.0 m/s.
- Be designed to provide a mixing intensity (G) of 5 to 50 s^{-1} (will vary depending on number of flocculation stages), where G can be determined according to the following formulation at 4°C.

$$G = 12.7 \times (H/t)^{0.5}$$

Where G = Mixing Intensity (dimensionless)
H = Headloss (m)
t = Residence time (sec)

5.3 Clarification

A method of clarification is provided in conventional treatment utilizing coagulation/flocculation processes prior to filtration.

5.3.1 Sedimentation

Sedimentation is the process by which flocculated particles are removed from suspension through settling. The retention time and loading rates used in a sedimentation basin will largely depend on the nature of the contaminant to be removed from the raw water, the chemicals added during coagulation and type of sedimentation process used. There are many proprietary variations of sedimentation process. The most common forms of sedimentation are:

- Conventional sedimentation.
- Plate and tube settlers.
- Solids contact clarifiers.
- Upflow sludge blanket clarifiers.
- Ballasted flocculation and sedimentation.

5.3.1.1 General

The following should apply to all sedimentation basins:

- A minimum of two trains should be provided.
- Basins, piping, and appurtenances should be constructed from corrosion resistant materials.
- Inlets should be designed such that influent water is distributed evenly across the entire basin and at uniform velocities using baffles.
- Should be designed such that short circuiting does not occur.
- Outlet weirs or submerged orifices should be designed to:
  - Not exceed discharge velocities of 250 m^3/day/m.
  - Have a maximum submergence depth of 1.0 m.
  - Not exceed an orifice entrance velocity of 0.15 m/s.
  - The use of submerged orifices is recommended in order to provide a volume above the orifices for storage when there are fluctuations in flow.
- An overflow weir or pipe should be provided to establish the maximum water level desired on top of the filters.
- A superstructure to house the sedimentation units is recommended.
- Basins should be designed with a drain or sump and bottom slopes should range from < 1% to 8% for mechanical and non-mechanical sludge collection, respectively.
- Mechanical sludge collection equipment is recommended.
- Sludge removal design requirements should be as follows:
  - Sludge removal piping should be minimum 75 mm diameter.
  - Entrance to sludge piping should be designed to prevent clogging.
  - Valves should be located on the basin exterior.
  - A means to observe sludge levels in-situ should be provided.
  - Sludge disposal should be completed by an approved method as stipulated by the Regulatory Authority having jurisdiction.
- Flushing lines should be provided.
- Handrails should be provided around the basins and ladders should be provided for access into the basins.

5.3.1.2 Conventional Sedimentation

Conventional sedimentation refers to low-rate sedimentation basins that are constructed without high-rate settling devices. The following design criteria should apply to sedimentation basins used for conventional treatment:

- Retention time should be between 2 and 4 hours after coagulation/flocculation processes.
- Retention time should be minimum 2 hours for lime softening processes.
- Surface overflow rates should not exceed 1.2 m/hour.
- Flow through the basin should be laminar and velocities through the sedimentation basin should not exceed 0.15 m/minute.
- Water depth should be 3.0 to 5.0 m, with minimum 0.3 m freeboard.
- Minimum length to width ratio = 4-to-1 (5-to-1 is recommended).
- Should meet the requirements of Sections 5.3.1.1 and 5.3.1.2.

5.3.1.3 Plate & Tube Sedimentation

Plate (or tube) sedimentation should refer to high-rate sedimentation processes that are constructed with high-rate settling devices. The following design criteria should apply to plate (or tube) sedimentation basins:

- Surface overflow rates should not exceed 4.8 m/hour.
- Application rates for plates (or tubes) should not exceed 1.2 m/hour, based on 80% of the horizontal projected area.
- Water depth should be 3.6 to 5.0 m, with 0.6 to 1.0 m freeboard.
- Inlet and outlet considerations (maintain velocities suitable for settling in the basin and minimize short-circuiting, with plate units designed to minimize maldistribution across the plates).
- Drain piping from the settling units should be designed to facilitate flushing of the basins.
- Should meet the requirements of Sections 5.3.1.1 and 5.3.1.3.
- Proprietary designs that do not meet these requirements should be subject to pilot testing requirements as per Section 3.1.2.2.

5.3.1.4 Solids Contact Clarifiers

Solids contact clarifiers (or reactor clarifiers) refer to high-rate flocculation and sedimentation processes whereby a sludge return feed is introduced into the clarifier. The following design criteria should apply to solids contact clarifiers:

- Solids contact clarifiers should be subject to pilot testing requirements as per Section 3.1.2.2.
- Solids contact clarifiers should be designed for the maximum flowrate and should be adjustable to changing flowrates and water quality.
- Flocculation time should be minimum 20 minutes and in a separate tank or in a baffled chamber.
- Surface overflow rates should not exceed 1.2 m/hour.
- Tubes may be used to increase loading rates and should meet the requirements of Section 5.3.1.4.
- Retention time should be 2 to 4 hours.
- Should have a means of measuring solids concentration and collecting sludge in the central flocculation zone
- Softening units should be designed such that continuous slurry concentrations of 1% or greater (by weight) can be maintained.
- Total water loss should not exceed 5% for clarifiers and 3% for softening units.
- Sludge waste concentration should not exceed 3% for clarifiers and 5% for softening units.
- Slurry recirculation rate should be 3 to 10 times the raw water flowrate.
- Should meet the requirements of Section 5.3.1.1.

5.3.1.5 Upflow Sludge Blanket Clarifiers

Upflow sludge blanket clarifiers should refer to high-rate flocculation and sedimentation processes whereby a flocculation and sedimentation occur simultaneously in the clarifier. The following design criteria should apply to upflow sludge blanket clarifiers:

- Upflow sludge blanket clarifiers should be subject to pilot testing requirements as per Section 3.1.2.2.
- Upflow sludge blanket clarifiers should be designed for the maximum flowrate and should be adjustable to changing flowrates and water quality.
- Pre-flocculation requirements should be determined by pilot testing as per Section 3.1.2.2.
- Surface overflow rates should not exceed 2.4 m/hour.
- Tubes and/or plates may be used to increase loading rates to 4.9 m/hour, however, pilot testing should be conducted as per Section 3.1.2.2.
- Retention time should be 1 to 2 hours.
- Should have a means of measuring solids concentration and collecting sludge in the central flocculation zone.
- Sludge waste concentration should not exceed 3% for clarifiers and 5% for softening units.
- Should meet the requirements of Section 5.3.1.1 and 5.3.1.5.

5.3.1.6 Ballasted Flocculation

Ballasted flocculation refers to the high-rate flocculation and sedimentation processes whereby relatively heavy particles (ballast) are used as a seed for floc formation in the flocculation process. The ballast provides surface area that enhances flocculation and acts to increase the relative density and weight of the resulting flocs. The heavier floc allows for clarifier designs with high overflow rates and short retention times. The ballasted flocculation process is well suited for difficult to treat waters such as those with rapidly fluctuating source water quality. These systems are typically proprietary in nature, however, the following general guidelines should apply to ballasted flocculation clarifiers:

- Ballasted flocculation clarifiers should be subject to pilot testing requirements as per Section 3.1.2.2.
- Clarifiers should be designed for the maximum flowrate and should be adjustable to changing flowrates and water quality.
- Tubes may be used to increase loading rates and should meet the requirements of Section 5.3.1.6.
- Should have a means of recycling and cleaning ballast for reintroduction to the flocculation process.
- Should meet the requirements of Section 5.3.1.1.

5.3.2 Dissolved Air Flotation

Dissolved Air Flotation (DAF) is the process by which flocculated particles are removed from suspension by floating them to the surface of the clarifier using microbubbles. Dissolved air flotation clarifiers are considered an acceptable alternative to sedimentation processes, particularly when treating water supplies low in mineral turbidity (i.e., low in inorganic particulate/colloid concentrations). The retention time and loading rates for DAF have increased significantly since its original introduction to drinking water treatment applications in North America, and typical flocculation time requirements have been significantly reduced. High-rate DAF processes are typically designed using Computational Fluid Dynamic (CFD) analysis to ensure that flow patterns in the clarifier at the design loading rate will be beneficial to solid-liquid separation performance. As outlined in Section 5.11, DAF treatment is highly effective in the removal of algae from source waters.

5.3.2.1 General

The following should apply to all DAF systems:

- A minimum of two trains should be provided.
- Basins, piping, and appurtenances should be constructed from corrosion resistant materials.
- Inlets should be designed such that influent water is distributed evenly across the entire basin and at uniform velocities.
- Should be designed such that short circuiting does not occur.
- An overflow weir or pipe should be provided.
- A superstructure to house the DAF units should be provided.
- Basins should be designed with a drain or sump and bottom slopes should be minimum 0.5%.
- Mechanical or hydraulic overflow float removal systems should be provided and should be discharged to a process wastewater handling system.
- Sludge disposal should be by an approved method as stipulated by the Regulatory Authority having jurisdiction.
- Handrails should be provided around the basins and ladders should be provided for access into the basins.

5.3.2.2 Design Criteria

The following design criteria should apply to DAF clarification systems:

- Maximum surface overflow rates should be determined by the DAF system vendor, and demonstrated by references to previous similar installations, considering basin configuration, dimensions, water quality, design flowrate, pre-chemical treatment, and control features. Where adequate past demonstrations are not available, pilot testing should be conducted to confirm acceptable performance can be achieved under design flow and water quality conditions. Generally, modern DAF clarifiers are operated in the range of 10 to 30 m/hour, and in some applications at 40 m/hour and above. Loading rates above 30 m/h should always be verified by pilot testing, regardless of past demonstrations.
- The clarified water should be collected at the bottom of the clarifier and discharged over a water level control weir to maintain the water level in the clarifier.
- The recycle flow should be introduced at such a location to ensure even distribution of the released air at the tank influent.
- Bubble diameter should be between 10 and 100 µm.
- Recycle ratio should be approximately 10%.
- Saturation pressure should be 400 to 600 kPa (58 to 87 psi).
- Air concentration in the process tank after injection should be between 8 and 10 mg/L.
- Air injection should be designed to ensure an even distribution of air across the inlet baffle.
- Air and recycle ratio should be adjustable.
- Should meet the requirements of Section 5.3.2.1.

5.3.3 Adsorption Clarification

Adsorption clarification is a high-rate treatment process that uses a combination of hydraulic flocculation/roughing filtration and rapid rate filtration.

As the coagulated water passes upward through the roughing filter, the floc agglomerates increase in size and are removed/adsorbed by the coarse media. These systems are more often applicable for higher quality surface water with low turbidity, iron, manganese, and colour. The limited flocculation time typically provided in these systems can be a concern at low raw water temperatures.

These systems are proprietary in nature, and the following guidelines generally apply:

- The units should be subject to pilot testing requirements as per Section 3.1.2.2.
- The units should be designed for the maximum flowrate and should be operated within the range of 50 to 100% of the design capacity.
- The surface overflow rates should be in the range of 19.5 to 25.5 m/hour.
- The filtration zones should be backwashed using air scour.
- The requirements of Section 5.3.3 should be met.

5.4 Filtration

Barring system specific exceptions, filtration should be provided for all supplies treating a surface water or a high-risk GUDI. Acceptable filtration processes include, upon the discretion of the Regulatory Authority, the following:

- Rapid Rate Gravity Filtration (RRGF).
- Rapid rate pressure filtration.
- Slow sand filtration.
- Direct filtration.
- Deep bed (i.e., RRGF).
- Biological filtration.
- Membrane filtration.
- Bag and cartridge filtration.

The use of any of the above processes should be supported by operating and water quality data over a reasonable period of time in a similar process configuration to support its use. Experimental and/or pilot studies may be required for some filtration options under certain conditions. The system-specific requirement for filtration and the acceptability of a proposed filtration process is determined by the Regulatory Authority having jurisdiction.

5.4.1 Rapid Rate Gravity Filtration

5.4.1.1 Pre-Treatment

Rapid rate gravity filters should have pre-treatment in the form of coagulation/flocculation and clarification and should meet the requirements of Section 5.3. Clarification is not required for those filters operating in “direct filtration” mode (see Section 5.4.3 for direct filtration requirements).

5.4.1.2 Rate of Filtration

Rapid gravity filters should be designed to provide a rate of filtration not greater than 9.0 m/hour. The actual rate of filtration should be determined through consideration of such factors as raw water quality, degree of pre-treatment, filter media, water quality control parameters, monitoring capability and other factors as required by the Regulatory Authority. The filtration rate should be justified by the Design Engineer to the satisfaction of the Regulatory Authority prior to the preparation of plans and specifications. Filtration rates higher than those identified herein may be subject to the pilot testing requirements of Section 3.1.2.2. The plant design should be based on the available filtration rate at the end of filter runs, not with a clean filter bed, if filters are not designed in a constant rate configuration.

5.4.1.3 Number of Units & Redundancy

A minimum of two filtration units should be provided. The filters should be designed to enable the facility to meet system demands with the largest filter out of service provided that provincial health related water quality requirements are met.

Where declining rate filtration is used, the variable aspect of filtration rates and the number of filters must be considered when determining the design capacity of the filters.

5.4.1.4 Headloss & Control

Filters should be designed with a maximum permissible headloss typically not greater than 2.5 m and a clean bed headloss of not less than 0.3 m. Excessive headloss can cause air binding and/or channeling and deterioration of filter performance. Filters should be designed to have at least 1.0 m of water above the media and in the case of high-rate filtration, this value should not be less than 1.5 m. Filters may be designed with significantly different values on a site-specific basis. Elements of filter design are proprietary in nature, and the performance of designs which deviate significantly from these Guidelines should be demonstrated based on relevant references and/or piloting.

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

5.4.1.5 Filter Flow Control

Controlling flow to rapid rate gravity filters can be done by splitting flow to each filter from a common feed header using modulating flow control valves on each filter outlet and a filter outlet flowmeter, or by using a hydraulic flow-splitting weir.

Where a modulating flow control valve is used, filters are typically operated in a constant-level operating mode, by which the water level above the filter is kept constant and does not change with changing flow through the filter, or with headloss in the filter over the course of a filter run. The flow control valve acts in this case as an induced source of headloss, which is decreased throughout the filter run as filter headloss increases, to maintain a constant combined total headloss required to achieve a specific filter flowrate.

Where no modulating flow control valve is used, flow through the filter may still be controlled in an increasing-level configuration, where a flow splitting weir or other form of flow control is used upstream. The downstream filter piping arrangement is designed to always maintain a minimum level in the filter above the top of the media bed, and the water level above the filter will increase over the filter run and with increasing flows, as headloss in the filter increases.

Where no modulating flow control valve is used, and no flow control/splitting is done upstream of the filters, individual filters will operate in a declining rate mode with increasing level. Headlosses through each filter will be equal across each filter, but flowrates through each individual filter will vary significantly based on the cleanliness of the filter bed (i.e., time since last backwash). Flowrates will be significantly higher through the cleanest filter bed.

5.4.1.6 Structural & Hydraulic Details

The structural and hydraulic design should provide for the following:

- Vertical walls within the filter.
- No protrusion of filter walls into the filter media.
- The units should be covered by a super structure.
- Headroom should permit normal inspection and operation.
- The minimum depth of filter box should be 2.6 m.
- The minimum water depth over surface of media should be 1.0 m.
- The effluent pipe should be trapped to prevent backflow of air to the bottom of the filters.
- Prevention of floor drainage to the filter with a minimum of 100 mm curbing around the filters.
- Prevention of flooding by providing an overflow.
- Maximum velocity of treated water in pipe and conduits to filters of 0.6 m/s.
- Cleanouts and straight alignment for influent pipes or conduits where solids loading is heavy or following lime softening.
- Washwater drain capacity to carry maximum flow.
- Walkways around filters should be not less than 0.6 m wide.
- Safety handrails or walls should be placed around all filter walkways.
- The units should be constructed to prevent cross connections and common walls between potable and non-potable water.

Washwater troughs should be constructed to have:

- The bottom elevation above the maximum level of expanded media during washing.
- Fifty (50) mm freeboard at the maximum rate of wash.
- The top edge level and at the same elevation.
- Spacing so that each trough serves the same number of square meters of filter area.
- The maximum horizontal travel of suspended particles to reach the trough should not exceed 1.0 m.

5.4.1.7 Filter Media

Filters should be dual- or multi-media type, and should meet the following requirements:

1. The total depth of media should not be less than 600 mm.
2. The effective size of the smallest media should be between 0.45 mm to 0.55 mm.
3. Uniformity coefficient of smallest media should not be greater than 1.65.
4. The filter media should conform to the latest editions of *AWWA B100-16 Granular Filter Material* from the and *NSF/ANSI 61: Drinking Water System Components - Health Effects*.
5. Dual-media specifications (see Table 5.1).
6. Multi-media specifications (see Table 5.2).
7. Torpedo sand (support sand) (see Table 5.3).
8. Granular Activated Carbon (GAC) as a single media may be considered for filtration only after the piloting requirements of Section 3.1.2.2 have been satisfied, and provided the design meets the requirements outlined in Table 5.4).
9. Other media, including mixed-media (i.e., media not conforming to the above criteria), should be considered experimental in nature and should be subject to pilot testing as per the requirements of Section 3.1.2.2.

Table 5.1: Dual-Media Specifications

	Range	Typical
Anthracite:		
Depth (mm)	300 - 600	450
Effective size (mm)	0.8 - 2.0	1.2
Uniformity coefficient	1.3 - 1.8	1.65
Silica Sand:		
Depth (mm)	150 - 300	300
Effective size (mm)	0.45 - 0.55	0.50
Uniformity coefficient	< 1.7	< 1.65

Table 5.2: Multi-media Specifications

	Range	Typical
Anthracite:		
Depth (mm)	500 - 600	550
Effective size (mm)	0.8 - 2.0	1.2
Uniformity coefficient	1.3 - 1.8	1.65
Silica Sand:		
Depth (mm)	150 - 300	200
Effective size (mm)	0.45 - 0.55	0.50
Uniformity coefficient	< 1.7	1.65
Garnet:		
Depth (mm)	50 - 100	75
Effective size (mm)	0.15 - 0.35	0.25
Uniformity coefficient	< 1.7	< 1.65

Table 5.3: Torpedo Sand (Support Sand)

	Range	Typical
Depth (mm)	75	75
Effective size (mm)	0.8 - 2.0	1.2
Uniformity coefficient	< 1.7	1.5

The media should meet the specifications (from AWWA/American Society of Civil Engineers (ASCE)) outlined in Table 5.4).

Table 5.4: Granular Activated Carbon

Iodide number:	> 500 mg/g carbon
Density:	0.25 g/cm^3
Moisture content:	< 8% by weight
Ash content:	< 4% by weight
Effective size:	1.2 - 1.6 mm
Uniformity coefficient:	< 1.9
Empty bed CT:	5 - 25 minutes
Depth:	0.3 - 1.2 m
Effective size:	0.50 - 0.65 mm

- There should be a means for periodic treatment of filter material for control of bacterial and other growth (typically utilizing an oxidant or disinfectant).
- Provisions should be made for replacement, or regeneration, of media.

5.4.1.8 Filter Underdrains

Filter underdrains may consist of proprietary designs with slotted blocks, plates, or nozzles, for filtered water collection and backwash and/or air scour distribution, and which may be designed to either replace gravel supports of be used in conjunction with gravels. A non-proprietary filter underdrain design typically consists of a pipe manifold arrangement with slotted or perforated pipes connecting to a header in a gravel support bed.

Gravel, when used as a supporting media, should consist of cleaned and washed, hard, rounded silica particles and should not include flat or elongated particles. The specification of support gravels should be done in conjunction with the design of the filtration layers and collection/distribution system in use. In accordance with the technical guidance for conventional filter media gravel support design provided in Appendix D of the latest edition of the *AWWA B100-16 Granular Filter Material* (Appendix B: Filter-Media Support Gravel Size and Layer Depth):

- Each gravel layer should be as uniform as possible, with maximum particle size in a layer no more than twice the size of the minimum particle size in that layer.
- Each layer thickness should be a minimum of three times the maximum particle size in that layer and not less than 76 mm.
- The minimum size of the top gravel layer should be 4 to 4.5 times the effective size of the finest filtration media.
- The maximum particle size of each layer should be no greater than 4 times the minimum size of the finer layer above.
- The bottom layer should be coarse enough to prevent displacement by air or water jets from the collection system below.
- The bottom layer should be a minimum of two times the size of the collection system openings (i.e., perforation diameters/slot widths).

An example of a graded gravel underdrain conforming to each of these Guidelines, assuming a fine sand filtration layer effective size of 0.5 mm and collection manifold perforations 10 mm in diameter, is as follows (from top to bottom):

Table 5.5: Example of Grated Gravel Underdrain

Layer	Size Range (mm)	Minimum Depth (mm)
Top	2 - 4	76
Second	4 - 8	76
Third	8 - 16	76
Fourth	20 - 32	96

Manifold type underdrain systems should meet the following requirements, unless otherwise approved:

- Minimize headloss in the manifold and laterals.
- Ensure an even distribution of backwash water and an even rate of filtration over the entire area of the filter.

- Provide the ratio of the area of the final openings of the strainer system to the area of the filter at approximately 0.003.
- Provide the total cross-sectional area of the laterals at approximately 200% of the total area of the final openings.
- Provide the cross-sectional area of the manifold at approximately 150 to 200% of the total area of the laterals.
- Lateral perforations without strainers should be directed downwards.

5.4.1.9 Surface Wash or Subsurface Wash

Surface or subsurface wash facilities should be provided, except for filters used exclusively for iron and manganese control, and should meet the following requirements:

- Systems should be of a fixed nozzle or revolving type apparatus.
- Water pressure should be minimum 310 kPa (45 psi).
- A vacuum or siphon breaking device should be installed to prevent back siphonage, if connected to the treated water system.
- Rate of flow to be 4.9 m/hour for fixed nozzles and 1.2 m/hour for revolving arms.
- Air wash should be considered based on experimental and/or operating experience.

Surface wash systems can be replaced by air scour systems, provided that the requirements of Section 5.4.1.13 are satisfied.

5.4.1.10 Filter-to-Waste

Filter-to-waste connections should be provided for all filters and should be directed to the waste treatment and/or disposal system. Filter control should include a provision to automatically filter-to-waste at a given filter turbidity setpoint and/or immediately after backwashing, in accordance with requirements of the Regulatory Authority having jurisdiction.

5.4.1.11 Filter Appurtenances

The following should be provided for all filters:

- Inlet and outlet sampling taps.
- An indicating loss of head gauge.
- An indicting rate of flow meter.
- A rate controller which limits the rate of filtration to the maximum rate should be used.
- Wall sleeves providing access to the filter interior at several locations for sampling or pressure sensing.
- A pressure hose and storage rack at the operating floor for washing filter walls.

5.4.1.12 Backwashing

5.4.1.12.1 Storage Requirements

Sufficient volume of treated water should be provided for backwashing all filters every 24 hours. An equivalent volume of equalization may be required for plants that store their backwash prior to treatment and/or ultimate disposal.

5.4.1.12.2 System Design

Backwashing systems should be designed to meet the following requirements:

- Backwashing rates should be:
  - Sufficient to provide minimum 50% expansion of the filter bed.
  - Between 36 and 54 m/hour for systems not using air scour.
  - Between 12 and 18 m/hour for systems using air scour.
  - Twenty-four (24) m/hour for full depth anthracite or GAC filters.
- Backwashing duration should be:
  - A minimum 15 minutes of backwash water for systems that do not use air scour.
  - A minimum 10 minutes of backwash water for systems that use air scour.
- Air scour duration should be as specified in Section 5.4.1.13.
- Backwash water should be filtered water, provided from the clearwell, backwash tanks, or the service watermain.
- Backwash pumps should include a minimum of one duty and one stand-by pump.
- A flow regulator and a flow meter should be provided on the main backwash header.
- System should be designed such that rapid changes in backwash water flowrate do not occur.
- Backwash systems should be operator initiated, and automatic systems should be operator adjustable.

5.4.1.13 Air Scour

Air scour systems should meet the following requirements:

- Air scour systems should be designed with an air scour airflow rate of 54 to 90 m/hour.
- Air scour duration should be 3 to 5 minutes.
- Air is to be introduced in the underdrain system.
- Design should minimize loss of filter media.
- Air scour should be followed by backwashing as per Section 5.4.1.12.
- Air should be free of contamination.
- Air distribution piping should be sufficient to prevent pipe collapse or bursting under maximum pressures.
- Air delivery piping should not pass through the unfiltered water.
- Consideration should be given to maintenance and replacement of air delivery piping.

5.4.2 Rapid Rate Pressure Filtration

Pressure filtration is typically used in situations where an ion-selective media is used (e.g., iron and manganese removal systems), although it is also commonly used in small-scale applications for particle removal (as defined in Chapter 10). In any event, pressure filtration systems should not be used for filtration of surface water and should only be used for systems that do not require coagulation (due to the potential for floc breakup).

5.4.2.1 Rate of Filtration

Pressure filtration systems should be designed such that a maximum filtration rate of 7.2 m/hour is provided. Use of higher filtration rates will be subject to demonstration of successful application and/or pilot testing requirements as specified in Section 3.1.2.2.

5.4.2.2 Additional Requirements

Pressure filtration systems should meet the following requirements:

- Filter redundancy should be provided in accordance with the guidelines provided in Section 5.4.1.3.
- Loss of head gauges are to be provided on the inlet and outlet pipes of each filter.

- An easily readable flow meter should be provided for each bank of units and a flow indicator should be provided on each individual unit.
- Minimum sidewall height should be 1,500 mm.
- Backwash water troughs/collectors should be minimum 450 mm above media surface.
- An adequate underdrain system capable of uniformly distributing a backwash water flowrate suitable for the filter media installed in the pressure filter and should conform to the guidelines provided in Section 5.4.1.8.
- Filtration to waste should be provided in accordance with the guidelines provided in Section 5.4.1.10.
- Backwash water flow indicators should be provided, and backwashing should conform to the guidelines provided in Section 5.4.1.12.
- If air scour is used, air scour design should conform to the guidelines provided in Section 5.4.1.13.
- Air release valves on the highest points of each filter should be provided.
- A manway should be provided on filters greater than 900 mm in diameter and handholes should be provided on filters less than 900 mm in diameter.
- Cross-connection control measures should be provided.
- Manholes should be greater than 600 mm in diameter.

5.4.3 Direct Filtration

Rapid rate gravity filtration processes that do not use clarification should be considered direct filtration. Direct filtration is to be used only for high quality surface water. The raw water should have the following characteristics:

- Colour < 20 colour units.
- Turbidity < 5 NTU (Nephelometric Turbidity Unit).
- Algae < 2,000 asu/mL (algal standard units).
- Iron < 0.3 mg/L.
- Manganese < 0.05 mg/L.

5.4.3.1 Piloting & Approval Requirements

Where direct filtration is proposed, an engineering report should be submitted prior to conducting pilot studies.

This report should include a historical summary of the source water quality with special reference to fluctuations in quality, potential future water quality changes (e.g., from development and climate change impacts), and possible sources of contamination in the source water. The report should also include a description of methods and work to be conducted during the piloting phase.

The following raw water quality data should be evaluated in the report:

- Colour.
- Turbidity.
- Concentrations of microbiological COC.
- Temperature.
- Total solids.
- General inorganic chemical characteristics.

After approval of the engineering report, a pilot study demonstration should be conducted and should meet the requirements of Section 3.1.2.2 and be to the satisfaction of the Regulatory Authority. In-plant demonstration studies may be appropriate where conventional treatment plants are converted to direct filtration plants.

The pilot study should be conducted over a sufficient period of time to experience all expected raw water conditions throughout the year. The study should emphasize, but not be limited to, the following:

- Chemical mixing conditions including shear gradients and detention periods.
- Chemical feed rates.
- Use of various coagulants and coagulant aids.
- Flocculation conditions.
- Filtration rates.
- Filter gradation, types of media, and depth of media.
- Filter breakthrough conditions.
- Impact of recycling backwash water.

The pilot scale system should be of a similar type and configuration to that proposed for the full-scale facility. Prior to developing plans and specifications, a final report including the engineer's design recommendations should be submitted to the Regulatory Authority for approval where required by the Regulatory Authority.

5.4.3.2 Pre-Treatment

The coagulation and flocculation processes should be designed as per the design criteria outlined in the pilot studies and as per Section 5.2. Direct filtration systems should also be designed such that a clarification process could be installed at a later date, should one be required.

5.4.3.3 General Design

Filters used for direct filtration should be dual-media or mixed-media rapid rate gravity filters and should meet the requirements of Section 5.4.1, unless otherwise noted. Pressure filtration should not be used.

Online turbidity monitoring should be provided for each filter. Coagulant concentration monitoring should also be performed routinely.

5.4.3.4 Rate of Filtration

Filtration rates should be determined during pilot testing but in no case should exceed those rates specified in Section 5.4.1.2.

5.4.4 Slow Sand Filtration

Slow sand filtration refers to the process in which water is gravity filtered at very low rates through a sand bed in which a biologically active layer forms on the top of the media. This biologically active layer is commonly referred to as a *Schmutzdecke*.

5.4.4.1 Application

The use of these filters will only be suitable for a very small percentage of water supplies and prior engineering and pilot studies as specified in Section 3.1.2.2 should be undertaken to confirm the suitability of the process for the raw water quality.

Slow sand filtration should not be used when either the raw water colour or the raw water turbidity exceeds 15 Total Colour Units (TCU) or 10 NTU, respectively, on any given day. Extensive raw water quality and piloting data should be obtained and should cover a period of at least 1 year to capture all of the seasonal water quality fluctuations. Note that slow sand filtration will have difficulty meeting treated water turbidity requirements in place in most jurisdictions, making its application limited.

5.4.4.2 Number & Redundancy

The number of units should be as specified in Section 5.4.1.3.

5.4.4.3 General Design

Slow sand filters should be designed to provide:

- A cover.
- Headroom to permit normal movement by operating personnel for scraping and sand removal operations.
- Adequate access hatches and access ports for ventilation and handling of sand.
- Filter-to-waste.
- Overflow at the maximum water level.
- Drain at the harrowing level (above top of filter bed level).
- Protection from freezing.

5.4.4.4 Rate of Filtration

Filtration rates should range from 0.04 to 0.40 m/hour. Filtration rates above this range will have to be adequately demonstrated through piloting studies as per Section 3.1.2.2.

5.4.4.5 Underdrains

The supporting gravel should be as per the requirements of Section 5.4.1.8.

Each filter unit should be equipped with a main drain and an adequate number evenly spaced (maximum 1,000 mm) laterals to collect the filtered water, with a maximum water velocity of 0.23 m/s.

5.4.4.6 Filter Media

Filter media should be clean, washed silica sand meeting the following requirements:

- Minimum initial sand depth of 750 to 1,300 mm.
- Effective size between 0.15 and 0.30 mm.
- Uniformity coefficient be less than 2.5.
- Reuse of sand to promote biological seeding should be done such that the old sand is placed on top of new sand.
- Influent piping should be a minimum of 0.3 m above the media to prevent media scour during operation, or distribution lateral with outlets designed to prevent agitation of media under design flow and level conditions.

5.4.4.7 Water Depth & Headloss

Design water depth should be between 1,800 and 2,100 mm and the effluent piping design should ensure that the water level is maintained above the level of the filter sand (*AWWA/ASCE; Great Lakes Upper Mississippi River Board (GLUMRB)* recommends 0.9 to 1.8 m; selected to allow for headloss).

Headloss should be between 0.1 m (i.e., clean bed) and 2.0 m (i.e., final bed).

5.4.4.8 Appurtenances
Each filter should be equipped with a headloss gauge and a flow metering device and an effluent pipe designed to maintain the water level above the top of the filter sand.

5.4.4.9 Scraping & Ripening
Slow sand filters should be scraped as required to ensure the regulatory requirements are consistently met. Slow sand filters should be allowed to ripen for a sufficient amount of time to ensure the regulatory requirements are consistently met. Filter-to-waste should be directed to the waste treatment and/or disposal system. Frequency of scraping will vary with sand depth and raw water quality and can be more accurately determined during piloting. Ripening duration should also be confirmed during pilot testing. Filter harrowing (raking) as an intermediate maintenance activity between scrapings may prolong the life of the media and considerations to allow harrowing should be made during design of the filter basin and piping.

5.4.5 Biological Filtration
Biological filtration should refer to the filtration of a surface water, or a groundwater with iron, manganese, or significant organic material, which includes the establishment and maintenance of biological activity within the filtration media.

It is important to note that biological activity within a filter can have adverse effects on turbidity and microbial pathogen removal, head loss development, filter run times and distribution system corrosion. This said, this can be overcome with regular and frequent backwashing cycles as described in Section 5.4.1.12.

5.4.5.1 General Design
Design of biologically active filters should ensure that aerobic conditions are maintained at all times.

Biological filtration may include the use of ozone as a pre-oxidant to break down organic matter into biodegradable organic matter. Granular activated carbon media may be used to support denser biofilms.

Filters used in biological filtration should be designed as rapid rate gravity filters and should meet the requirements of Section 5.4.1, unless otherwise noted. Pressure filtration should not be used for biological filtration, except where biological filtration is targeting specific contaminants (e.g., iron and manganese).

5.4.5.2 Piloting Requirements
Biological filtration systems should not be constructed without undertaking pilot studies as per the requirements of Section 3.1.2.2.

5.4.6 Membrane Filtration
Membrane systems are emerging as a very popular water treatment unit process due to their ability to provide excellent quality water under variable raw water conditions. There are currently a wide variety of membrane processes available and as such, detailed standards, and guidelines for each is beyond the scope of this document. This said, some basic design criteria will be specified that pertains to all membrane systems.

5.4.6.1 Applicable Processes

The following membrane systems have emerged as feasible for use in potable water systems and, therefore, should be considered for approval by the Regulatory Authority:

- Microfiltration.
- Ultrafiltration (UF).
- Nanofiltration (NF).
- Reverse osmosis.

Membranes have generally been classified into the categories based on their approximate pore size ranges. These categories are as follows:

Microfiltration	0.1 µm pore size
Ultrafiltration	0.01 to 0.1 µm pore size
Nanofiltration	0.001 to 0.01 µm pore size
Reverse osmosis	0.0001 µm pore size

$$\mu m = micrometre = (1 \times 10^{-6}\, metres = 1 \times 10^{-3}\, millimetres)$$

Membrane porosity for high-pressure membranes is also often described in terms of Molecular Weight Cut-Off (MWCO), which is defined as the molecular weight where 90% of removal across the membrane occurs. Molecular weight cut-off is measured in Daltons (atomic weight units) and is used where measurement in microns is insufficient to accurately describe removals of dissolved constituents.

Generally, only NF and RO have small enough pore sizes to reject aqueous salts, resulting in demineralization.

Depending on the source water, pre-treatment requirements for membrane treatment can be significant. Generally, the feed water should be very low in organic and inorganic colloidal substances, metal oxides (particularly iron and manganese), and biological substances. In addition, most membranes will not tolerate high/low pH water or free chlorine.

Membranes used for pathogen reduction should be certified by an independent third party to have successfully undergone product-specific challenge testing as outlined in the latest edition of the *Membrane Filtration Guidance Manual* from the United States Environmental Protection Agency. Systems should be equipped with mechanisms for both automatic direct integrity testing and continuous indirect integrity testing, both of which may be required by the Regulatory Authority having jurisdiction in order to be approved for pathogen removal log credits, as described by the membrane equipment manufacturer and further herein.

5.4.6.2 Number & Redundancy

Since most membranes are modular in nature, redundancy should be provided such that the following conditions are satisfied:

- A minimum of two trains are provided.
- A minimum of one redundant feed/suction pump is provided.
- The design capacity of the facility can be met with a minimum of 25% of the modules out of service at the approved flux rates.

For smaller membrane systems (i.e., < 2,000 L/minute), it may be acceptable to provide an additional module only, or, to design the system for 25% additional capacity.

5.4.6.3 Piloting Requirements

As with all water treatment technologies, membrane filtration systems should not be constructed unless adequate water quality and operating data exist to confirm the suitability and efficacy of such processes for a particular water supply source. If such data does not exist, pilot testing should be conducted and should meet the requirements of Section 3.1.2.2.

5.4.6.4 Membrane Materials

Membranes can be made from either organic polymers or inorganic materials. Material selection depends on the type of membrane, quality of water and the desired finished water quality. Properties of various membrane materials are provided in Table 5.6.

Table 5.6: Properties of Various Membrane Materials

Material	pH Range	Tolerance to Chlorine (mg/L)	Maximum Temperature (°C)
Cellulose acetate	3 - 6	~ 1.0	530
Polyamide	2 - 12	< 0.1	80
Polysulfone	1 - 13	~ 100	75
Polyvinylidene Fluoride (PVDF)	2 - 10	> 100	75
Aluminum oxide (ceramic)	0 - 14	> 100	> 100

The two most important organic polymeric materials include cellulose acetate and polyamide, with other membranes being made from polypropylene, Polyethylene, aromatic polyamides, polysulfone, and other polymers. Membranes can be constructed in either asymmetric or symmetric configurations.

Inorganic membranes are typically made of glass, ceramics or carbon and are fabricated with composite layers of inorganic material having different porosity or granularity. Inorganic membranes resist compaction, high temperature, and extreme pH values and can operate under a broad range of temperatures. The major drawback of inorganic membranes is their high density and cost.

Membranes can consist of hydrophilic or hydrophobic materials, which can have an effect on fouling. Hydrophobic materials are more prone to fouling because they adsorb organic matter to a greater degree relative to the hydrophilic materials, however, hydrophobic membranes will also have a stronger affinity for removal of DBP precursor.

5.4.6.5 Membrane Configurations

Membrane systems consist of membrane elements or modules that are generally manufactured in two different configurations, hollow fiber and spiral. Microfiltration and UF generally use the hollow fiber. This geometry does not require extensive pre-treatment because the fibers can be periodically backwashed and the conditions of turbulent flow over the membrane improve the “scouring” of the membrane surface. The advantage to using hollow fiber membranes is that there is a lower pressure drop within a membrane module as compared to spiral, therefore, resulting in lower energy consumption.

Flow through a hollow fiber membrane can either be from the inner lumen to the outside (inside-out flow) or from the outside to the inside of the fibers (outside-in flow). For inside-out flow configuration, a positive pressure is required to push the water through the membrane. With this method, particle fouling will occur on the inside of the fiber, which may decrease the efficiency of backwashing. With outside-in flow configuration, a negative pressure or suction is required to draw the water through the membrane.

5.4.6.6 Design Criteria

Membranes should be designed according to the general design criteria provided in Table 5.7.

Table 5.7: Typical Membrane System Design Criteria

Design Parameter	Microfiltration	Ultrafiltration	Nanofiltration	Reverse Osmosis
Flux rate (L/m^2/hour)	34 - 170	34 - 170	14 - 34	10 - 34
Transmembrane Pressure (TMP) (kPa)	20 - 600	30 - 700	310 - 1,000	2,000 - 10,000
Recovery	90 - 98%	85 - 95%	60 - 75%	50 - 60%
Temperature range (°C)	0 - 35	0 - 35	0 - 35	20 - 35
Cleaning frequency (days)	14 - 90	14 - 90	14 - 180	30 - 360
Removal rating	0.1 - 0.2 μm	0.01 - 0.1 μm	95 - 98% rejection of $MgSO_4$	98 - 99.7% rejection of NaCl

5.4.6.7 Integrity Testing

There should be a means to directly measure membrane integrity every 24 hours such as through a pressure-decay test, diffusive air test or water displacement test. Indirect integrity testing methods using water quality parameters such as turbidity, particle counts, Dissolved Organic Carbon (DOC), and/or conductivity should also be routinely performed and should be online where possible. In the absence of direct integrity testing for NF/RO membranes, molecular markers such as Rhodamine WT or dyes may be considered.

5.5 Disinfection

Barring system specific exceptions, disinfection should be provided for all public potable water supplies. Chlorine is the preferred disinfecting agent as it has good disinfection capabilities, established modes of transport, storage, and handling, is well researched, cost-effective and has a measurable residual. This said, other disinfectants such as chloramines, ozone, chlorine dioxide, UV light, or mixed oxidants may also be considered. Careful consideration should be given to potential DBP increases when selecting disinfectants and processes that require pre-chlorination.

5.5.1 Chlorination

Chlorination can be accomplished using either gas/liquid chlorine or calcium/sodium hypochlorite. Continuous feed of chlorine at locations upstream of the final physical separation unit in a treatment process has the potential to increase system DBPs.

5.5.1.1 Inactivation Requirements

The method of determining adequate disinfection for chlorination should be the CT (i.e., CT = free chlorine concentration in mg/L x disinfectant CT in minutes) concept. Contact time should be measured as the amount of time from when the chlorine is injected until it reaches the point of use. This may include both the retention time in chlorine contact chambers as well as transmission mains. In chlorine contact chambers, this should be at the discharge of the chamber. In pipes, this should be at the first customer. Chlorine contact chambers and pipes should be considered as separate reactors. The disinfectant concentration used in CT calculations should always be the concentration at the discharge of the reactor or at the point of first use.

Due consideration should be given to CT of the chlorine in water with relation to pH, ammonia, taste, temperature, microbiological quality, and DBPfp.

All chlorine contact chambers should be designed to minimize short-circuiting and the T_{10} concept should be utilized. Use of the T_{10} concept should ensure that 90% of the water treated will be disinfected within the specified retention. Tracer studies may be required to determine the T_{10} value in some circumstances. In most cases, baffling factors may be used to determine the T_{10} value. The required retention time should be the theoretical retention time divided by an appropriate baffling factor. A general guide to baffling factors is provided in Table 5.8. Tracer studies may be required to determine a more accurate baffling factor in some circumstances.

Table 5.8: Baffling Factors for Contact Time Calculations

Baffling Condition	T_{10}/T	Baffling Description
Unbaffled	0.1	No baffling, agitated basin, very low length-to-width ratio, high inlet and outlet velocities.
Poor	0.3	Single or multiple unbaffled inlets and outlets, no baffles.
Average	0.5	Baffled inlet or outlet with some intrabasin baffles.
Superior	0.7	Perforated inlet baffle, serpentine or perforated intrabasin baffles, outlet weir or perforated launders.
Perfect	1.0	Pipes or basins with very high length to width ratio, perforated inlet, outlet and intrabasin baffles.

When determining the appropriate CT, consideration should be given to the required log removals necessary to meet regulatory requirements. Consideration should also be given to possible log-removal credits offered through the treatment unit processes, if any.

The following general guidelines should be followed when performing CT calculations for design purposes:

- Use maximum instantaneous flowrate that will occur in the contact chamber.
- Determine the volume of each process unit in the disinfection system using the minimum water level.
- Calculate the theoretical retention time.
- Determine the baffling factor based on contact chamber baffling conditions or by tracer studies.
- Calculate T_{10} by multiplying theoretical retention time by baffling factor.
- Multiply the minimum chlorine residual that will occur, theoretical retention time, and baffling factor to establish the design CT.

Further information on the CT method for log inactivation is available in the latest edition of the *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document- Enteric Protozoa: Giardia and Cryptosporidium* from Health Canada.

At plants treating surface water, provisions should be made for applying disinfectant at various locations, depending on the system configuration. For systems supplying groundwater, consideration should be made for applying disinfectant to the incoming raw water and the water being fed to the distribution system where additional treatment units are in place.

5.5.1.2 Residual Chlorine

As a best practice, chlorination systems should be designed to provide a minimum free chlorine residual of 0.2 mg/L and maximum level of 4.0 mg/L throughout the distribution system, or within an acceptable range as designated by the Regulatory Authority. Minimum combined chlorine residual, if applicable, should be 1.0 to 3.0 mg/L. A specific range of minimum and maximum acceptable free combined, and total chlorine residuals concentrations may be defined by the Regulatory Authority having jurisdiction.

5.5.1.3 Chlorination Equipment

5.5.1.3.1 Type

Solution feed gas chlorinators or hypochlorite feeders of the positive displacement type should be provided.

5.5.1.3.2 Capacity

The chlorinator capacity should be such that primary disinfection requirements can be met under the maximum flow conditions at the facility, and the secondary disinfection requirements can be met under all conditions. The equipment should be designed such that it will provide an accurate chlorine feed over the entire dosing range.

5.5.1.3.3 Stand-by Equipment

Where chlorination is provided for the protection of public health, redundant stand-by equipment should be provided such that it can replace the largest unit. Spare parts should be made available to replace parts subject to wear or breakage. Accurate metering of emergency units should also be provided.

5.5.1.3.4 Automatic Switchover

For gas chlorination systems, automatic switchover of chlorine cylinders should be provided to prevent inadequately disinfected water from entering the distribution system.

5.5.1.3.5 Automatic Proportioning

Automatic proportioning (flow-pacing) chlorinators should be provided where the rate of flow does not remain constant.

5.5.1.3.6 Eductor

For gas chlorination systems, each eductor should be selected for the point of application with consideration given to the quantity of chlorine to be added, the maximum injector flowrate, the injector location pressure, the injector operating pressure, and the size of the chlorine solution piping. Gauges for measuring water pressure and vacuum at the inlet and outlet of each eductor should be provided.

5.5.1.3.7 Injector/Diffuser
For gas chlorination systems, the chlorine solution injector/diffuser should be compatible with the point of application to provide a rapid and thorough mix with the water being treated. Where chlorine is injected into pipes, injectors should extend to the center of the pipe.

5.5.1.3.8 Residual Monitoring Equipment
Continuous online monitoring of chlorine residuals should be provided at all locations where disinfected water enters the distribution system. Chlorine residual test equipment recognized in the latest edition of *Standard Methods for the Examination of Water and Wastewater* from the American Public Health Association, the AWWA, and the Water Environment Federation should be provided and should be capable of measuring disinfectant residuals to 0.02 mg/L. It is recommended that the diffusion pressure deficit method that utilizes digital readout be used, as a minimum. Automatic chlorine residual analyzers should also be provided at a location immediately prior to the location where the treated water enters the transmission or distribution system. Residual monitoring equipment should also be provided at treated water storage reservoirs at the point where the stored water enters the distribution system.

5.5.1.3.9 Automatic Shut-Off Capability
In the absence of automatic redundant equipment (combined with stand-by power facilities), the ability to shut off the water supply system in the event of lower than required chlorine residuals should be provided. This is necessary to prevent inadequately disinfected water from entering the distribution system.

5.5.1.3.10 Chlorinator Piping
For gas chlorination systems, the chlorinator water supply piping should be designed to prevent contamination of the treated water supply by sources of questionable quality. At all facilities applying chlorine to surface water prior to filtration, pre- and post-chlorination systems should be independent to prevent possible cross-contamination with the contents of the clearwell. The water supply to each eductor should have a separate shut-off valve and master shut-off valves will not be permitted.

The pipes carrying elemental liquid or dry gaseous chlorine under pressure should be Schedule 80 seamless steel tubing or another material approved by the Chlorine Institute (note that PVC is not recommended). Rubber, PVC, Polyethylene, or other materials approved by the Chlorine Institute should be used for chlorine solution pipe and fittings (nylon materials are not recommended for any part of the chlorine solution piping system). Efforts should also be taken to minimize the length of pipe used to carry chlorine gas, liquid or concentrate (see Sections 4.5.2.12 and 4.5.3.2).

5.5.1.3.11 Housing
Adequate housing should be provided for chlorination equipment and chlorine storage (see Chapter 4).

5.5.1.3.12 Gas Chlorination General Guidelines
In addition to the requirements of Section 4.5.3.2, the following should be provided for all disinfection systems that use gas chlorination:

- Weigh scales constructed from corrosion resistant material and located remote from sources of moisture.
- Chlorine leak detection equipment as per Chapter 4.
- Consideration should be given to chlorine gas scrubbers in highly populated areas.

Gas chlorination system design should take into consideration the following items:

- Chlorine cylinders stored separately and adequately secured to prevent damage to the cylinders.
- Chlorine cylinders stored away from flammable material, heating/ventilation units, elevator shafts or uneven surfaces.
- Temperature in the chlorination room and chlorine storage room should be the same to avoid condensation or evaporation in the piping conveying gas.
- The chlorine gas conveyance piping should slope upwards towards the chlorinators to allow condensation to drain back to the chlorine cylinders.
- The chlorine gas conveyance piping should not be located on an outside wall or any location where low temperatures may be encountered.
- It is recommended that a strainer be installed on the waterline to the injector to prevent any possible grit or foreign material from entering and blocking the injector. Provision for flushing the screen is recommended and should precede the booster pump.
- Tonne cylinders should be moved using an approved lifting mechanism.
- Chlorine Institute Emergency Kit A and/or B should be provided depending on the storage container type in use.

5.5.2 Alternate Disinfectants

There are many types of disinfectants in addition to chlorine that have the potential to be used in potable water treatment applications, however, provisions of standards and guidelines for all of these is beyond the scope of these Guidelines. Rather, a few of the more common alternate disinfectants will be identified and some general guidelines provided.

5.5.2.1 Types of Alternate Disinfectants

The following alternate disinfection processes should be given consideration by the Regulatory Authority:

- Chloramination.
- Ozonation.
- Chlorine dioxide.
- Ultraviolet disinfection.
- Onsite Hypochlorite Generation (OSG) and mixed oxidants.

Consultation with the Regulatory Authority for specific requirements is recommended prior to proposing or proceeding with design using alternate disinfectants.

5.5.2.2 Process Descriptions

5.5.2.2.1 Chloramination

Chloramines are a weak primary disinfectant and require long CTs for adequate disinfection, however, they do have a long-lasting residual. They form lower concentrations of THMs and Haloacetic Acid (HAAs) in comparison to free chlorine, but are associated with increased formation of other DBPs such as N-nitrosodimethylamine (NDMA), and other regulated nitrogen-containing compounds such as nitrite and nitrate which can lead to nitrification. For that reason, chloramines may be best suited as a stable distribution system secondary disinfectant. The application of chloramines to systems previously using only chlorine disinfection only must be closely evaluated for impacts on the existing distribution network and premise plumbing, particularly where lead pipes or lead deposits or materials in premise plumbing are expected. Chloramines may accelerate the rate of corrosion in leaded plumbing and should, therefore, be avoided unless the designer has thoroughly examined the particulars of the system under consideration. Pilot testing including the application of test pipe loops on representative premise plumbing with and without the addition of corrosion inhibitors in treatment is recommended at minimum.

When using chloramines, consideration should be given to the ammonia residuals in the finished water. Amounts fed in excess of the stoichiometric amount should be minimized to inhibit growth of nitrifying bacteria.

5.5.2.2.2 Ozonation & Chlorine Dioxide

Ozone (O_3) is a very effective disinfectant for both protozoans and viruses and is also used for taste and odour control and destruction of algal toxins. There are, however, by-products of ozonation, which are regulated in some jurisdictions. Ozone does not provide a disinfectant residual and, therefore, should only be used in conjunction with a secondary disinfectant such as chlorine or chloramines. Ozone systems should include provisions for leak detection and alarms as well as an ozone off-gas destruction system.

Chlorine dioxide is a strong disinfectant and does not tend to form THMs and HAAs, but it does not have a persistent residual for use as a secondary disinfectant. Chlorine dioxide is formed by the mixing of chlorine with sodium chlorite, which forms an explosive gas and as such, advanced leak detection, explosion proof measures and special safety precautions should be provided. Chlorine dioxide addition will result in the formation of chlorite and chlorate DBPs, which have health-based MACs of 1.0 mg/L in the latest edition of the *Guidelines for Canadian Drinking Water Quality - Summary Table* from Health Canada. Chlorine dioxide dosing should be kept to a maximum of 1.2 mg/L to limit the formation of these DBPs.

Health Canada provides disinfection CT equivalent tables for ozone and chlorine dioxide disinfection in the latest edition of *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document- Enteric Protozoa: Giardia and Cryptosporidium* from Health Canada.

5.5.2.2.3 Ultraviolet Disinfection

Ultraviolet disinfection is the process where UV light is applied to the water to be treated, which results in the inactivation of microbiological contaminants due to the mutagenic properties of the UV radiation. Ultraviolet systems may provide relatively high inactivation of *Giardia*, *Cryptosporidium*, and viruses, while not forming DBPs. Ultraviolet systems do not, however, provide a residual and as such, a secondary disinfectant such as chlorine should be provided. Ultraviolet dose requirements for pathogen inactivation are provided in Table 5.9.

Table 5.9: Ultraviolet Dose Requirements for Pathogen Inactivation

Microorganism	1-log	2-log	3-log	4-log
Giardia	2.1	5.2	11	22
Cryptosporidium	2.5	5.8	12	22
Adenoviruses	58	100	143	186
Other viruses	4 - 10	8.2 - 26	12.3 - 44	16.4 - 61

Table 5.9 was adapted from Health Canada *Guidelines for Canadian Drinking Water Quality - Summary Table* from Health Canada.

The design of UV systems for potable water treatment should consider the following:

- Be based on the lowest transmittance of the supply and should provide microbiological inactivation consistent with regulatory requirements.
- Provide a minimum of two units (one duty and one stand-by) or a minimum of 50% redundancy (two duty and one stand-by).
- Be based on maximum instantaneous flowrates of the system at the point of disinfection.
- Both Low Pressure-High Output (LPHO) and Medium Pressure (MP) design configurations.
- The UV dose requirements for inactivation of *Giardia*, *Cryptosporidium*, and enteric viruses outlined by Health Canada and compiled in Table 5.9 should be used to meet the log inactivation requirements unless a lower Reduction Equivalent Dose (RED) has been demonstrated through on-site validation testing as per the latest edition of *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule* from the United States Environmental Protection Agency.
- The requirements for start-up and cool-down of reactors.
- Pretreatment requirements for reduction of turbidity, suspended solids, and colour prior to UV disinfection.
- Confirmation of UV reactor validation to achieve required pathogen inactivation.
- The provision of continuous UVT monitoring with alarms, SCADA control, and automatic switchover to the stand-by UV module in the event of low UVT.
- The quality of the power supply and provision of stand-by power, automatic shut-off capability, or alternate disinfection to prevent inadequately disinfected water from entering the distribution system.
- Lamp aging and fouling potential.
- Reactor hydrodynamics to ensure uniform UV dose distribution throughout the reactor.
- Facility hydraulics to ensure even flow distribution through parallel reactors, in accordance with reactor manufacturer's recommendations.
- Headloss requirements.
- Cooling water requirements.
- Reactor isolation and lamp breakage response plans.

5.5.2.2.4 Onsite Hypochlorite Generation & Mixed Oxidants

Onsite hypochlorite generation systems use brine solution and an electrolytic reaction to generate a sodium hypochlorite solution used for disinfection and hydrogen gas, which must be controlled and vented safely. A supply of softened water must typically be provided for the electrolysis reactor. Onsite hypochlorite generation systems are generally proprietary in nature; design of OSG systems must account for manufacturer's recommendations for design requirements.

Mixed oxidants are proprietary oxidants that are formed by a combination of disinfectants specifically tailored to the treatment objectives and will require evaluation of their appropriateness on an individual basis. Information concerning pathogen inactivation will need to be demonstrated by the manufacturer and potential DBPs should be disclosed.

5.5.2.3 Contact Time

Alternate disinfectants should meet either the CT requirements of Section 5.5.1.1, or an approved equivalent disinfection ability such as the required microbiological removal requirements as per regulatory requirements (e.g., ultraviolet disinfection).

5.5.2.4 Disinfectant Residual

Regardless of the primary disinfectant used, free chlorine, total chlorine or chloramine residuals should be provided consistent with Section 5.5.1.2 and/or as defined by the Regulatory Authority having jurisdiction. Should the primary disinfectant not be capable of providing the required chlorine residuals, then a secondary disinfection system should also be provided, consistent with the requirements of Section 5.5.1.

5.5.2.5 Piloting Requirements

Alternate disinfection systems should not be constructed unless adequate water quality and operating data exist to confirm the suitability and efficacy of such processes for a particular water supply source. If such data does not exist, pilot testing should be conducted and should meet the requirements of Section 3.1.2.2.

5.6 Softening

The softening process selected should be based on the mineral qualities of the raw water and the desired finished water quality.

5.6.1 Lime or Lime-Soda Processes

Lime or lime-soda softening processes should meet the following criteria:

- Design of coagulation and clarification facilities should be as outlined in Section 5.2.
- When split treatment is used, the by-pass should be designed to accommodate the total plant flow, and an accurate means of measuring and splitting flow should be provided.
- Determinations should be made for the carbon dioxide content of the raw water to determine if removal by aeration is feasible.
- Lime and recycled sludge should be introduced into the rapid mix basins.
- Stabilization of the water softened by the lime or lime-soda process should be provided.
- Mechanical sludge removal equipment should be provided in the sedimentation basins.
- Provisions should be included for proper disposal of softening sludge.
- The use of excess lime should not be considered an acceptable substitute for disinfection.
- Manual plant start-up should be provided after a plant shut-down.

5.6.2 Cation Exchange Processes

Cation exchange processes for removal of hardness should meet the following requirements:

- Pre-treatment for iron or manganese should be provided when the combined concentration is 1.0 mg/L or greater.
- Water having a turbidity greater than 5.0 NTU should not be applied to a cation exchange softener.
- The units may be of the pressure type and of either upflow or downflow design.
- Automatic regeneration based on volume of water softened should be provided.
- Manual overrides should be provided.
- The design capacity for removal of hardness should not exceed 46 kg/m^3 when resin is generated with 0.14 kg of salt per kilogram of hardness removed.
- The depth of the cation exchange resin should not exceed 1,000 mm.
- The rate of softening should not exceed 17 m/hour.
- Backwash rates range from 14 to 20 m/hour and the backwash water collector should be minimum 600 mm above the resin on downflow systems.
- Underdrain systems and supporting gravel should conform to Section 5.4.1.8.

- Facilities should be included for even distribution of brine over the entire surface of both upflow and downflow units.
- Backwash, rinse, and air relief pipes should be installed in such a manner as to prevent possibility of back-siphonage.
- A metered by-pass should be provided around the softening units with an automatic proportioning or regulating device.
- Silica gel resins should not be used for waters having a pH above 8.4 or containing less than 6.0 mg/L silica or when iron is present.
- When the applied water contains a chlorine residual, the cation exchange resin should be resistant to chlorine (phenolic resin should not be used).
- Sampling taps are to be provided on the softener influent, effluent, blended water, and brine tank discharge piping.
- Brine storage tanks:
  - Salt dissolving or brine storage tanks should be covered and should be corrosion resistant.
  - The make-up water inlet should be protected from back-siphonage and the filling pipes should be located above the brine level in the tank.
  - Automatic declining level control system should be provided on the make-up water line.
  - Wet salt storage basins should be equipped with manholes or hatchways for access and direct dumping of salt from a truck or railcar (openings should be watertight).
  - Overflows, where provided, should be protected with corrosion resistant screens, should have a turned down bend at the termination point and should have a free-fall discharge or a self-closing flap valve.
  - Two wet salt storage tanks designed to operate independently should be provided.
  - Salt should be placed on graduated layers of gravel placed over a brine collection system.
- Total salt storage should have the greater of 1.5 truckloads of salt or be sufficient for 30 days of storage.
- An eductor may be used to transfer brine from the brine tank to the softeners or, alternatively, if a pump is used a brine measuring tank should be provided.
- A suitable means of water stabilization should be provided.
- Suitable disposal should be provided for brine waste.
- Piping should be resistant to the aggressiveness of salt (plastic and red brass are acceptable, however, steel and concrete should be adequately lined).
- Bagged and dry bulk salt storage should be enclosed and be separate from other operating areas.
- Test equipment for alkalinity, total hardness, carbon dioxide content, and pH should be provided.

5.7 Aeration

Aeration may be used for any one of the following reasons:

- To help remove taste and odour.
- To remove volatile organic matter.
- To remove carbon dioxide.
- To assist in iron and/or manganese oxidation.

Aeration is typically provided by the following methods, depending on treatment objectives:

- Natural draft aeration.
- Forced or induced draft aeration.
- Packed Tower Aeration (PTA).

5.7.1 Natural Draft Aeration

Design should provide:

- Perforations to the distribution pan 5 to 12 mm in diameter, spaced 25 to 75 mm on centers to maintain a 150 mm water depth.
- For distribution of water uniformly over the top tray.
- Discharge through a series of three or more trays with separation of trays not less than 300 mm.
- A loading rate of 2.5 to 1.5 m/hour.
- Trays with slotted, heavy wire mesh (12 mm openings) or perforated bottoms.
- Construction of durable material resistant to aggressiveness of water and dissolved gases.
- Protection from loss of spray water by wind using enclosures with louvers sloped to the inside at an angle of 45°.
- Protection from insects by 24-mesh screen (0.7 mm square openings).

5.7.2 Forced or Induced Draft Aeration

Devices should be designed to:

- Include a blower with a weatherproof motor in a tight housing and screened enclosure.
- Ensure adequate countercurrent of air through the aerator column.
- Exhaust air directly to the outside atmosphere.
- Include a down turned and 24-mesh (0.7 mm square openings) screened air inlet/outlet.
- Introduce air into the column as free from fumes, dust, and dirt as possible.
- Be such that sections of the aerator can be easily removed for maintenance of the interior or installed in a separate aerator room.
- Provide a loading rate of 2.5 to 12.5 m/hour.
- Ensure that the water outlet is adequately sealed to prevent unwarranted loss of air.
- Discharge through a series of five or more trays not less than 150 mm.
- Provide water distribution uniformly over the tray.
- Be resistant to corrosion.

5.7.3 Spray Aeration

Design should provide:

- A hydraulic head of between 1.5 and 7.6 m.
- Nozzles, with the size, number and spacing of the nozzles being dependent on the flowrate, space, and amount of head available.
- Nozzle diameters in the range of 25 to 38 mm.
- An enclosed basin to contain the spray.
- Twenty-four (24)-mesh screen (0.7 mm square openings) for openings for ventilation.

5.7.4 Pressure Aeration

Pressure aeration for oxidation purposes should be subject to pilot testing as per the requirements of Section 3.1.2.2. Pressure aeration should not be considered for the removal of dissolved gases. Filters following pressure aeration should have adequate exhaust devices for release of air.

Pressure aeration systems should be designed to:

- Give thorough mixing of compressed air with the water being treated.
- Provide screened and filtered air, free of dust, fumes, oil, and dirt.

5.7.5 Packed Tower Aeration

Packed tower aeration is also commonly known as “air stripping” and is generally used for removing volatile organic chemicals, THMs, carbon dioxide, and radon.

5.7.5.1 Piloting Requirements

Packed tower aeration is generally only satisfactory for removing compounds with a Henry’s Constant greater than 100 (atm mol/mol) and is not normally feasible for compounds with a Henry’s Constant less than 10. For values between 10 and 100, pilot testing should be conducted and should meet the requirements of Section 3.1.2.2. Values for Henry’s constant should be discussed with the Regulatory Authority prior to developing plans and specifications.

In addition to those requirements in Section 3.1.2.2, pilot testing should evaluate a variety of loading rates and air to water ratios at the peak contaminant concentrations. Special consideration should be given to removal efficiencies when multiple contaminations occur.

Piloting may not be required where sufficient operating data adequately demonstrates the feasibility of the process for a specific contaminant. Such will be evaluated on a case-by-case basis by the Regulatory Authority.

5.7.5.2 Process Design

Process design for PTA requires the determination of Henry’s Constant for contaminant, the mass transfer coefficient, the air pressure drop and the stripping factor. The design should consider the height and diameter of the unit, the air to water ratio, the packing depth, and the surface loading rate. The tower should also be designed to meet the following:

- Contaminants should be reduced to below the regulatory requirement and to the lowest practical level.
- The ratio of column diameter to packing diameter should be minimum 10 to 1.
- The volumetric air to water ratio at peak flow should be between 25 to 1 and 80 to 1.
- The design should consider potential fouling due to calcium carbonate and iron precipitation from bacterial regrowth (a pre-treatment system may be required).
- The effects of temperature should also be considered.

5.7.5.3 Materials of Construction

The tower and the packing material should be resistant to the aggressiveness of the water and should be suitable for contact with potable water.

5.7.5.4 Water Flow System

The water flow system should be designed to meet the following requirements:

- Water should be distributed uniformly at the top of the tower using spray nozzles or orifice-type diffusers with one injection point every 190 cm^2 of tower cross-sectional area.
- A mist eliminator should be provided.

- A side wiper redistribution ring should be provided at least every 3.0 m to prevent water channeling and short circuiting along the tower wall.
- Sample taps should be provided on the influent and effluent piping.
- The effluent sump, if provided, should have easy access and be equipped with a drain valve, which should not be connected to any storm or wastewater system.
- A blow-offline should be provided in the effluent piping to allow discharge of cleaning chemicals and water.
- The design should prevent freezing of the influent riser and effluent piping when the unit is not operational (if buried, the piping should be maintained under positive pressure).
- The water flow to each tower should be metered.
- An overflow should be provided with proper drainage.
- Means of preventing flooding of the air blower should be provided.
- The influent pipe should be supported separately from the tower itself.

5.7.5.5 Air Flow System

The air flow system design should:

- Ensure the air inlet to the blower is turned down and covered with a 24-mesh screen (0.7 mm square openings). It is also recommended that a 4-mesh screen (5.0 mm square openings) be provided over the air inlet.
- Have an air inlet in a protected location.
- Provide air flow metering on the influent air piping.
- Provide a positive air flow sensing device and a pressure gauge on the air influent piping (the air flow sensing device should be part of an automatic control system that will turn off the influent water if air flow is not detected).
- A backup blower motor or stand-by blower should be provided.

5.7.5.6 Other

Other measures that should be provided include:

- A sufficient number of access ports with a minimum diameter of 600 mm to facilitate inspection, media replacement, media cleaning and maintenance of the interior.
- A method of cleaning the packing material should be provided.
- Tower effluent collection and pumping wells should be constructed to clearwell standards.
- Provisions for future plant expansion and tower height increase.
- An acceptable alternative supply should be available during periods of O&M interruption.
- No by-pass should be provided.
- Disinfection application points should be provided both upstream and downstream of the tower.
- Adequate packing support should be provided to allow free flow of water and prevent deformation of packing material.
- Stand-by power should be provided as per Chapter 4 for blower and disinfectant feeding equipment.
- Security measures should be provided as per Chapter 4.
- An access ladder and safety cage should be provided for inspection of the exhaust port and demister.
- Electrical interconnection between blower, well pump, and disinfectant feeder should be provided.
- Adequate foundation.
- Check with local Regulatory Authorities to determine if permits are required for the air discharge.
- Noise control should be considered for PTA systems located in residential areas.

5.7.6 Other Methods of Aeration

Other methods of aeration such as spraying, diffused air, cascades, and mechanical aeration may be considered and may be subject to pilot testing requirements.

5.7.7 Protection of Aerators

All aerators, except those discharging to lime softening or clarification plants, should be protected from contamination by wind, debris, birds, insects, rainfall, and water draining off the exterior of the aerator.

Disinfection should meet the requirements of Section 5.5.

5.7.8 By-Pass

A by-pass should be provided for all aeration units except those installed to comply with maximum contaminant levels.

5.7.9 Monitoring

Equipment should be provided to test for DO, pH and temperature. Equipment to test for iron, manganese, and carbon dioxide should be considered where aeration is used for removal of these parameters.

5.8 Iron & Manganese Control

Iron and manganese control, as used herein, refers solely to those treatment processes designed specifically for iron and manganese removal, and the treatment process used should be dependent on the raw water quality and treated water objectives. In any event, the treatment process selected should be capable of removing not only iron and manganese, but also any other contaminants that may be present at or above the regulatory requirements.

5.8.1 Removal by Oxidation, Detention, & Filtration

Oxidation may be by aeration, as indicated in Section 5.7, or by chemical oxidation with chlorine, $KMnO_4$, ozone, or chlorine dioxide. A minimum detention time of 30 minutes should be provided following aeration, unless indicated otherwise through pilot testing (see Section 3.1.2.2). The detention basin may be designed as a holding tank without provisions for sludge removal with sufficient baffling to prevent short-circuiting. Removal with oxidation by $KMnO_4$, chlorine and chlorine dioxide is “rapid” and the design of detention basins should provide minimum 5 minutes of CT.

Sedimentation basins should be provided when treating for high iron and/or manganese content, or where chemical coagulation is used. Provisions for sludge removal should be made. Sedimentation basin design should meet the requirements of Section 5.3.1. Filters should meet the requirements of Section 5.4.

5.8.2 Removal by Lime-Soda Softening

Removal of iron and/or manganese by the lime-soda softening process should meet the requirements of Section 5.6.

5.8.3 Removal by Manganese Coated Media Filtration

Removal of iron and manganese by contact adsorption using pre-coated filter media is a common method of treating iron and/or manganese at concentrations commonly found in Atlantic Canada.

5.8.3.1 Oxidant Addition

An oxidant, typically air, chlorine, or $KMnO_4$, is added to the raw water to oxidize soluble iron and manganese. Dosages should be selected that will take into consideration all oxidant demands including the contaminants to be removed as well as DOC, ammonia, and hydrogen sulfide, among others, and the effect of oxidant addition on other water quality parameters (e.g., formation of DBPs). Multiple oxidizing agents may be used to reduce the required primary oxidant dosage. Pilot studies as per the requirements of Section 3.1.2.2 may be required to confirm actual required dosages. Provisions should be made to apply the oxidant as far in advance of the filter as possible to maximize the CT prior to the oxidized water reaching the filters (this may require a small contact tank in some cases to ensure adequate CT). This process is highly pH dependant. Elevated pH levels may be required for adequate removals particularly for manganese. The optimum operational pH level will be site specific.

5.8.3.2 Media

Manganese oxide coated filter media is commonly used for the removal of iron and manganese. Removal systems for iron, or iron and manganese together, may be dual-media systems incorporating a layer of anthracite a minimum of 150 mm thick to remove particulate (oxidized) iron in the bulk water. Manganese oxide coated media should be in conformance with the latest edition of *AWWA B102 Manganese Greensand for Filters*.

5.8.3.3 Design

Iron and manganese removal systems should be designed as outlined in Table 5.10.

Table 5.10: Iron & Manganese Removal System Design Criteria

	Iron Removal	Manganese Removal
Bed type	Dual media	Single
Anthracite	375 - 450 mm	None
Manganese oxide coated media	450 - 600 mm	> 750 mm
pH	6.2 - 8.5	7.0 - 8.5
Filtration rate	4.0 - 12 m/hour	4.0 - 12 m/hour
Headloss	1.5 m maximum	1.5 m maximum
Backwash	40% bed expansion	40% bed expansion

Filter loading rates for iron and/or manganese removal should be established based on a review of manufacturer literature and these Guidelines. It should be noted that raw water quality, pre-treatment, bed depths, regeneration method used, treatment objectives, etc. will each influence the selection of appropriate loading rates for new installations. It is recommended that the lower range of filtration loading rates be applied unless the design is based on adequate references to similar applications or pilot testing is completed.

Backwash rates should be on the order of 20 to 40 m/hour for manganese oxide coated media in accordance with the media manufacturer's recommendations or based on adequate references or pilot studies. Air scour should also be provided as per Section 5.4.1.13. Iron and manganese are often present together. Ensuring adequate removals of both may require bench or pilot-scale studies to establish the optimum oxidant, pH, and filter media composition.

5.8.3.4 Sample Taps

Sample taps should be provided at the following locations:

- Prior to the application point of oxidant.
- Immediately before filtration.
- At points between the anthracite media and the manganese coated media.
- At the individual filter effluents.
- The combined filter effluent.

5.8.4 Proprietary Media

There are a number of proprietary iron and manganese removal media currently available. Their discussion is beyond the scope of these Guidelines. These proprietary media may be satisfactory in many circumstances. If, in the opinion of the Regulatory Authority, sufficient data is not present to establish the feasibility of the process, pilot studies may be required.

5.8.5 Removal by Ion Exchange

Dissolved iron and manganese can be removed by common cationic ion exchange system (i.e., water softeners), whereby these dissolved ions are removed in the same manner as dissolved hardness ions. Consideration of the form of iron and manganese (dissolved vs. total), the need for pre-treatment, and competing ions that may reduce treatment efficacy must be considered. Where water is generally high quality with the exception of dissolved iron and manganese, as is often found in groundwater supplies, ion exchange may be a feasible treatment technology. Regeneration of ion exchange media produces iron and manganese-laden brine waste, which must be disposed of in a manner which is not detrimental to the receiving environment and is acceptable to the local Regulatory Authority. Iron and manganese are less readily removed from many cationic exchange resin by brine regeneration, and, therefore, typical softener resin may require more frequent replacement than when used for hardness removal alone.

5.8.6 Sequestration

5.8.6.1 Polyphosphates Sequestration

This process should not be used for water containing 1.0 mg/L of iron or above the MAC of manganese. The total phosphate applied must not exceed the maximum allowable dose certified by *NSF 60* testing and should be limited to as low a dose as possible to achieve the desired aesthetic effect. Polyphosphate addition in some cases has resulted in accelerated corrosion, most problematically in lead and copper premise plumbing. Polyphosphate dose should be minimized to mitigate any adverse effect on corrosion control in the distribution system.

Stock phosphate solution should be kept covered and disinfected by carrying approximately 10 mg/L free chlorine residual. Phosphate solutions having a pH of 2.0 or less may be exempt from this requirement.

Polyphosphates should not be applied ahead of iron and/or manganese removal treatment. The point of application should be prior to any aeration, oxidation, or disinfection if no iron or manganese removal treatment is provided.

5.8.6.2 Sodium Silicates Sequestration

Sodium silicate sequestration of iron and manganese may be appropriate for water containing up to 2.0 mg/L of iron, and the MAC of manganese, and is also only suitable for groundwater supplies prior to air contact. On-site pilot testing should be conducted for sodium silicate sequestration as per Section 3.1.2.2. Rapid oxidation of iron and/or manganese by chlorine or chlorine dioxide should accompany or precede sodium silicate addition by no greater than 15 seconds.

Chlorine residuals in the distribution system should not be adversely affected. The amount of silicate added should be limited to 20 mg/L as SiO_2, and the amount of silicate added and natural silicate should not exceed 60 mg/L as SiO_2. Sodium silicate should not be applied before iron and manganese removal processes.

5.8.7 Testing

Testing equipment should be provided for all plants and should meet the requirements of Section 4.7.2. The equipment should have the capacity to measure iron and manganese to minimum concentrations of 0.1 and 0.01 mg/L, respectively. Where polyphosphate sequestration is practiced, phosphate testing equipment should be provided.

5.9 Fluoridation

5.9.1 Naturally Occurring Fluoride

Where fluoride is naturally occurring and above the *Guidelines for Canadian Drinking Water Quality - Summary Table* from Health Canada or regulatory requirements, fluoride should be removed by an acceptable means to less than the required limit. Such methods might include activated alumina media adsorption, ion exchange, RO, or proprietary technologies.

5.9.2 Artificial Fluoridation

Where artificial fluoridation is provided, a dosage of 0.7 mg/L of fluoride is recommended and should not exceed 1.0 mg/L. The presence of background fluoride concentrations in the raw water and removal rates in the treatment process should be well established and taken into consideration when designing fluoride dosing. Sodium fluoride, sodium silicofluoride and fluorosilicic acid may be used for fluoridation and should meet the latest editions of *M4 Water Fluoridation Principles and Practices* from the AWWA and *NSF/ANSI 60: Drinking Water Treatment Chemicals - Health Effects*. Any other compounds used for fluoridation may be considered on an individual basis.

5.9.2.1 Fluoride Compound Storage

Fluoride chemicals should be isolated from other chemicals to prevent contamination. Compounds should be stored in covered or unopened shipping containers within a building. Unsealed storage units for fluorosilicic acid should be vented to the atmosphere at an exterior location. Bags, fiber drums, and steel drums should be stored on pallets.

5.9.2.2 Chemical Feed Equipment & Methods

In addition to the requirements in Section 4.5 fluoride systems should contain the following:

- Scales, loss-of-weight recorder, or liquid level indicators should be provided, accurate to within 5% of the average daily change in readings.
- Feeders should be accurate to within 5% of any desired feed rate.
- Fluoride hoppers should be designed to hold a 24-hour supply of fluoride.
- Fluoride compound should not be added prior to lime-soda softening or ion exchange softening processes.
- The application point of fluorosilicic acid, if in a pipe, should be in the lower half of the pipe.
- A fluoride solution should be applied by a positive displacement pump having a stroke rate not less than 20 strokes per minute.
- A day tank capable of holding a 24-hour supply of fluoride should be provided.
- A spring-opposed or solenoid operated diaphragm-type anti-siphon device should be provided for all fluoride feed lines and dilution water lines.
- The dilution water pipe should terminate at least two pipe diameters above the solution tank.
- Water used for sodium fluoride dissolution should be softened if hardness exceeds 75 mg/L (as $CaCO_3$).
- Fluoride solutions should be injected at a point of continuous positive pressure or a suitable air gap provided.
- The electrical outlet used for the fluoride feed pump should have a non-standard receptacle and should be interconnected with the well or service pump.
- Saturators should be of the upflow type and be provided with a meter and backflow protection on the make-up water pipe.
- All fluoridated water should be metered.
- Floor drains should not be provided, unless discharged to an appropriate treatment system or holding facility.
- Construction should be of corrosion resistant material.
- Should provide dripping tap at each pipe drain.
- Locate only basic essential electrical controls in the fluoride room.
- Use explosion proof motors and electrical components.
- Install conduits such that servicing is easily facilitated.
- All light and fan switches should not be located within the fluoride room.
- Feeders should be provided with anti-siphon devices on the discharge.
- Alarm signals are recommended, where appropriate.
- Flow proportioning or a compound loop residual control system is recommended.

5.9.2.3 Secondary Controls

Secondary control systems for fluoride chemical feed devices should be provided as a means of reducing the possibility of overfeeding. These devices may include flow or pressure switches, or other such devices.

5.9.2.4 Protective Equipment

Personal protective equipment should be provided for operators handling fluoride compounds. Deluge showers and eye wash stations should be provided at all fluorosilic acid installations.

5.9.2.5 Dust Control

Provision should be made for the transfer of dry fluoride compounds from shipping containers to storage bins or hoppers in such a way as to minimize the quantity of fluoride dust which may result. The enclosure should be provided with an exhaust fan and dust filter which place the hopper under a negative pressure. Air exhausted from the fluoride handling equipment should pass through a dust filter and discharge to the exterior of the facility, away from any air intakes.

Provision should be made for disposing of empty bags, drums or barrels in a manner which will minimize dust generation. A floor drain should be provided for wash down of floors in the fluoride area.

5.9.2.6 Testing Equipment

Equipment should be provided for measuring fluoride in the raw and treated water with a minimum range of 0.1 to 2.0 mg/L.

5.10 Corrosion Control

This document is not intended to provide a comprehensive literature review of corrosion in distribution systems, as a wide range of peer-reviewed literature generated by various provinces, Health Canada, the Environmental Protection Agency (EPA), and various scientific journals is available. Some useful reference documents include the following. Note the latest versions of these documents should always be used to ensure up-to-date guidance is followed.

1. *Revised Lead and Copper Rule* from the United States Environmental Protection Agency.
2. *Guidance on Controlling Corrosion in Drinking Water Distribution Systems* from Health Canada.
3. *Optimal Corrosion Control Treatment Evaluation Technical Recommendations for Primacy Agencies and Public Water Systems* from the United States Environmental Protection Agency.
4. *M58 Internal Corrosion Control in Water Distribution Systems* from the AWWA.
5. *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Lead* from Health Canada.
6. *Pitting corrosion of copper in waters with high pH and low alkalinity* written by Lytle et al. and published in Journal AWWA).
7. *Corrosion and solubility of lead in drinking water* from the American Water Works Association Research Foundation (AWWRF) (now referred to as the Water Research Foundation).

There are many other examples – this document is intended to summarize some key points made in these documents and others to simplify corrosion control in drinking water problems and potential solutions; the issue is complex and some introduction on the subject is required prior to expanding into treatment and monitoring guidelines. New documents produced by or referenced by provincial Regulatory Authorities or Health Canada pertaining to corrosion control published after these Guidelines should also be consulted and considered given the advancing science and regulatory standards for corrosion and corrosion by-products in drinking water.

5.10.1 Introduction

Corrosion in drinking water distribution systems may be characterized as either uniform corrosion or non-uniform corrosion. Non-uniform corrosion can be a byproduct of poor-quality plumbing or piping, poor-quality installation, dissimilar metal plumbing connections, excessive water velocity or stagnation in piping which allows for longer corrosion reaction time and can lead to microbiologically induced corrosion. Factors leading to non-uniform corrosion and mitigation measures are addressed elsewhere in this guidance document, in the national plumbing code and in industry best practices for the design and installation of buried piping and premise plumbing, therefore, non-uniform corrosion is not discussed further in great detail in this section. External corrosion factors (e.g., design of buried piping in areas with corrosive soil) are also not discussed in this section, as these factors are not directly related to drinking water quality and design of water treatment processes.

Uniform corrosion is related to the interaction of piping and plumbing materials in contact with the water, and the water itself, and is driven by water quality and piping materials. Reducing uniform corrosion can be done by adjustment of the physicochemical characteristics of the water being distributed or replacing/augmenting the piping and plumbing materials in the distribution systems with materials less susceptible to metallic corrosion (e.g., replacing metal piping with plastic or lining piping with a corrosion-inhibiting barrier). The reactions which occur and resulting materials which form on pipe walls is of utmost importance when considering uniform corrosion; ideally, a passivating (stable) chemical layer forms on a copper or lead pipe wall which inhibits further corrosion. Depending on water quality, and on previous scale formation, other types of scaling can occur which are more soluble or unstable. Scale type and changes to water quality can have significant impacts on metal concentrations ultimately released into drinking water; ultimately, preventing release of metals such as copper and lead into the water is the primary goal of corrosion control in drinking water systems.

In municipal drinking water corrosion control, the primary goal should be the reduction of the concentrations of metals in water at the consumer's tap. Removal of piping and plumbing products which contains lead is a straightforward and effective approach to reducing lead in drinking water but can be prohibitively expensive in the short term. Uniform corrosion may be considered on a system-wide basis and, therefore, the evaluation and mitigation of uniform corrosion in a distribution system is a key aspect of corrosion control in municipal drinking water systems. Municipal corrosion control planning can consider system-specific uniform corrosion issues, such as corrosion of iron or cement lined distribution mains, by adjusting water quality via treatment. That said, the industry and regulatory focus has shifted to emphasize the prevention of corrosion in services lines, both publicly and privately owned, and premise plumbing (indoor potable water building plumbing).

The most significant focus should be on the prevention of lead and copper corrosion. Copper corrosion can result in unpleasant aesthetic impacts at lower concentrations and has recently (2019) been assigned a health-based MAC by Health Canada of 2.0 mg/L, due to short-term gastrointestinal effects and long-term liver and kidney effects. The health effects of lead, particularly the impairment of neurological development in children, are extensively documented elsewhere, and demonstrate the importance of mitigating corrosion leading to elevated lead concentrations in drinking water. The Health Canada MAC was reduced in 2019 to 0.005 mg/L or "as low as reasonably achievable", as there is no safe level for lead in drinking water.

5.10.2 Evaluation of Water Quality for Corrosiveness

The relationship of key water quality parameters with corrosion rates in distribution system piping and premise plumbing can be complex, but the following water quality parameters are known to influence lead and copper corrosion and should be monitored as part of any evaluation of water corrosiveness.

5.10.2.1 pH

The single most significant factor in lead and copper corrosion is pH. The solubility of most metals (including lead and copper) increases with decreasing pH. Health Canada recommends drinking water pH levels be kept between 7.0 to 10.5, for the express purpose of reducing lead and copper corrosion. Lead solubility is at a minimum at pH levels of 9.6 to 9.8 when Dissolved Inorganic Carbon (DIC) is low. A target pH of 9.5 is recommended for DIC levels below 40 mg/L elemental carbon per liter (C/L) or 137 mg $CaCO_3$/L. When DIC levels are above this increasing the pH is not the best method for reducing lead solubility.

5.10.2.2 Dissolved Inorganic Carbon & Alkalinity

Alkalinity is a measurement of the carbonate, bicarbonate, and hydroxide concentrations in water – these ions have the ability to accept H+ ions, buffering the solution from pH decreases. When an acid is added to solution the alkalinity provides buffering to mitigate pH decreases. As alkalinity provides buffering capacity to reduce localized pH decreases and the resulting lead and copper corrosion, sufficient alkalinity is required for corrosion control. Alkalinity can be increased with the addition of a concentrated base chemical, such as sodium hydroxide (caustic) which contributes hydroxide-based alkalinity, or calcium carbonate (lime) which contributes carbonate-based alkalinity while also increasing DIC.

Dissolved inorganic carbon is a measurement of carbonate, bicarbonate, and dissolved CO_2 (carbonic acid), ions which contribute the inorganic fraction of carbon to drinking water and which play a major role in scale formation and scale solubility. While alkalinity and DIC are similar, they are distinct and separate – CO_2 addition increases the DIC in water while lowering pH and not affecting alkalinity, which does not account for dissolved CO_2. The relationship between copper and lead solubility with DIC is complex, but generally it is understood that higher DIC (particularly at low pH) can increase the corrosion potential of lead and copper in plumbing. The relationship between DIC and lead and copper corrosion is not fully understood, but increasing corrosiveness at high DIC levels is potentially due to the reduced stability and increased solubility of the carbonate-based scales.

5.10.2.3 Chloride to Sulphate Mass Ratio

A higher Chloride to Sulphate Mass Ratio (CSMR) generally results in higher corrosion of lead in lead-copper plumbing, particularly above a CSMR value of 0.5, due to increased galvanic reactions between dissimilar metals in piping systems. Lead corrosion rates can be significantly affected by various other water quality and plumbing component factors (organics, pH, phosphate concentration, etc.). A CSMR less than 0.5 can mitigate lead corrosion by encouraging passivating lead-sulphate complexes to form on lead surfaces. The introduction of a higher CSMR water to a pipe network conditioned with lower CSMR water (e.g., switching coagulants from sulphate-based to chloride-based) has led to significant documented corrosion events and, therefore, great care should be taken if this type of operational change.

5.10.2.4 Natural Organic Matter

Higher NOM concentrations are likely to increase lead and copper solubility, while in some cases NOM has been found to reduce corrosion of piping and pipe scales under specific water quality conditions. NOM removal is typically maximized to the greatest possible extent during treatment as it is a DBP precursor and, therefore, it is not recommended that utilities should aim to control NOM in treated water for the purposes of attempted corrosion mitigation where other factors can typically be optimized with fewer potential negative side effects.

5.10.2.5 Oxidation-Reduction Potential

Oxidation-Reduction Potential (ORP) or “redox potential” is a measurement of the oxidation state of water, which reflects the potential for corrosion reactions where a solid material (i.e., pipe or scale) is oxidized in a reduction-oxidation reaction, resulting in a release of a dissolved metal ion. Oxidation-reduction potential in drinking water distribution systems is driven by pH and free oxidants in the water, including chemical disinfectants and DO.

5.10.2.6 Other Transitional Effects

In plumbing which has been exposed to one type of water chemistry over many years, it is expected that certain pipe scales form within the plumbing. The type of scale which are likely to form are dependent on the factors above, however, if the water chemistry is altered significantly there is a likelihood that the pre-existing scale will be destabilized, resulting in a potential release of lead and copper plumbing components into the water supply. This can occur even when the change in water quality is from a “more corrosive” to a “less corrosive” source – the “corrosion” that can take place is not of copper piping, but of the scale buildup on the internal plumbing components which has been developed under the original water chemistry conditions and is destabilized as a new, more passive scale is formed.

5.10.2.7 Carbonate Saturation

The Langelier Index was used to determine the carbonate scale-forming potential in water, with an assumption that a scale which forms a protective layer between the pipe inner walls and water would act to inhibit corrosion reactions. This theory is no longer considered valid as calcium carbonate scale formation has been found not to effectively inhibit copper and lead corrosion due to the nature of the scale development. High DIC often occurring along with carbonate oversaturation is more likely to result in accelerated lead and copper corrosion. A system with carbonate-based scale may be highly susceptible to scale disruption if pH levels drop, resulting in a significant corresponding release of dissolved and particulate corrosion by-products containing lead and copper. A water with balanced Langelier Index may contain elevated pH, moderate levels of DIC and sufficient alkalinity for buffering capacity, but this measurement should not be used as a direct evaluation of the lead and copper corrosion potential of water. The Langelier Index should be used to predict scale formation as a potential negative for aesthetic water quality and maintenance, particularly in hot water systems and kitchen appliances, but not for the purposes of lead and copper corrosion potential evaluation.

5.10.2.8 Corrosion Studies

Beyond water quality analysis and review, corrosion studies which are intended to quantify corrosiveness in the distribution system over time and with changing source water, treatment practices or piping materials may utilize a coupon rack or pipe loop arrangement system to do so. The design of this type of study will vary with the objectives and, therefore, there is not set guidance on the number of test points, optimal location of the apparatus in the distribution system, materials studied, flowrates and patterns used, testing parameters and water quality adjustments. Corrosion studies may yield information on the short-term effects on existing distribution system piping, but often these studies are established on a longer-term basis to determine seasonal and multi-year corrosion rates and/or the effects of corrosion control measures taken or under consideration.

A simple example of a corrosion study would be for a System Owner which is considering the potential impact of a switch to an alternative disinfectant on copper corrosion. The corrosion study would be designed to evaluate the effects on system-wide copper corrosion from making the disinfectant switch. A pipe loop apparatus consisting of two copper pipes (ideally old pipes taken from the distribution system which have been conditioned with the existing supply) could be set up in parallel, with one pipe being fed from downstream of the existing disinfection system. The other pipe would be fed from just upstream of existing disinfection system, and the alternative disinfectant would be metered into the test loop at the same concentration that would be present if the System Owner were to make the switch. All other environmental conditions (flow, pressure, temperature, etc.) would be held constant for each pipe, and regular measurements of copper in the water from each loop would be taken. The pipes themselves could also be removed and analyzed visually, or using scanning electron microscopes in more advanced studies, to identify changes to the composition of pipe wall and scale.

5.10.3 Monitoring for Corrosion in Distribution Systems

The *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document - Lead* from Health Canada, which was updated in 2019 along with the lead MAC, contains detailed guidance on how to conduct lead sampling in residential and non-residential buildings; this is consistent with *Guidance on Controlling Corrosion in Drinking Water Distribution Systems* from Health Canada (2009). Both these documents focus on improving the accuracy of monitoring for corrosion and lead exposure at the consumer's tap by outlining specific sampling methodology. Since lead in drinking water most commonly originates in older lead service lines and older premise plumbing components and not at the source or in distribution mains, a sampling point in a new building with an unleaded service line, located directly adjacent to an older building with high lead concentrations at the tap, will not provide any indication of issues there. Similarly, a home with lead service lines and leaded premise plumbing components may show negligible lead levels in a sample taken immediately after flushing fresh water from the distribution main through the service line and premise plumbing. The methodology applied during lead sampling can, therefore, either obscure significant lead concentrations in drinking water in a specific building or point of use or confirm presence and concentrations of lead, as well as determine the likely source of lead (i.e., fixtures, plumbing section, or service line). For that reason, the corrosion monitoring program methodology and sampling methodology at individual sites should align with the information that the program and individual sample are intended to provide.

A municipal corrosion control program should include evaluation, treatment, and monitoring of water quality at the points of use in the distribution system most susceptible to lead corrosion (e.g., buildings with lead service lines or lead plumbing), or where populations at greater risk (e.g., daycares and schools). The program should be developed in accordance with guidance from the Regulatory Authority having jurisdiction and using the approaches outlined in the latest edition of *Guidance on Controlling Corrosion in Drinking Water Distribution Systems* from Health Canada.

5.10.4 Treatment for Corrosion Control

Corrosion control by municipal water providers should include, at a minimum, regular monitoring of key water quality characteristics and completing system-wide corrosion monitoring in accordance with Section 5.10.3. If monitoring demonstrates that corrosion control goals cannot be met, corrosion control via treatment may be required. Corrosion control treatment involves the adjustment of water quality via chemical addition; this may mean dose adjustment of chemicals used in the existing treatment and disinfection process, or separate chemical feed designed specifically for corrosion inhibition. Key water quality criteria should be established and treatment for corrosion control should include regular measurement and verification that key water quality targets are being met. Laboratory testing equipment should be provided for determining the effectiveness of stabilization treatments where specific water quality parameter targets have been established (e.g., pH and alkalinity).

Monitoring, setting of treated water quality criteria, treatment modifications, and treated water quality verification should be considered a circular process, requiring iterative adjustments to ensure an effective corrosion control program. If monitoring results in a need for water quality adjustments via treatment, the following actions may be considered:

- Increase pH.
- Balance dissolved inorganic carbon/alkalinity.
- Reduce the CSMR.
- Balance ORP.

- Corrosion inhibitors.
- Carbon dioxide addition.

The following sections outline more information on each action.

5.10.4.1 Increase pH

The relationship between lead, copper, and other metals with pH, where the metals are more soluble at lower pH levels, explains why pH is the most significant factor in corrosion of metal piping systems. pH should be increased to a range within the *Guidelines for Canadian Drinking Water Quality - Summary Table* from Health Canada, 7.0 to 10.5. Increasing pH above 8.0 is unlikely to result in any additional benefits unless DIC is extremely high and may cause negative effects on corrosion between 8.0 to 8.5. Where WTPs may already have a pH adjustment process step, it may be relatively simple to increase pH by simply increasing the dose of this chemical (if used for post-treatment pH adjustment) or adding a second dosing point post-treatment if the pH is controlled for other treatment processes (e.g., coagulation).

5.10.4.2 Balance Dissolved Inorganic Carbon & Alkalinity

Very low alkalinity treated water is poorly buffered and results in low pH areas within the piping network, and hence accelerated corrosion. Excess DIC can increase the solubility of corrosion byproducts, having the same effect on dissolved metals concentrations. For that reason, the DIC/alkalinity should be balanced. The target DIC/alkalinity is dependent on other water quality characteristics, such as pH, chlorine residual and NOM, but generally should be within the range of 30 to 75 mg/L alkalinity as $CaCO_3$. DIC should be above 5.0 mg/L as C at minimum, but the level of DIC which may increase corrosion rates is highly site specific. DIC reduction can be achieved by blending with another source, ion exchange or high-pressure membrane filtration—each of these approaches can also negatively affect the corrosiveness of the water in many scenarios and should be considered carefully. A source with high DIC should ensure pH is kept within the optimum range and is well buffered, and the use of corrosion inhibitors should be considered.

5.10.4.3 Reduce the Chloride to Sulphate Mass Ratio

If the chloride to sulphate ratio is close to 0.5, any reduction in the CSMR may yield benefits specifically to lead corrosion due to galvanic reactions if all other factors are held equal. Many treatment systems do not have the ability to adjust this factor, however, and the source water quality will often be the determining factor in CSMR, particularly where the source water has high ionic strength (in Atlantic Canada, this is most often only found in groundwater sources).

5.10.4.4 Balance Oxidation-Reduction Potential

Free chlorine or chloramine disinfectants are the two most common oxidants found in treated water distribution systems and tend to be the determining factors in ORP. Disinfectant residual should, therefore, be kept at the lowest possible level while still maintaining an adequate concentration for secondary disinfection. In some cases, DO plays a significant role in ORP and, therefore, DO levels should be more closely controlled (particularly where aeration is used in the treatment process).

5.10.4.5 Corrosion Inhibitors

Orthophosphate can effectively form a passivating scale on pipe walls to limit corrosion and has an optimum pH for use which is typical in drinking water in Atlantic Canada. Orthophoshate has been applied widely and successfully for corrosion control in Atlantic Canada.

Silicate-based corrosion inhibitors are also available, but there is limited information on how these chemicals work. Silicates are typically a basic compound associated with an increase in pH, making it difficult to attribute reductions in lead and copper to sodium silicate alone when an increase in pH also decreases lead and copper concentrations. Some research indicates that the addition of silicate-based inhibitors may actually increase lead concentrations in drinking water by destabilizing existing corrosion scales.

Polyphosphate does not provide corrosion protection and, therefore, an orthophosphate-based chemical should be used unless studies specific to the water system in question have demonstrated effectiveness of a polyphosphate chemical. Polyphosphate is used to react with metals and keep the ions in aqueous solution (and thereby address “red water” issues in distribution systems experience these issues), whereas orthophosphate reactions result in precipitation and hence scale formation. Polyphosphate can potentially increase lead concentrations by similar mechanisms that result in red water control.

Where phosphate-based corrosion inhibitors are used:

- Feed equipment should conform to Section 4.5.
- Stock phosphate solution should be kept covered and disinfected by maintaining approximately 10 mg/L chlorine residual (phosphate solutions having a pH of 2 or less may be exempt from this requirement).
- Adequate chlorine residuals should be maintained in the distribution system.
- Chemicals should be marked *NSF 60* and dose should not exceed the maximum dose listed on the NSF certification.

5.10.4.6 Carbon Dioxide Addition

Carbon dioxide is used to reduce pH without reducing alkalinity, replacing hydroxide ions in solution with carbonate, and is commonly applied after pH boosting treatment steps. Re-carbonation basins should provide:

- A total minimum detention time of 20 minutes.
- Two compartments, with a depth that will provide a diffuser submergence greater than 2.3 m but not greater that the submergence recommended by the manufacturer, as follows:
  - A mixing compartment having a minimum detention time of 3 minutes.
  - A reaction compartment.
- Plants generating carbon dioxide from combustion should have open top re-carbonation tanks in order to dissipate carbon monoxide gas.
- Where liquid carbon dioxide is used, adequate precautions should be taken to prevent carbon dioxide from entering the plant during the re-carbonation process.
- Provisions should be made for draining the re-carbonation basin and for removing sludge.

5.11 Harmful Algal Blooms

Harmful algal blooms events occur when there is prolific growth of algae or cyanobacteria in a water body that can cause harm to people, animals, or local ecology. For a treatment plant, a HAB event can result in increased biomass loadings, toxins, taste and odour compounds or a combination of the three reaching the raw water intake and entering the treatment processes. Detection of an algal bloom in the source water is not mutually inclusive to the presences of increased biomass loadings, toxins or taste and odour compounds and appropriate investigation should be completed to confirm if the algal bloom is harmful/noxious. Treatment required to remove biomass loadings, toxins or taste and odour compounds will vary depending on the parameters and concentrations present and may vary between bloom events. Factors within a watershed or source water that can contribute to HAB events occurring include nutrient loading, water temperature, water stagnation, wind patterns and available sunlight. Conditions that lead to shallow, warm, stagnate water are favourable for algal and cyanobacteria growth.

5.11.1 Cyanobacteria

Cyanobacteria, also known as blue green algae, are photosynthetic bacteria that can be found in many aquatic ecosystems and can be an important factor in the ecosystem food chain, however, excessive growth of cyanobacteria can result in public health and water quality concerns. When rapid growth occurs, it is often referred to as a cyanobacteria bloom or a HAB. Depending on the cyanobacteria species present, the bacteria may have the ability to produce taste and odour compounds such as geosmin or 2-methylisoborneol (MIB), cyanotoxins, and increased biomass loadings. There are over 3,000 known species of cyanobacteria known, however, approximately roughly 50 species produce cyanotoxins or taste and odour compounds. Some of the most common species that occur are *Microcystis*, *Dolichospermum*, and *Planktothrix*. Detecting a cyanobacteria bloom in a source water supply does not always indicate that cyanotoxins or taste and odour compounds will be present, however, the bloom should be investigated to confirm.

Cyanotoxins are chemical compounds produced by certain species of cyanobacteria that have toxicological properties. The cyanotoxins are often grouped based on what they toxicologically target. The most commonly found cyanotoxins are microcystin, cylindrospermopsin, anatoxin and saxitoxin. Cyanotoxins can be located within an intact cyanobacteria cell (referred to as intracellular) or can be released from the cell into the water matrix (which is referred to as extracellular). The form of the cyanotoxin is important to determine the treatment processes and strategies that will be effective for removal.

Cyanotoxins (as of publishing) have a MAC of 1.5 ug/L as total microcystin in treated drinking water as outlined by the *Guidelines for Canadian Drinking Water Quality - Summary Table* from Health Canada. Guidance is also provided in the *Guidelines for Canadian Drinking Water Quality - Summary Table* from Health Canada that when conditions are present where microcystin concentrations are greater than 0.4 ug/L in the treated water, the public should use an alternative suitable water supply (bottled water) for reconstituting infant formula. The *Guidelines for Canadian Drinking Water Quality - Summary Table* from Health Canada have not been developed at this time for other cyanotoxins, due to insufficient data available. Other jurisdictions (as of publishing), including United States Environmental Protection Agency (USEPA) and Quebec have developed guidance levels for other toxins, and the World Health Organization has guidance documents that can be reviewed for additional information.

Geosmin and MIB are two highly volatile taste and odour compounds that can be produced by cyanobacteria. They are typically associated with musty, earthy odours and can be detected by humans at very low concentrations. While they do not have health-based water quality guidelines, they can contribute to taste and odour complaints from customers.

In Atlantic Canada, cyanobacteria and cyanotoxins have been identified as an emerging water quality concern as occurrences of blooms in the region historically was limited and treatment plants were not typically designed for cyanotoxin removal. With changing surface water source quality due to lake recovery, potential climate change impacts, and eutrophication that can favour conditions for HAB events to occur, the risk that surface water source supplies could be susceptible to a bloom has increased. As existing WTPs were likely not designed for cyanobacteria/cyanotoxin events and likely have limited experience with operating conditions during an event, surface WTPs may be vulnerable in the event a bloom occurs. An assessment of existing WTPs and treatment processes should be completed to identify current strategies and processes in place that could handle a bloom event and to identify areas that would be vulnerable and may require additional treatment processes to provide a robust response to a HAB event that would ensure treated water quality is preserved. Tools such as CyanoTOX (provided through AWWA) can be used in assessing the capabilities of existing treatment processes.

5.11.2 Algae

In addition to cyanobacteria, there are many species of algae that can experience excessive growth and result in a HAB. Similar to cyanobacteria, HABs as a result of algal growth can contribute increased biomass loadings, taste and odour compounds, toxins (that are not classified as cyanotoxins) or a combination of the three to a source water. Increased biomass loadings from algae can contribute to decreased treatment plant performance, clogging of filtration systems and decreases in treated water plant capacity. Algal species that are commonly associated with HABs and decreased plant performance include (but are not limited to) chlorophytes (green algae), ochrophytes, and bacillariophyta (diatoms).

Algal blooms should be investigated to determine if toxins may be produced by the species present and if it may be harmful. The presences of an algal bloom in the source water is not a definite indicator that there will be a health risk or result in decreases in treatment plant operations, but should be investigated and monitored to confirm.

5.11.3 Taste & Odour Compounds

Taste and odour in drinking water may come from inorganic and anthropogenic sources but is generally referred herein as taste and odours caused by microbiological activity in the source water. This includes taste and odour compounds released by algal and or cyanobacteria during a HAB. Taste and odour compounds from a HAB event are typically the result of VOCs that are release from the algae or cyanobacteria as the bloom grows or dies off. Taste and odour compounds released during a cyanobacteria bloom are most notably geosmin and MIB, and typically have an earthy/musty/grassy odour. Taste and odour compounds produced by algal species such as chrysophytes, synurophytes, and diatoms can have a fishy, oily, floral, or cucumber smell to humans. A visible bloom may not be present when a taste and odour event occurs in a source water and as such can be difficult to predict, resulting in reactive rather than proactive actions for treatment.

Taste and odour compounds typically do not pose a health risk to humans but can contribute to aesthetic concerns and complaints from consumers. While the correlation between the presences of taste and odour compounds and toxins is not fully understood, the presences of taste and odour compounds should lead to further investigation in the source water to confirm that toxins, that could pose a health risk to consumers, are not present. Depending on the bloom and parameters of concern (toxins, increased biomass) that are present, the treatment process required for removing taste and odour compounds may vary.

Taste and odour issues may also occur in groundwater supplies and these typically relate to sulfur-reducing or iron-reducing bacteria.

5.11.4 Monitoring Harmful Algal Blooms in Source Water

Guidance for monitoring cyanobacteria, algae biomass and taste and odour compounds is regularly evolving. Regular baseline sampling of common water quality parameters in the source water and within the WTP can be used for monitoring for conditions that may indicate a bloom is occurring.

These parameters include, but are not limited to:

- Temperature.
- pH.
- Alkalinity.
- Turbidity.
- Dissolved oxygen.
- UV254.
- Total organic carbon.
- Nutrients (Total Nitrogen (TN) and Total Phosphorus (TP)).
- Phycocyanin.
- Chlorophyll *a*.

These parameters are not exclusive to cyanobacteria, cyanotoxins or algal growth, but trending of baseline water quality can be used as a screening tool to indicate that favourable conditions for a bloom are occurring in the watershed. Regular visual inspections of the watershed should be completed during spring and summer months for source waters that could be susceptible to a HAB event. Blooms can have varying buoyance throughout the day and visibility of the bloom may change, so multiple visual inspections may be required. Visual detection or significant variation from baseline water quality conditions should trigger direct measurement for cyanobacteria, cyanotoxins or taste and odour compounds.

If a bloom is present or suspected in the source water, field test kits (including test strips) can be used as a rapid presences/absence test to identify if a bloom is toxic. The field kits should not replace quantitative analyses and may only account for extracellular toxins if a lysing agent is not used. Field kits are available with and without a lysing agent and it is important to ensure the correct type of kit is being used for the water being tested (e.g., raw water vs. treated water). Algae/cyanobacteria identification and cell count can also be used as a primary screening tool to determine if the species present in the bloom are capable of producing cyanotoxins.

The two most commonly accepted methods for quantification of cyanotoxins are Enzyme-Linked Immunosorbent Assay (ELISA) (considered semi-quantitative) and Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS). Each test method has varying advantages and disadvantages, and the standardization of methods for detection of cyanotoxins is still evolving.

If a HAB event is suspected or confirmed, regular sampling in the watershed and the WTP should be completed. Multiple locations in the WTP should be considered including raw water intake, clarified water, filtered water, treated water post CT, clarifier sludge and waste streams.

5.11.5 Treatment Strategies for Harmful Algal Blooms

Strategies for responding to cyanobacteria or a HAB event can be categorized into source water management strategies and treatment processes within the WTP.

5.11.5.1 Source Water

5.11.5.1.1 Algaecides

The application of an algaecide to address a cyanobacteria or algal bloom is often a short-term solution. The most commonly used algacides are copper based, typically copper sulfate. It is not recommended to use copper sulfate during a bloom as it will lyse the cyanobacteria cells and release intracellular toxins into the water, which are more difficult to remove with conventional treatment trains. Copper sulphate can be toxic to other aquatic organisms and can result in copper accumulation in the lake/reservoir sediment. If used, algaecides should be used early into a bloom to limit the release of intracellular toxins, with regulatory approval and when alternative options are not feasible.

5.11.5.1.2 Artificial Mixing

Artificial mixing may be effective for smaller lakes or reservoirs. It works by reducing stratification in the body of water and minimizes the extent of a bloom or can be implemented to break up an emerging bloom. Artificial mixing can be completed with mechanical mixers, aerators, or wind mixing. To be effective, artificial mixing should:

- Mix at least 80% of the water volume.
- Have a mixing rate greater than the vertical movement of the cyanobacteria.
- Have a body of water that is sufficiently deep to ensure circulation.

5.11.5.1.3 Aeration/Hypolimnetic Oxygenation

Aeration or hypolimnetic oxygenation can be used to reduce the release of nutrients from the sediment from anoxic conditions, limiting nutrients available for a cyanobacteria bloom in the upper water layers. Hypolimnetic oxygenation works as a preventative measure for maintaining conditions in the water body rather than a method for reacting to a cyanobacteria bloom. Oxygenation can be completed using airlift pumps, Speece cone or bubble-plume diffuser. A nutrient budget should be developed for the water body to confirm that sediment released phosphorus contributes a significant portion of the water's phosphorus loading prior to moving forward with aeration, as there can be high capital and annual costs for an aeration system.

The system should be designed to introduce oxygen to the hypolimnion layer, but not to disrupt the thermal stratification of the lake.

5.11.5.1.4 Sonication

Sonication involves using ultrasound to control cyanobacteria blooms in a reservoir. The ultrasound wave disrupts the function and structure of the cyanobacteria cells and can control algae growth. This said, there have been limited applications and further research into the technology is required.

5.11.5.1.5 Phosphorous Sequestering

Phosphorus is a limiting nutrient for algae growth. Phosphorus sequestering agents, such as aluminum based or bentonite-based products, can be added to the source water to bind to available phosphorus to limit a cyanobacteria bloom using it as a nutrient. Factors that influence the use of phosphorus sequestering include the dose required, area of source water/reservoir to treat and regulatory limits for the source water (i.e., aluminum concentrations).

5.11.5.1.6 Alternative Intake or Source Water

If the WTP has multiple source waters or multiple intakes for a source water, avoiding water that contains cyanobacteria may be possible. Some cyanobacteria (such as *Microcystis* or *Anabaena*) typically follow diurnal buoyancy patterns and can travel throughout the water column on a regular schedule. Alternative intakes or adjustments to pumping schedules may be used to avoid cyanobacteria entering the facility if the location of the bacteria in the water column can be determined through monitoring and sampling. *Planktorhrix* or *Cylindrospermopsis* bacteria typically do not follow a diurnal buoyancy pattern and tend to be spread throughout the water column.

Changes in source waters during a bloom event (i.e., from surface water to groundwater) should be done in consideration with other water quality concerns such as DBP formation or corrosion control.

5.11.5.2 Within Treatment Plant

5.11.5.2.1 Conventional Treatment

Modifications and optimizations to conventional treatment trains can be effective for removal of intact cyanobacteria and intracellular toxins. The objective when using a conventional treatment train (coagulation, flocculation, clarification, and filtration) is to remove intact cyanobacteria cells if the toxin is intracellular without lysing and releasing the cyanotoxins. Conventional treatment processes would not be effective for removing extracellular cyanotoxins or for removing geosmin or MIB compounds.

The cyanobacteria cell shape, size and particle charge can vary greatly between HAB events and can affect coagulation performance. Due to the variability in HAB events and WTP process trains, specific coagulation guidelines cannot be provided. Jar testing should be completed regularly throughout a HAB event to set full-scale operational conditions and inform operators of plant performance. Parameters that could be used to evaluate coagulation performance during a HAB event include but are not limited to:

- Natural organic matter.
- Particle count.
- Streaming current/zeta potential.
- Phycocyanin.
- Chlorophyll *a*.
- Turbidity.
- pH.

If pre-oxidation is used at the WTP, consideration should be given whether to turn it off during the HAB event to prevent cell lysing. Attention to potential impact on other water quality objectives such as manganese or organics removal should be considered, and mitigation strategies developed.

Clarification and filtration processes, when optimized, can be effective for removing intact cyanobacteria and intracellular cyanotoxins. Dissolved air flotation has been shown to be more effective for removal of intact cyanobacteria when compared to sedimentation, however, is dependent on the buoyancy of the cells. Ballasted flocculation has also been demonstrated to be effective for removal of intact cells.

Conventional dual media filters, when coupled with optimized coagulation, flocculation, and clarification, can be effective at removing intact cyanobacteria cells, however, would not be effective for removal of extracellular toxins or taste and odour compounds.

Sludge age in clarifiers should be minimized to prevent degradation of cells and release of extracellular toxins. More frequent backwashing of filters to prevent clogging, filter head loss increase, or filter breakthrough due to increased solids loadings may be required and could result in decreased production volumes for the facility during the HAB event.

5.11.5.2.2 Adsorption – Granular Activated Carbon

Granular activated carbon can be effective for extracellular cyanotoxin, taste, and odour removal and is typically used for WTPs that are repeatedly affected by cyanobacteria, cyanotoxins, and/or taste and odour compounds.

There are many factors that can affect the performance of activated carbon for the removal of cyanotoxins or taste and odour compounds including but not limited to the pore size and structure of the selected activated carbon media, effective size of the target cyanotoxin/taste and odour compound, presence of NOM in the source water and pH.

Commercially, activated carbons are typically divided into three categories based on the raw materials they are produced from:
- Wood-based.
- Coconut based.
- Bituminous/coal based.

Literature has shown that wood based activated carbons generally have larger mesopores which can be effective for microcystin and cylindrospermopsin removal. Coconut base activated carbons have been shown to be effective for anatoxins, saxitoxins, and taste and odour compounds due to the distribution of micropore structures on the media. Bituminous activated carbon has a wider range of pore sizes, which can be applicable for multiple cyanotoxins or taste and odour compounds.

Rapid Small-Scale Column Tests (RSSCTs) or Accelerated Column Tests (ACTs) can be completed to evaluate different activated carbon media based on specific source water conditions. One size will not fit all, and pilot testing is essential to determining what type and design of GAC filter or contactor would be suitable for a facility.

Granular activated carbon can be implemented as either a filter cap (portion of multimedia filter bed is GAC media) or as a GAC contactor following multimedia filtration as a polishing step. With either application, the empty bed CT is an important design parameter. Increased empty bed CT will allow for more increased parameter removal and provide greater resiliency to competing parameters such as NOM. From literature, empty bed CT typically varied between 5 to 15 minutes for effective removal, with 10 minutes commonly recommended as a minimum CT for design.

The expected effective GAC media life is site specific and will vary between applications. Continuous adsorption of TOC/DOC on the media under normal operating conditions will reduce the capacity of the GAC over the operation of the media. As such it can be very difficult to predict when the GAC media may no longer provide effective adsorption removal of cyanotoxins and/or taste and odour compounds and needs to be regenerated or replaced. It is recommended that testing is completed on a regular basis to estimate the available capacity of the GAC media to handle a cyanotoxin and/or taste and odour event occurring and to identify if replacement or regeneration is required. Laboratory testing could also be completed to determine if removal of target parameters is being completed by adsorption alone or a combination of adsorption and biodegradation by biofilms established on the filter media, which could also influence replacement of the filter media.

For applications where GAC is added as a filter cap to existing filters, modifications to existing backwashing procedures should be considered to have an effective backwash and to limit loss of media.

Granular activated carbon filters or contactors should be designed in accordance with Section 5.4.1.7.

5.11.5.2.3 Adsorption - Powered Activated Carbon

Powdered Activated Carbon (PAC) can be used on a short term or seasonal basis for effective extracellular cyanotoxin removal and taste and odour control. The type of carbon that is used, along with the mesopore size and structure will influence the adsorption of cyanotoxins or taste and odour compounds. The pH of the water along with presence of completing parameters, such as NOM or pre-oxidants (i.e., permanganate or chlorine), will also affect the adsorption process.

Wood based PACs typically have a large distribution of mesopores and have been found to be most effective for microcystin removal. Coconut based PAC generally has smaller micropore structures which can be more effective for anatoxin, saxitoxin and taste and odour compounds. Bituminous and coal-based carbons typically have combination of pore structures, which can make it effective for removal of a combination of cyanotoxins and taste and odour compounds. Bench-scale testing should be completed as part of the process for PAC selection process to determine the appropriate activated carbon type. Commercial availability of the activated carbon type should also be included in the selection process.

Powdered activated carbon dosing for cyanotoxin and taste and odour removal typically starts as a basepoint in the range of 10 to 40 mg/L. Contact times can vary between 30 to 90 minutes for effective removal. To achieve adequate CT, PAC feed points such as the raw water intake, rapid mix tank or prior to clarification should be considered. Consideration for the interaction between PAC and other pre-treatment chemicals used by the facility should be given. Jar testing should be completed to determine PAC dose and CT for optimal performance as it is highly source water and treatment process dependent.

For WTPs that are retrofitting an existing facility to incorporate PAC addition on a seasonal or as needed basis, the following should be considered:

- Powdered activated carbon can be hazardous and/or explosive when handled. Sufficient storage and handling space is required for safe operations.
- Sourcing of sufficient PAC supply should be completed ahead of anticipated cyanobacteria/taste and odour season to ensure supply.
- Addition of PAC increases solids loading on the WTPs clarifier and filters. An assessment of the capacity of existing treatment processes to handle PAC solids loadings could be completed. Powdered activated carbon can cause damage to equipment such as mixers or sludge rakes if they are not designed to handle the additional solids loadings.
- High PAC doses can result in PAC breakthrough of filters, which can increase filter effluent turbidity and reduce filter runtimes.
- Careful consideration of disposal of spent PAC to limit potential desorption of cyanotoxins or taste and odour compounds back into the treated water.

Designs for PAC systems should meet the following requirements:

- Powdered activated carbon should be added as early as possible in the treatment process to provide maximum CT.
- Flexibility to add PAC at several points is recommended.
- Powdered activated carbon should not be applied near the point of chlorine addition or other oxidants.
- Powdered activated carbon can be added as a pre-mixed slurry or by means of dry feed.
- Continuous agitation should be provided to ensure that the PAC does not deposit in the slurry storage tank.
- Powdered activated carbon slurry storage tanks should be designed to avoid excessive slurry age and improve consistency.

- Provision should be made for adequate dust control.
- Provision should made for a rate of PAC feed up to 40 mg/L.
- Powdered activated carbon should be considered potentially combustible material and should be stored in a separate fire-retardant building or room equipped with explosion proof outlets, lights, and motors.

5.11.5.2.4 Oxidation – Chlorine

Chlorine has been shown to be effective for oxidizing some extracellular toxins. The effectiveness is dependent on the chlorine dose, pH, CT, temperature, and dosing location within the treatment train, along with the target toxin. Chlorine has been shown to be effective at oxidizing extracellular microcystins, cylindrospermopsin, and saxatoxins and not effective at oxidizing anatoxin. The CT and free chlorine dose required to oxidize cyanotoxins is typically higher than required for disinfection, so consideration should be given to balancing the needs for disinfection and cyanobacteria treatment and meeting treated water quality compliance.

Oxidization of geosmin and MIB is limited using chlorine as the oxidant.

The location chlorine oxidation within the treatment train should be considered. Pre-oxidation with chlorine could risk lysing intact cyanobacteria and release of intracellular toxins. Consideration of increased DBP formation should be included for pre-oxidation with chlorine.

Chlorine systems for algae, cyanotoxin, or taste and odour treatment should be designed as per Section 5.5.1.

5.11.5.2.5 Oxidation - Chlorine Dioxide

Chlorine dioxide is not considered an effective treatment option for oxidation of cyanotoxins at doses and CT values normally used in water treatment.

Taste and odour control by chlorine dioxide requires proper storage and handling of sodium chlorite, as per Section 5.5.2. Chlorite and chlorate DBPs result from chlorine dioxide application and, therefore, the dose of chlorine dioxide must be limited to a maximum of 1.2 mg/L.

5.11.5.2.6 Oxidation – Chloramines

Chloramines are not considered an effective treatment option for oxidation of cyanotoxins at doses and CT values normally used in water treatment.

5.11.5.2.7 Oxidation – Potassium Permanganate

$KMnO_4$ has been shown to be effective at oxidizing extracellular microcystin and anatoxins, however, is not effective at oxidizing cylindrospermopsin or saxitoxins. For microcystin, studies show that the reaction is not pH dependent, however, the reaction is pH depended for anatoxins. The required target $KMnO_4$ dose will be site specific and vary based on water quality and cyanotoxin concentrations. Studies have shown that a dose of 1.0 to 2.0 mg/L has been effective for oxidizing extracellular toxins. Adequate CT should be provided to ensure that extracellular toxins are oxidized.

$KMnO_4$ is not very effective for oxidation of geosmin or MIB.

When $KMnO_4$ is used as a pre-oxidant, there is a potential that the dose can result in lysing of intact cyanobacteria cells and releasing of extracellular toxins. Studies have shown that lysing of cyanobacteria cells can occur at doses greater than 3.0 mg/L, however, this would be site-specific based on raw water quality. If pre-oxidization with $KMnO_4$ is to be used, the dose applied should be sufficient to lyse the cells and react with the dissolved toxins. If the potassium $KMnO_4$ is inadequate, there is an increased risk that the cyanobacteria cells will lyse and release dissolved toxins without destroying the toxins, resulting in increased dissolved toxins to be removed by downstream processes.

$KMnO_4$ is often used at a WTP for pre-oxidation of manganese, DBP precursor removal or for taste and odour control. Considerations should be made for competition between constituents and what the treatment plant water quality priorities would be during a HAB event. $KMnO_4$ has been shown to not be effective for geosmin or MIB removal.

$KMnO_4$ systems designed for cyanotoxin treatment should be designed as per Section 5.8.3.1. Dosing of $KMnO_4$ should be completed to prevent the occurrence of finished pink water.

5.11.5.2.8 Oxidation – Ozone

Ozone is a powerful oxidant and has been demonstrated to be very effective at oxidizing microcystin, geosmin and MIB. It has also been shown to be effective for oxidizing cylindrospermospin and anatoxin, with limited effectiveness for saxitoxins. The reaction is dependent on many factors such as NOM, pH, temperature, and CT. Limited information is available in literature for the required CT values to achieve cyanotoxin degradation with ozone, however, studies have shown that an ozone dose in the range of 1.0 mg/L can reduce cyanotoxins to low levels. Bench scale and pilot testing should be completed to inform the selection and design process.

The location of ozonation within the treatment train should be considered. The common application points include raw water (pre-treatment), pre-filtration, and disinfection. Consideration of the effect of competing constituents such as organic matter and the potential formation of DBPs (bromate) should be given when choosing the dosing point.

Ozonation systems for cyanotoxin and taste and odour oxidation should be designed in accordance with Section 5.5.2.

5.11.5.2.9 Membrane Filtration

Microfiltration and UF membranes are not effective for the removal of extracellular cyanotoxins or taste and odour compounds as the pore sizes are larger than the size of the dissolved toxins/taste and odour compounds, however, would be effective at removing intact cyanobacteria cells. The risk associated with stressing or lysing of cells

Nanofiltration and RO have been shown in literature to be capable of removing extracellular cyanotoxins through size exclusion and charge effects. This said, the rejection rates of the cyanotoxins is dependent on the molecular size of the cyanotoxin, surface chemistry of the membrane and membrane type.

In the event that cyanotoxins are removed by the membrane filters, consideration should be given to the concentrate stream which may have high cyanotoxin concentration and appropriate disposal.

5.11.5.2.10 Biological Filtration

Biological filtration has been shown to remove microcystins and cylindrospermopsin along with some taste and odour compounds. Biological filtration is not effective for saxitoxin and in some instances can result in toxic biodegradation products. Performance of biofiltration is dependent on water quality, temperature, cyanotoxins present, the availability and capacity of bacteria capable of biodegrading cyanotoxins and presence of organic matter and metals. The presences of a biofilm on a filter does not indicate that the bacteria would be capable of biodegrading cyanotoxins. Hydraulic loading rate and empty bed CT also are important factors for the performance of biological filters.

Studies have also shown that there can be a lag between the presences of cyanotoxins in the water and the biodegradation by the bacteria in the biofilm. The lag period should be taken into consideration in the planning for a response to a cyanobacteria event if biofiltration is included in the overall strategy. On site validation of the capability of the bacteria should be completed to confirm the process will have effective removal.

Biological filtration should be designed in accordance with Section 5.4.5.

5.11.5.2.11 Ultraviolet Irradiation

Ultraviolet radiation, at doses commonly used for disinfection, is not an effective treatment option for oxidation of cyanotoxins or taste and odour compounds.

5.11.5.2.12 Emerging Technologies - Advanced Oxidation Processes

Advanced Oxidation Processes (AOPs) such as UV and hydrogen peroxide, ozone and UV, and ozone and hydrogen peroxide have been shown to be effective at oxidizing extracellular microcystins, cylindrospermopsin, and anatoxin, along with geosmin and MIB. This said, there is limited applications of AOPs at full scale WTPs. As the technology evolves and becomes more cost-effective, these processes may be implemented in more WTPs.

5.12 Waste Handling

5.12.1 General

Provisions should be made for proper handling and disposal of WTP wastes, whether they are sanitary wastes, laboratory wastes, clarifier sludge, spent filter backwash, softening sludge, brines, or neutralization chemicals. All waste discharges are regulated by the Regulatory Authority having jurisdiction. Water quality requirements imposed by the Regulatory Authority will dictate the allowable rate of discharge and discharge quality, which will dictate the treatment requirements, if any. The requirements indicated herein, therefore, should be considered minimum requirements and where a discrepancy exists between these minimum requirements and those of the Regulatory Authority having jurisdiction, the latter should govern.

5.12.2 Wastewater

Wastewater from WTPs include waste from washroom facilities, kitchen facilities, lunchrooms, and laboratory wastes. The sanitary waste from WTPs, pumping stations and other waterworks installations should receive treatment. Waste from these facilities should discharged directly to a sanitary sewer, when available and feasible, or to an adequate on-site wastewater disposal system designed and constructed to meet the requirements of the province in which it is to be constructed.

5.12.3 Water Treatment Plant Residuals

The nature and treatability of the waste material to be produced as a result of the treatment process should be adequately characterized. Waste characterization, in addition to the ultimate disposal requirements, should be given a high degree of consideration in the planning and selection of water treatment processes. Alternative methods of reducing waste volumes should also be considered.

5.12.3.1 Brine Waste

Brine waste is produced from ion exchange plants, demineralization plants, or other plants which remove ions from solution. Water quality requirements imposed by the Regulatory Authority will dictate the allowable rate of discharge.

5.12.3.2 Lime Softening Sludge

Sludge from WTPs that use lime softening varies in quality and chemical characteristics and the quantity is often larger than stoichiometric calculations would indicate. The lime softening process typically produces a sludge with high concentrations of precipitates such as calcium carbonate, calcium sulfate, magnesium hydroxide, silica, iron oxides, aluminum oxides, and unreacted lime. The sludges are typically of high solids content and are readily settleable. The high pH of this material can make it difficult to provide adequate treatment and disposal of this waste.

5.12.3.3 Coagulation Sludges

Typically, aluminum and/or iron coagulants are used in conventional surface WTPs, therefore, the sludge from coagulation/flocculation and clarification systems is typically high in organic material, aluminum and/or iron, dissolved and colloidal contaminants and pathogens. These sludges can range from thick and readily settleable to light and slow to settle depending on the contaminants removed during the coagulation and clarification processes. In Atlantic Canada, however, these materials are often difficult to settle due to the high organic matter content.

5.12.3.4 Spent Filter Backwash Water

Spent Filter Backwash Water (SFBW) refers to backwash water from conventional rapid gravity filters, which contains materials that are not removed during clarification and are subsequently removed during filtration. The concentration of solids in SFBW will depend on the efficiency of the coagulation/flocculation, clarification, and filtration processes, as well as the amount of water used for backwashing the filters.

In Atlantic Canada, this material is often light and slow to settle due to high organic content in the metal hydroxide flocs in the SFBW, therefore, the selection of treatment process is not an obvious one and may require piloting in some circumstances.

5.12.4 Quantity

An accurate means of measuring residuals/waste streams and their respective quantities should be provided.

5.12.5 Direct Discharge to Wastewater System

Where ultimate disposal is to be to a wastewater system, consideration should be given to the capacity of the system and Wastewater Treatment Plant (WWTP) and, as a result, may require holding tanks to prevent overloading of WWTPs. Consideration should also be given to future capacity scenarios, including climate change considerations. Discharge to wastewater lagoons should also consider evaporation effects of the lagoons.

Disposal of plant process wastewater and sludges to municipal sewers may be limited by provincial regulations and/or municipal by-laws and consultation with the Regulatory Authority is recommended.

Discharge of lime sludge to sanitary sewers should be avoided and may only be used in situations where the system capacity is adequate to accommodate the lime sludge. Mixing of lime sludge with activated sludge waste may be considered as a means of co-disposal.

5.12.6 Waste Treatment

The choice of residuals treatment process will depend on the raw water, the main treatment plant processes as well as the discharge and ultimate disposal requirements. In cases where there is not enough data to determine which waste treatment process is most suitable for a given residuals stream, pilot testing should be performed and should meet the requirements of Section 3.1.2.2.

5.12.6.1 Waste Equalization & Mixing

Adequate storage should be provided to ensure a controlled discharge of waste over a 24-hour period. Equalization and continuous agitation should be provided for those wastes which are to be treated by high-rate residuals treatment processes such as thickening/sedimentation, DAF, or membranes.

5.12.6.2 Lagoon Treatment

Lagoon systems should be designed such that they can be cleaned periodically and should be designed to provide a retention time between 15 and 30 days, with at least 2 years of sludge storage. A minimum of two lagoons should be provided so that one system may be taken out of service for cleaning. An acceptable means of final sludge disposal should be provided. Provisions should be made to facilitate sludge removal.

Lagoon design should provide for:

- Provisions to account for climate change (e.g., potential increases in the intensity of precipitation events).
- Located outside of flood risk areas and at a minimum elevation which exceeds the 1-in-100-year flood level including climate change considerations (refer to Chapter 2 for further guidance).
- When necessary, dykes, deflecting gutters, or other means of diverting surface water away from or around the lagoons.
- A minimum side water depth of 1.5 m.
- A minimum freeboard of 0.9 m.
- Adjustable decanting device.
- Low permeability liner.
- Effluent sampling location.
- Adequate safety and security provisions.
- Parallel operation ability.

Note that lagoons may not be sufficient for removal of aluminum levels to meet the discharge regulatory requirements for some WTPs using aluminum-based coagulants and discharging to freshwater bodies. Careful consideration should be given to coagulant alternatives to alum in these circumstances. In addition, receiving water studies may be required by the Regulatory Authority to confirm the discharge aluminum levels proposed will not cause adverse impacts on fish species or benthic communities.

5.12.6.3 Thickening & Sedimentation

Thickening refers to the process by which equalized clarifier sludge and/or backwash wastes are further concentrated in a thickening basin. Feed to the thickener should be as uniform as possible in both quality and quantity through providing both equalization and agitation. Design of gravity thickening units should be based on surface overflow rate and should not exceed 0.005 m/hour.

Sedimentation, with respect to waste treatment, refers to the process by which residuals are reflocculated prior to settling. Sedimentation basins should be designed with a surface overflow rate between 0.3 and 0.6 m/hour.

Gravity thickening and sedimentation units should be designed with two trains and may be either circular or square tankage. Units should also be designed to minimize short-circuiting and to accommodate sludge removal as per the requirements of Section 4.3.1.

Coagulant addition, if necessary, should meet the requirements of Section 5.2.

5.12.6.4 Dissolved Air Flotation

Dissolved air flotation may be applicable for treatment of WTP residuals that are very light and would exhibit poor settleability. The design of DAF clarification systems for residuals should provide for a surface overflow rate ranging from 2.4 to 9.6 m/hour. Dissolved air flotation system design should also meet the requirements of Section 5.3.2. Coagulant addition, if necessary, should meet the requirements of Section 5.2.

5.12.6.5 Membranes

Membranes may be suitable for the treatment of WTP residuals. Careful consideration should be given to allowable flux rates and such would have to be confirmed through pilot testing as per Section 3.1.2.2.

5.12.6.6 Polymer Addition

Polymer addition has the potential to increase the allowable surface overflow rates for residuals treatment processes significantly. Equalization tankage and continuous agitation should be provided as per Section 5.12.6.3 to ensure consistent chemical feed can be maintained. Polymer system design should meet the requirements of Chapter 4.

5.12.6.7 Iron & Manganese Wastes

Iron and manganese waste or “red water” wastes can be treated using sand filtration, sedimentation basins, lagoons, or discharge to a sanitary sewer. Discharge to a sanitary sewer should conform to Section 5.12.5.

Sand Filters

Sand filters should have the following features:

- A total filter area adequate to dewater the applied solids.
- Two filters should be provided, unless the filter is of size small enough that it may be cleaned and returned to service in 1 day.
- The red water filter should have sufficient capacity to contain the entire backwash volume generated by washing all of the filters, unless the filters are washed on a rotating schedule and the flow through the filters is regulated by true rate flow controllers (sufficient volume should also be provided to properly dispose of the wash water involved).
- The filter area should be such that no more than 600 mm of backwash water accumulates over the sand media at any time.
- The filter should not be subjected to flooding by runoff water and should be constructed at an elevation that will facilitate maintenance.

- Non-watertight structures should not be used for the construction of filter sidewalls.
- Filter media should consist of minimum 300 mm sand and should generally be designed in accordance with Section 5.4.1.7.
- Filter sand should have an effective size of 0.3 to 0.5 mm and a uniformity coefficient not to exceed 3.5 mm.
- The filter should be provided with adequate under-drainage collection system to permit satisfactory discharge of filtrate.
- Provision should be made for sampling of filter effluent.
- Overflow devices should not be permitted.
- Provisions should be made for covering the filters during winter months.
- Precautions should be taken to ensure cross-connection with treated water does not occur.
- Any deviations to the above should be subject to pilot testing requirements as per Section 3.1.2.2.

Lagoons

Lagoons should have the following features:

- Provisions which account for climate change (e.g., increases in freeze-thaw cycles), and located at a minimum elevation which exceeds the 1-in-100 flood level including climate change considerations (refer to Chapter 2 for further guidance).
- Volume should be 10 times the total quantity of water discharged during any 24-hour period.
- A minimum sidewater depth of 1.0 m.
- Minimum length to width ratio of 4 to 1 and a minimum width to depth ratio of 3 to 1.
- Outlets and inlet located to minimize short-circuiting.
- A weir outlet device with a weir length equal to or greater than the liquid depth.
- Velocity to be dissipated at the inlet.

5.12.7 Spent Filter Backwash Water Recycling

Spent filter backwash water recycling is practiced in many WTPs throughout the United States and Canada Waste recycling has been shown to be an effective method of water recovery and is considered a climate change resiliency feature. Furthermore, the indicates that SFBW recycling may be acceptable provided hydraulic surges due to recycling are kept below 10% of the plant influent flowrate and provided the recycle is introduced at a location in the process train to ensure all recycle flows are subjected to all treatment processes at the respective plants.

Spent filter backwash water treatment and recycle may be considered as part of the design for surface water and groundwater treatment plants. Where used, the system design should conform to the latest edition of the *Filter Backwash Recycling Rule: Technical Guidance Manual* from the United States Environmental Protection Agency. Designers should demonstrate, as part of Design Brief documentation, that a proposed recycle application provides a level of pathogen protection and online monitoring sufficient to satisfy the Regulatory Authority that risks are acceptable.

5.12.8 Dewatering

Methods of dewatering include the following:

- Air/gravity drying processes:
  - Sand drying beds.
  - Freeze-thaw beds.
  - Geotubes.

- Solar drying beds.
- Vacuum assisted drying beds.
- Mechanical dewatering processes:
  - Belt and diaphragm filter presses.
  - Centrifuges.
  - Pressure filters.

A complete discussion on each of these dewatering processes is beyond the scope of these Guidelines. Some general guidance, however, is provided.

5.12.8.1 Air/Gravity Drying Processes

Sand drying beds dewater primarily by gravity drainage of water from the sludge by placing the sludge on a sand medium and are more effective for lime sludges than for coagulant sludges. Loading rates are typically between 1.0 and 2.4 kg/m^2. Draining time is typically 3 to 4 days. Applied sludge depth should be 20 to 75 cm for coagulant sludges and 30 to 120 cm for lime sludges.

Freeze-assisted drying beds use a freeze-thaw cycle to break the molecular bonds with the water and the sludge, which greatly enhances the dewatering rate. These systems are more suitable for dewatering alum sludges in cold climates. Freeze-thaw systems should be designed using two drying beds, each sized to accommodate 1 year of sludge storage.

Geotubes refer to large porous bag filters, often used for dewatering concentrated sludge during lagoon dredging in addition for direct clarifier/filter sludge dewatering. Geotubes are strategically located where filtrate through the geotextile bag filters can be returned to a lagoon or other liquid waste handling stream, while the filtered sludge solids and geotube bag itself remain in place. The geotube may be located and used at its ultimate disposal location or planned to be removed after filling with solids for thickened sludge disposal. Full geotubes cannot be removed as a whole; rather, the bag must be opened and sludge solids excavated for off-site disposal.

Solar drying beds use asphalt as a sub-base for dewatering of sludge. The heat effects promote faster drying. This process does not have widespread applicability in Atlantic Canada.

Vacuum-assisted drying beds provide a suction to the underside of a rigid, porous media plates upon which the residuals are placed, which draws the water from the sludge. Frequent plate cleaning and chemical sludge conditioning is typically required for this type of process.

Decanting and drainage systems should be provided and required solids concentration, climate, drainage discharge location and regulatory requirements should be considered. Sludge layers should be kept thin to maximize drying rates.

5.12.8.2 Mechanical Dewatering Processes

Belt and diaphragm filter presses dewater residuals by sandwiching sludge between two porous belts and are suitable for dewatering lime sludges to 50 to 60% and coagulant sludges to 15 to 20%. The applied pressure is typically in the 600 to 1,500 kPa (87 to 218 psi) range. Roller bearings should be designed to have an L-10 service life of approximately 300,000 hours. A polymer conditioning system should be provided for all belt filter presses.

Consideration should also be given to desired cake solids content, conditioning requirements, pressure requirements, belt speed, belt tension, belt type and belt mesh size.

Centrifuges dewater residuals by forcing water from solids under high centrifugal forces. Both concurrent and counter-current designs are acceptable. Design criteria will be proprietary in nature and the manufacturer should be consulted in each case a centrifuge is being considered. A polymer conditioning system should be provided for all centrifuge systems.

Pressure filters provide removal of solids via size exclusion through a media bed or porous surfaces (e.g., cartridge/bag filtration). Pressure filters should generally conform to the design requirements outlined in Section 5.4.2. Filtration media and cartridge/bag selection should be optimized based on the characteristics of waste/sludge to be treated. If insufficient data or references of similar applications is unavailable, a pilot program may be required and should follow the requirements for pilot testing outlined in Section 3.1.2.2.

Similar to air/gravity drying processes, decanting and drainage systems should be provided and required solids concentration, drainage discharge location and regulatory requirements should be considered.

5.12.8.3 Comparison of Dewatering Processes

The relative performance of the dewatering processes described above are provided in Table 5.11.

Table 5.11: Relative Performance for Dewatering Processes

Percent Solids Content		
Process	**Lime Sludge**	**Coagulant Sludge**
Gravity thickening	15 - 30	3 - 4
Scroll centrifuge	55 - 65	10 - 15
Belt filter press	No data	10 - 15
Vacuum filter	45 - 65	No data
Pressure filter	55 - 70	35 - 45
Sand drying bed	50	20 - 25
Storage lagoon	50 - 60	7 - 15
Freeze-thaw bed	No data	No data

5.12.9 Sludge Disposal

The application of liquid sludge to farmland should be considered as a method of ultimate disposal. Prior to land application, a chemical analysis of the sludge should be completed, including calcium and heavy metals. Approval from the Regulatory Authority must be obtained. When this method is utilized, the following provisions should be made:

- Transport of sludge by vehicle or pipeline should incorporate a plan or design which prevents spillage or leakage.
- Interim storage areas at the application site should be kept to a minimum and facilities should be provided to prevent wash off of sludge and/or flooding.
- Sludge should not be applied to land where wash off could occur unless provisions are made for immediate incorporation into the soil.
- An acceptable method of incorporating sludge into the soil should be provided prior to land application

- Trace metal loadings to the soil should be limited.
- Each area of land to receive lime sludge should be considered individually and a determination made as to the amount of sludge needed to raise the soil pH to the optimum for the crop to be grown.
- Mechanical dewatering or calcination of lime sludges may be considered, provided pilot studies (see Section 3.1.2.2) are conducted.

Landfill disposal may be considered provided the landfill is capable of accepting the waste

Drying beds for lime sludge are not recommended.

5.13 Emerging Technologies

Due to regulatory requirements, there is a need to develop cost-effective process alternatives so that water purveyors can provide the required level of service at an affordable cost. This usually results in improvements in process loading rates to reduce footprints and/or development of technologies that achieve more stringent water quality objectives with less equipment and infrastructure. The application of emerging technologies is, therefore, encouraged.

A complete discussion of all available emerging technologies is beyond the scope of these Guidelines. All emerging technologies should, however, be subject to the pilot testing requirements of Section 3.1.2.2. An engineering report is recommended to be submitted to the Regulatory Authority prior to pilot testing. Pilot testing should then be followed with a report, which outlines the results, design criteria, conclusions, and recommendations prior to proceeding with the development of plans and specifications for the proposed works.

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Chapter 6 Pumping Facilities

Water pumping stations have special risks and considerations pertaining to potential explosive conditions, corrosion, and personal safety. Careful attention and understanding of the latest editions of *NFPA 20 Standard for the Installation of Stationary Pumps for Fire Protection* from the National Fire Protection Association (NFPA) and the *CSA C22.1 Canadian Electrical Code, Part 1: Safety Standard for Electrical Installations* from the Canadian Standards Association is required.

6.1 Facility Types

6.1.1 Raw Water Pumping Facility

Raw water pumping facilities generally pump raw (non-potable) water from a surface water supply to a WTP. The raw water is typically pumped from a river, natural lake, or an artificial reservoir. Depending on the source and the ultimate use of the water, raw water pumping facilities are usually a combination of only three basic components:

- Raw water intake structure.
- The pumping facilities.
- Screening facilities (which may or may not be required).

Most raw water pumping facilities are shoreline installations.

6.1.2 Booster Pumping Facility

Water booster pumping stations are incorporated within the water distribution system. The purpose of these stations is to maintain adequate pressures and flows in water distribution systems as a result of changes in ground elevation and/or distance from the source of supply. Booster pumping facilities serve specific areas within a water distribution system, based on defined limits. These areas are generally isolated from the remainder of the distribution system.

Booster pumping facilities can generally be divided into two main categories:

- In-line.
- Distribution facilities.

In-line booster stations take suction from an incoming pipeline, increase the line pressure, and discharge it to another pipeline.

Distribution booster stations typically take suction from storage and maintain a given pressure (within limits) for supply in a distribution system at wide ranges of demand. Either type of facility may have incorporated with part of their operation, elevated or ground storage reservoirs on the discharge side of the station. These reservoirs will, in effect, serve to supplement extreme production requirements, such as peak hour and fire flow demands.

6.1.3 Fire Pumping Facility

Fire pump facilities are incorporated within water distribution systems to provide adequate pressures and flows under fire demand conditions. These types of facilities are required when changes in ground elevation, distance from source of supply, or the central water distribution system limits the amount of available fire flows and pressures under conventional gravity supply. Fire pump facilities typically take suction from storage and maintain a minimum required pressure under fire flow conditions.

6.2 Facility Construction

6.2.1 General

Pumping facilities should be designed to maintain the potable water quality of pumped water. Subsurface pits or pump rooms and inaccessible installations should be avoided

6.2.2 Location

The pumping station should be located such that the proposed site will meet the requirements for sanitary protection of water quality, hydraulics of the system and protection against interruption of service by fire, flood, or any other hazard. The impacts of climate change should be considered when locating a pumping station.

6.2.2.1 Site Protection

Pumping station designs should include the following:

- The pumping station should be elevated to a minimum which exceeds the 1-in-100-year flood level including climate change considerations (refer to Chapter 2 for further guidance).
- Structures and electrical and mechanical equipment should be protected from physical damage from flooding events (flood events should account for climate change).
- The pumping station should be located in areas where it will remain fully operational and fully accessible during flooding events (flood events should account for climate change), through the provision of backup generators or alternative power supply.
- The pumping station should be protected to prevent vandalism and entrance by animals or unauthorized persons.
- The pumping station should be located off street right-of-way in an appropriate area designated for pumping station purposes.

6.2.3 Pumping Stations

Pumping stations should:

- Include a pump station building of adequate size to accommodate the pumps, pump motors, control panel, auxiliary power supply, fuel storage, any required future pumping equipment, and other accessories. These items should be in the building taking into consideration safety for operators and convenient access for maintenance.
- Include a pump station building of which the design and construction should meet the requirements of the latest edition of the *National Building Code of Canada* from the National Research Council of Canada and should also meet the specific requirements of the System Owner.
- Have a floor elevation of at least 150 mm above the finished external ground surface.
- Have below grade occupied spaces or vaults.

- Have all floors drained in such a manner that the quality of the potable water will not be endangered. All floors should slope at least 75 mm in every 3.0 m to a suitable drain.
- Provide a suitable outlet for drainage for pump glands without discharging on the floor.
- Have suitable vehicle access to allow for convenient equipment servicing.
- Have all interior wall surfaces, doors, and trim painted to a colour scheme approved by the System Owner.
- Have outward opening doors.

6.2.4 Suction Wells

Suction wells should:

- Be watertight.
- Have floors sloped to permit removal of water and entrained solids.
- Be covered or otherwise protected against contamination.
- Have two pumping compartments with suitable valving, gates, or other means to allow one suction well to be taken out of service for inspection, cleaning, maintenance, or repair, without disrupting service.
- Suction pipe inlets should be designed in accordance with good design practice to prevent vortexing, air-entrainment, inlet interference, and other phenomena that may interfere with proper operation and pumping.

6.2.5 Screening/Fish Attraction

All intakes in fish bearing waters require DFO approval.

Screen mesh size should be governed by the raw water quality and the species of fish present in the raw water supply. Screen size requirements should be in accordance with requirements of the provincial Regulatory Authority and DFO.

Screens should be constructed at the intake structure itself, or if required may be in-plant just prior to the raw water pumping facility. For small treatment plants with in-plant screens, two fixed screens in series will suffice, while for larger plants the use of at least two mechanically cleaned screens operating in parallel is recommended. A combination of fixed and mechanically cleaned screens may be used for medium capacity plants. Screens at the intake should comply with the requirements stipulated by the federal and provincial Regulatory Authorities. Fixed screens should have lifting lugs for removal and washing. Screen waste should not be returned to a raw water storage area.

6.2.6 Equipment Servicing

Pump stations should be provided with:

- Crane-ways, hoist beams, eyebolts, or other adequate facilities for servicing or removal of pumps, motors, or other heavy equipment.
- Openings in floors, roofs or wherever else needed for removal of heavy or bulky equipment.
- A convenient tool board, or other facilities as needed, for proper maintenance of the equipment.

When accommodating for maintenance and servicing, the creation of confined spaces should be avoided.

6.2.7 Stairway & Ladders

Stairways or ladders should:

- Be provided between all floors, and in pits or compartments which must be entered.
- Have handrails on both sides, and treads of non-slip materials. Stairs are preferred in areas where there is frequent traffic or where supplies are transported by hand. Stairs should be designed in accordance with the latest edition of the *National Building Code of Canada* from the National Research Council of Canada.

6.2.8 Heating

Provisions should be made for adequate heating for:

- The comfort of the operator.
- Prevent freezing conditions in spaces.
- The safe and efficient operation of the equipment.

6.2.9 Ventilation

Ventilation equipment must meet the requirements of the System Owner, and, as a minimum, must ensure that sufficient ventilation is supplied so that heat generated by electrical equipment is adequately dissipated.

Generator radiator ventilation should be sized with air velocities that do not cause negative pressures inside the building.

Ventilation, or another form of cooling, should be considered to prevent excessive temperatures as a result of heat generated by motors, other electro-mechanical equipment.

6.2.10 Dehumidification

Dehumidification should be considered in areas where excess moisture could cause safety hazards or damage.

6.2.11 Lighting

Pump stations should be adequately lighted throughout. All electrical work should conform to the requirements of the latest edition of *CSA C22.1 Canadian Electrical Code, Part 1: Safety Standard for Electrical Installations* and to relevant provincial codes.

6.2.12 Sanitary & Other Conveniences

All pumping stations that are occupied for extended periods should be provided with potable water, washroom facilities. Acceptable options for the disposal of wastewater include, but are not limited to, a municipal system, on-site wastewater disposal systems, or a holding tank.

6.3 Pumps

At least two pumping units should be provided. With any pump out of service, the remaining pump or pumps should be capable of providing the maximum pumping demand of the system. The pumping units should:

- Have ample capacity to supply the peak demand against the required distribution system pressure without dangerous overloading.
- Be driven by prime movers able to meet the maximum horsepower condition of the pumps.

- Be provided with readily available spare parts and tools.
- Be served by control equipment that has proper heat and overload protection for air temperature encountered.
- Selected to operate at flows as close as practical to the Best Efficiency Point (BEP) of the pump based on the pressure, flow, and time that the pumps will be operating. Operating near the BEP, the hydraulic efficiency and the operational reliability of the pump are not substantially degraded. Near the BEP, the design service life of the pump will not be affected by the internal hydraulic loads or flow-induced vibration.
- Have a hydraulic efficiency above 80%.

6.3.1 Selection

Selection of the appropriate pump is dependent on the requirements and conditions under which the equipment will operate, as stated below.

6.3.1.1 Water Quality

Water quality can have a significant effect on choice of pumping unit(s). Differences will almost certainly exist when considering raw water and potable water pumps, such as:
- Aggressiveness of the water can influence choice of material of construction.
- Suspended solids (particularly in raw water) may demand higher specification for seals and abrasion resistance within pump.
- Erosion due to high particle content may cause premature performance decline, and large particles may require more open impeller design.

6.3.1.2 System Head Curves

A clear understanding is required of the process and the system in which the pumping equipment will operate. Development of system head curves showing the relationship between flowrate and hydraulic losses is required. Allowances for system performance decline over time due to corrosion, scale, etc. and future requirements is essential.

6.3.1.3 Modes of Operation

System operating modes are important considerations when specifying pumping equipment. The following operational parameters need to be considered:
- Continuous or intermittent pump operation mode.
- Differences in head and flowrate requirements.
- Pump operation in series or parallel.
- Maintenance requirements.

6.3.1.4 Pump Flow/Head Margins

Pumps are normally specified with a capacity margin above what has been determined necessary for the process. In addition, the calculated system head losses are also determined conservatively. This is required because:
- System design requires many assumptions for pump selection, some of these assumptions may prove to be incorrect.
- During the design life, system conditions will change, and pump performance will decline.

- Pipe networks invariably change.
- System hydraulics will change due to corrosion, scaling, etc.

Pumps should be selected to work as close as practical to the BEP based on the pressure, flow, and time that the pumps will be operating. Care must be taken when applying margins that a pump is not oversized. A total head that is too large may cause problems to the system, or a flow that is too great may have costly penalties in energy costs. In the case of centrifugal pumps, impellers can be upgraded and/or additional stages can be added over time.

Designers should, however, be aware of potential future changes and incorporate flexibility or a strategy to deal with changing conditions.

6.3.1.5 Type of Pump Control

The type of control for the required pump(s) is an important consideration for pump specification and selection. Various types of control should be considered depending on the needs of the system and complexity required.

Considerations include:

- A control valve (not normally supplied by the pump manufacturer) may be required to adjust the system curve over the life of the unit(s).
- Flow sensing control provides the most stable operation for most systems and pressure control can have a significant effect on the operation of a pump, in particular if it is operating on a flat part of the performance curve.
- Temperature and level sensing controls may also be required.
- Low lift pumps should be operated using a closed-loop controller to maintain the flows through the system. A closed-loop controller should monitor output flow and influences the pump control speed via feedback to alter the pump effort and maintain a constant flow.
- Booster pumps should be controlled so that automatic shut-off or a low-pressure controller maintains a constant pressure in the suction line under all operating conditions. A valve to control the pressure across the pump should be considered if suction and discharge pressures vary.
- A fire pump controller should be used to operate fire pumps. The controller is to maintain pressure in the fire protection piping system to an artificially high level so that the operation of a single fire suppression device will cause a pressure drop which will be sensed by the fire pump controller, causing the fire pump to start. No device capable of interrupting the fire pump circuit, other than a circuit breaker specifically approved for fire pump service, should be placed between the service box and a fire pump transfer switch or a fire pump controller.

6.3.1.6 Future System Changes

When future system demand can be predicted with a degree of certainty, the system can be designed with that in mind. Rather than selecting a pump that is operating at the high end of its preferred operating region, the next sized pump operating at the beginning of the preferred operating range might be considered. In addition, the capability of installing a larger impeller to handle future requirements must be considered. Minimizing capital and operating costs should be considered. Oversizing pumps is not normal practice. Pumps should operate efficiently and reliably.

6.3.2 Suction Lift Pumps

Suction lift pumps should:

- Be avoided, if possible, to reduce possible cavitation, the need for self-priming, reduce station pipework complexity, and provide a more operator friendly station.
- Be within allowable limits, preferably less than 5.0 m. To avoid cavitation (the phenomenon of formation of vapour bubbles of a flowing liquid in a region, where the pressure of the liquid falls below its vapour pressure) it is important to compare the Net Positive Suction Head Required (NPSHr) to the Net Positive Suction Head Available (NPSHa). Total suction head calculated for NPSHr should account for geodetic differences and suction pipe losses.

6.3.3 Priming

Prime water should not be of lesser quality than that of the water being pumped. Means should be provided to prevent either backpressure or back siphonage backflow. When an air-operated ejector is used, the screened intake should draw clean air from a point at least 3.0 m above the ground or other source of possible contamination, unless the air is filtered by an apparatus approved by the Regulatory Authority. Vacuum priming may be used.

6.4 Booster Pumps

In addition to applicable requirements previously outlined in this chapter, booster pumps should be located or controlled so that:

- They will not produce negative pressure in their suction lines.
- The intake pressure should be at least 140 kPa (20 psi) when the pump is in normal operation.
- Automatic cut-off or low-pressure controller should maintain at least 70 kPa (10 psi) in the suction line under all operating conditions.
- Automatic or remote-control devices should have a range between the start and cut-off pressure which will prevent excessive cycling.
- A bypass is available.

Each booster pumping station should contain not less than two pumps with capacities such that peak demand can be satisfied with the largest pump out of service.

6.4.1 Metering

All booster pumping stations should contain a totalizer meter, with allowance of sufficient straight length of pipe upstream/downstream, per meter specifications.

6.4.2 Individual Home Booster Pumps

Individual booster pumps should not be used for any individual service from the public water supply mains unless approved by the System Owner.

6.5 Automatic & Remote-Controlled Stations

All automatic stations should be provided with automatic signaling apparatus which will report when the station is out of service. All remote-controlled stations should be electrically operated and controlled and should have signaling instrumentation of proven performance. Installation of instrumentation equipment should conform with the latest edition of applicable provincial and local electrical codes and *CSA C22.1 Canadian Electrical Code, Part 1: Safety Standard for Electrical Installations*.

6.6 Appurtenances

6.6.1 Isolation Valves

Pumps should be adequately valved to permit satisfactory operation, maintenance, and repair of the equipment. Valves may be either of the gate or butterfly type and should be installed on the suction and discharge line of each pump. Typically, on larger installations (i.e., 350 mm or greater), butterfly valves should be utilized. Gate valves, especially for suction isolation, may be utilized for smaller sized piping.

6.6.2 Check Valves

A self-closing check valve must be incorporated in the discharge of each pump unit between the pump and the isolation valve. It should be designed in such a way that if pump flow is lost, the valve will close automatically. The type and arrangement of check valves and discharge valves is dependent on the potential hydraulic transients that might be experienced in the pumping station.

If foot valves are necessary, they should have a net valve area of 2.5 times the area of the suction pipe and they should be screened.

6.6.3 Suction & Discharge Piping

In general, suction and discharge piping should be as follows:

- Designed and arranged to provide easy access for maintenance.
- Designed so that the friction losses will be minimized.
- Not be subject to contamination.
- Have watertight joints.
- Protected against surge or water hammer and provided with suitable restraints where necessary.
- Each pump should have an individual suction lines and be manifolded to ensure similar hydraulic and operating conditions, such that similar hydraulic operating conditions exist for each pump.
- Properly supported and designed with appropriate fittings to allow for expansion and contraction.
- Finished, treated, and painted to prevent rusting. Colour scheme and paint types should be approved by the System Owner.
- Have corrosion resistant fitted bolts.
- Include couplings where required to provide sufficient flexibility to allow removal of equipment and valves.
- Pipe material capable of functioning in the pumping application and should be approved by the System Owner.

The pipe work pressure class should be considered. Higher pressure rating means higher wall thickness and higher weight which in turn increases the purchase cost, installation cost, maintenance cost, and more space requirement. The higher the pressure rating, the thicker the wall thickness must be so that the pipe, fitting, or valve body will not rupture. Pipe class selection should be based on 150% of the maximum pump pressure generated in the system.

6.6.4 Gauge & Meters

Each pump should have:

- A standard pressure gauge on its discharge line.
- A compound gauge on its suction line.
- Recording gauges where applicable.

The station should have indicating, totalizing, and recording metering of the total water pumped.

6.6.5 Water Seals

Water seals should not be supplied with water of a lesser sanitary quality than that of the water being pumped. Where pumps are sealed with potable water and are pumping water of lesser sanitary quality, the seal should:

- Be provided with either an approved reduced pressure principle backflow preventer or a break tank open to atmospheric pressure.
- Where a break tank is provided, have an air gap of at least 150 mm or two pipe diameters, whichever is greater, between the feeder line and the flood rim of the tank.

6.6.6 Transient Pressure (Water Hammer) Control

A hydraulic transient pressure analysis should be undertaken for each pumping station to ensure that the transient pressure resulting from pumps starting, stopping, full load rejection during power failure, etc., do not adversely affect the customers on the water system, the piping in the station, or the water distribution system itself. Typically, methods of surge protection that can be used to protect pumping stations include:

- Surge anticipator systems that dissipate over-pressure from the discharge lines.
- Slow closing and opening control valves on pump discharges.
- Hydropneumatic surge tanks on discharge headers.
- Variable speed pumping units.
- Water storage reservoir in the vicinity.

6.7 Electrical

6.7.1 Power Supply

The pumping station should be provided with a three-phase power supply. Design and installation of the power supply system should meet all applicable and relevant standards and codes, including the latest edition of *CSA C22.1 Canadian Electrical Code, Part 1: Safety Standard for Electrical Installations*. Best practice is to provide underground electrical service to the pump station.

Power supply equipment located outside/above ground are vulnerable to extreme weather events. The impacts of climate change may result in an increased risk of power outages resulting from potential increases in the frequency and intensity of weather events (e.g., hurricanes and forest fires). If possible, the System Owner may locate electrical service equipment underground to provide resiliency from extreme weather events and the impacts of climate change.

6.7.2 Pump Motor

Each pump should be operated by an energy efficient electrical motor capable of operating the pump over the full range of load conditions. Motors should be located such that they cannot be flooded should a pipe failure occur. Resistance Temperature Detectors (RTDs) or other sensors should be considered for larger motors (100 hp or larger) and reduced voltage starters or Variable-Frequency Drives (VFDs) are required by certain electrical utilities to be installed and used with motors 10 hp or larger to assist with managing voltages in their systems. The pumping units must be served by control equipment that has proper heater and overload protection for air temperature encountered.

6.7.3 Stand-by Power

Full stand-by power supply should be provided utilizing a stand-by generator. The generator should be capable of providing continuous electrical power during any interruption of the normal power supply. The stand-by power unit should be designed with adequate capacity to operate fire and domestic pumps, control and monitoring systems, and heating and lighting systems within the pump house. The generator should be located above flood elevations, including climate change considerations (refer to Chapter 2 for further guidance). Provisions for stand-by power are important to reduce risk to interruptions to water supply operations and provide resiliency to the impacts of climate change.

The generating system should include the following items:

- Diesel or alternate fuel powered engine.
- Alternator.
- Control panel.
- Automatic change over equipment.
- Automatic ventilation system.
- Battery charger and battery.
- Fuel supply unit.

Fuel storage and supply lines must be designed to protect against spills and leaks.

For small pumping facilities, portable stand-by power units may be used when a fixed exterior electrical connection is provided.

6.7.4 Controls

Pumps, their prime movers, and accessories, should be controlled in such a manner that they will operate at rated capacity without dangerous overload. Where two or more pumps are installed, provision should be made for alternation. Provision should be made to prevent energizing the motor in the event of a reverse rotation. Equipment should be provided, or other arrangements made to prevent surge pressures from activating controls which switch on pumps or activate other equipment outside the normal design cycle of operation.

All electrical equipment should be located in an accessible location above grade with a clear access of 1.0 m around all pumps and motors.

All floor mounted electrical equipment should be mounted on minimum 100 mm high housekeeping pads.

6.8 Safety Precautions

Pumping stations and appurtenances should be designed in such a manner as to ensure the safety of operations, in accordance with all applicable municipal, provincial, and federal regulations including the latest edition of the applicable provincial *Occupational Health and Safety Act*. All moving equipment should be covered with suitable guards to prevent accidental contact.

Equipment that starts automatically should be designed to ensure that operators are aware of this condition. Lock-outs on all equipment should be supplied to ensure that the equipment is completely out of service when maintenance or servicing is being carried out.

6.9 Station Monitoring

Typically, pumping station functions should be monitored to ensure that the station is performing satisfactorily. Monitoring signals and alarms are normally transmitted to a central location which is operated on a 24-hour basis. In the case of very small stations, a single alarm, covering a variety of points, may be acceptable. In larger stations, typically the following signals and alarms should be considered for transmission to a central monitoring point:

Signals

- Station flow.
- Station pressure.
- Pump on/off status.
- Current.
- Three (3) -phase power status.

Alarm Points

- Pump alarms, including:
  - Discharge pressure too low.
  - Discharge pressure too high.
  - Motor temperature alarm.
- Station alarm points, including:
  - Building temperature alarm.
  - Building fire alarm.
  - Building station flood.
  - Power failure alarm.
  - Illegal entry alarm.
  - Surge valve alarm.

6.10 References

Health Canada, Water and Air Quality Bureau, and Healthy Environments and Consumer Safety Branch. *Guidelines for Canadian Drinking Water Quality - Summary Table*. Government of Canada, Ottawa, ON, September 2020. <https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/water-quality/guidelines-canadian-drinking-water-quality-summary-table.html >.

National Fire Protection Association. *NFPA 20 Standard for the Installation of Stationary Pumps for Fire Protection.* NFPA, New York. 2022. <https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=20>.

National Research Council of Canada. *National Building Code of Canada*. *Canadian Commission on Building and Fire Codes*. Ottawa, NRC, 2015. <https://nrc.canada.ca/en/certifications-evaluations-standards/codes-canada/codes-canada-publications/national-building-code-canada-2015>.

Province of Nova Scotia. “Chapter 7 of the Acts.” *Occupational Health and Safety Act*. 2017. <https://nslegislature.ca/sites/default/files/legc/statutes/occupational%20health%20and%20safety.pdf>.

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Table of Contents

Chapter 7 Treated Water Storage Facilities

7.1 General

Water storage is essential for meeting the domestic, public, industrial, commercial, and fire flow demands of almost all public water systems. This section addresses the requirements of treated water storage.

7.2 Definitions

Age of Treated Water

For the purposes of these Guidelines, the age of treated water is measured as the time from when the initial disinfecting took place.

Detention Time

Detention time (sometimes known as retention time or residence time) is defined as the average period during which the treated water remains in storage prior to entering the distribution system. This may not be a fixed period and is dependent on utilization of the treated water and mixing of the treated water in storage. There could also be significant detention time within the distribution system prior to water reaching the first customer.

Storage

Dead Storage

The volume of water that is not considered useful or available to the system.

Emergency Storage

The volume of water recommended to meet the demand during maintenance shut-downs or emergency situations, such as source of supply failures, watermain failures, electrical power outages, or natural disasters.

Fire Flow Storage

The volume of storage available for supplying the required fire flow volume.

Peak Balancing (or Demand Equalization Storage)

The volume of operational storage directly related to the amount of water necessary to meet peak demands. Peak balancing storage is designed to make up the difference between the consumers' peak demands and the system's available supply.

Tank

Any elevated tank, pressure tank, reservoir, or standpipe used for water storage.

Hydropneumatic Systems

Hydropneumatic tanks are partly filled with water and partly filled with air. They are generally steel pressure tanks, with a flexible membrane that separates the air and the water. Air is compressed in the upper part of the tank and is used to maintain water pressure in the distribution system when demand exceeds the pump capacity. It also reduces on-off cycling of pumps. See Figure 7.1.

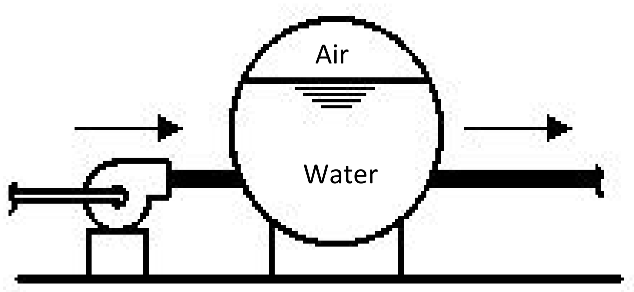

Figure 7.1: Pressure (Hydropneumatic) Tank Storage

Elevated Tank
Elevated tanks generally consist of a water tank supported by a steel or concrete tower that does not form part of the storage volume. In general, an elevated tank supplies peak balancing flows. See Figure 7.2 (part a).

Standpipe
A standpipe is a tank that is located on the ground surface and has a greater height than diameter. In most installations, water in the upper portion of the tank is used for peak flow balancing (equalization), the remaining volume is for fire flow and emergency storage. See Figure 7.2 (part b).

Reservoir
A treated water reservoir is a storage facility where the width/diameter is typically greater than the height and usually applies to large storage facilities.

Above-Ground Reservoir
An above-ground reservoir is a water storage structure that is primarily above ground. See Figure 7.2 (part c).

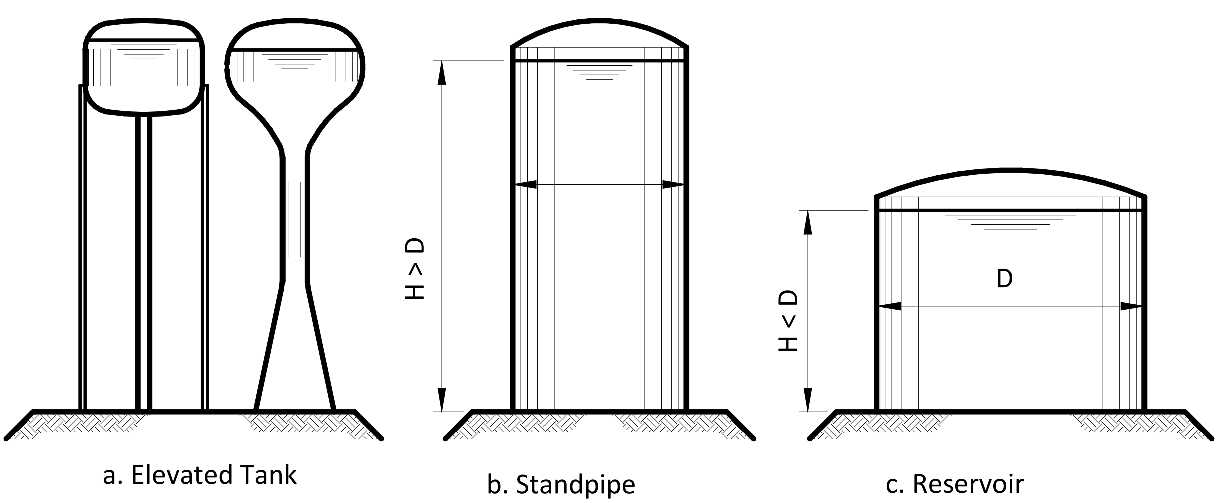

Figure 7.2: Above Ground Storage

In-Ground Reservoir
An in-ground reservoir is a water storage structure that is partially below the nominal surface of the ground. A typical construction has the reservoir located 50% above and 50% below ground. See Figure 7.3.

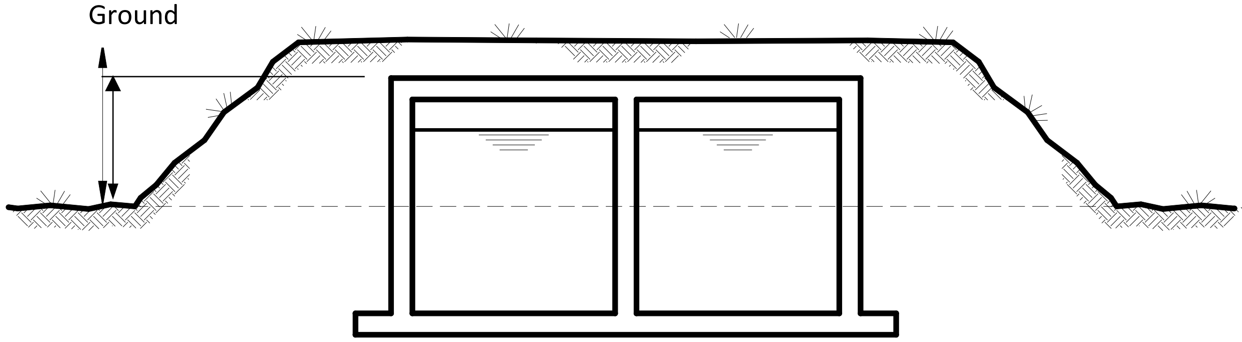

Figure 7.3: In Ground Reservoir

7.3 Materials of Construction

7.3.1 Standards & Materials Selection

Storage facilities, including pipes, fittings, and valves, should conform to the latest standards issued by the CSA or AWWA, and be acceptable to the Regulatory Authority. In the absence of such standards, materials meeting applicable Product Standards and acceptable to the Regulatory Authority may be selected. Special attention should be given to selecting materials that will protect against internal and external pipe corrosion. All products should comply with the latest AWWA and NSF/ANSI Standards. Any material that encounters drinking water must be certified to the latest edition of *NSF/ANSI 61: Drinking Water System Components - Health Effects*. See Chapter 8 for corrosion protection of buried piping systems.

Other materials of construction are acceptable when properly designed to meet the requirements of treated water storage. The design loading for these structures will be governed by the applicable AWWA Standards, building codes. Water treatment plants are designed to a post disaster rating and, therefore, are designed to the highest structural standard available. This higher design standard contributes to resilience against the impacts of climate change. That said, this contribution varies depending on the facility, and the post-disaster rating does not provide resilience against all types of climate change impacts (e.g., changes in freeze-thaw cycles, and power outages).

The materials and designs used for treated water storage structures should provide stability and durability as well as protect the quality of the stored water. The following subsections outline criteria that should be considered when selecting the more common materials for treated water storage facilities.

7.3.2 Steel Construction

Welded steel structures should follow the latest edition of *AWWA D100 Welded Carbon Steel Tanks for Water Storage* concerning tanks, standpipes, reservoirs, and elevated tanks. Welded structures are field coated and generally follow the latest edition of *AWWA D102 Coating Steel Water Storage Tanks*. Pre-finished Bolted Steel structures should follow the latest edition of *AWWA D103 Factory-Coated Bolted Carbon Steel Tanks for Water Storage*. Welded or Bolted Steel reservoir may be constructed with a self-supporting geodesic aluminum dome roof which should follow the latest edition of *AWWA D108 Aluminum Dome Roofs for Water Storage Facilities*. Welded and bolted steel reservoirs should be protected from corrosion with an adequately designed corrosion protection system in accordance with the latest edition of *AWWA D104 Automatically Controlled, Impressed-Current Cathodic Protection for the Interior Submerged Surfaces of Steel Water Storage Tanks* and *AWWA D106 Sacrificial Anode Cathodic Protection Systems for the Interior Submerged Surfaces of Steel Water Storage Tanks*.

7.3.3 Concrete Construction

Concrete structures should follow the latest edition of *AWWA D110 Wire and Strand-Wound, Circular, Prestressed Concrete Water Tanks* concerning pre-stressed circular concrete tanks, standpipes, reservoirs, wherever they are applicable. Where an in-ground reservoir is selected, cast-in-place, non-circular concrete construction may be considered. The application of the most latest edition of *NSF/ANSI 61: Drinking Water System Components - Health Effects* should be evaluated if a concrete tank is selected as the material of construction.

7.3.4 Composite Elevated Tank Construction

Composite elevated tank structures typically consist of a welded steel tank founded on a single concrete pedestal support structure. This type of construction should follow the latest edition of *AWWA D107 Composite Elevated Tanks for Water Storage*.

7.4 Storage Requirements

Water storage has several benefits:

System Operation (Convenience)
In some situations, storage is provided to allow a treatment plant to be operated for only one or two shifts, thereby reducing personnel costs. In this situation, storage provides the water required for the periods of time when the plant shuts down.

Peak Balancing
The demand for water is continually changing in all water systems, depending on time of day, day of the week, weather conditions and many other factors. If there is no storage at all, the System Owner has to continually match the changing demand by selecting pumps of varying sizes. Frequent cycling of pumps causes increased wear on controls and motors. Adequate elevated storage can minimize this effect by providing peak flow balancing capacity.

Pressure Surge Relief
When pumps are turned on and off and when valves are opened and closed, large pressure changes can occur throughout the distribution system which can damage pipes and appurtenances. Water storage tanks provide some assistance in absorbing transient pressure surges.

Reducing Power Requirements
Storage allows for pumping costs to be reduced, by reducing start-ups, avoiding using large pumps at peak demands and also benefiting from off-peak rates offered by the electricity utility during the night.

7.4.1 Water Storage Facility Design Capacity

Storage facilities should have sufficient capacity, as determined from engineering studies, to meet the required domestic demands, and where fire protection is provided, fire flow demands. Emergency storage volumes should be provided to supply demands in the event of pipeline or equipment breakdowns or maintenance shut-downs. Excessive storage capacity should be avoided where water quality deterioration may occur.

The total water storage requirements for a given water supply system where the treatment plant can supply only the maximum day demand may be calculated using the following equation (from the *Design Guidelines for Drinking-Water Systems* from the Ontario Ministry of the Environment):

$$S = A + B + C$$

Where:
S = Total storage requirement (m^3).
A = Fire Storage (m^3) (equal to require fire flow over required duration).
B = Peak Balancing Storage (m^3) (25% of maximum day demand).
C = Emergency Storage (m^3) (see Section 7.4.4).

Notes
1. The above equation is for the calculation of the storage requirement for a system where the WTP can supply only the maximum day demand. For situations where the WTP can supply more, the above storage requirements can be reduced accordingly.
2. The maximum day demand referred to in the foregoing equation should be calculated using the factors in Table 8.1 unless there is existing flow data available to support the use of different factors. Where existing data is available, the required storage should be calculated based on an evaluation of the flow characteristics within the system.
3. Should the System Owner have decided to provide a potable water supply and distribution system not capable of providing fire protection, the usable volume of storage to be provided should be 25% of design year maximum day plus 40% of the design year average day.
4. The designer should recognize that this formula for calculating treated water storage requirements must be supplemented with the plant water storage required for the operation of the WTP (e.g., backwash and domestic use).

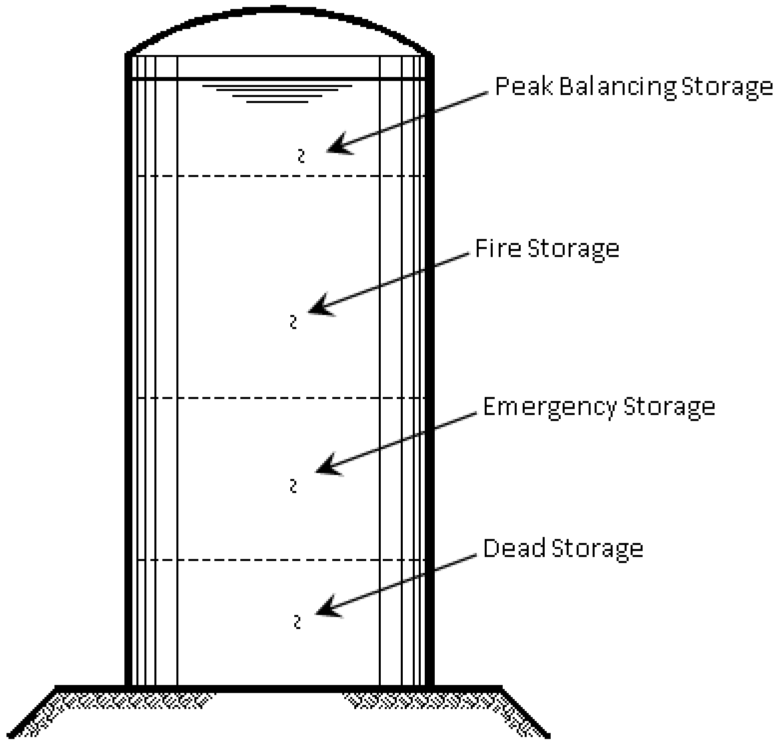

Figure 7.4: Sizing of Water Storage

7.4.2 Peak Balancing Storage Requirements

The demand for water normally changes throughout the day and night. If treated water is not available from storage, the wells and/or treatment plant must have sufficient capacity to meet the demand at peak flow. This capacity is not generally practical or economical. With adequate storage, water can be treated or supplied to the system at a relatively uniform rate over a 24-hour period with peak balancing flows at high demand periods during the day being supplied by water storage tanks.

Peak balancing storage, sometimes referred to as operational storage, is directly related to the amount of water necessary to meet peak demands. The intent of peak balancing storage is to make up the difference between the consumers' peak demands and the system's available supply. With peak balancing storage, system pressures are typically improved and stabilized. The value of the peak balancing storage is a function of the diurnal demand fluctuation in a community and is commonly estimated at 25% of the total maximum day demand.

7.4.3 Fire Flow Storage Requirements

Fire flow storage, where provided, is typically established by the System Owner. The System Owner may elect to provide higher fire flow requirements or entirely forgo fire protection by way of the drinking-water distribution system. Fire demands may not occur very often, however, when it does occur, the rate of water use can be much greater than for domestic peak demand, especially for small communities. The designer should, therefore, be aware of all applicable requirements. For smaller communities, the required fire storage volume can greatly exceed the domestic consumption storage requirements. In sizing storage facilities for small systems, the designer should also consider the importance of maintaining water quality (refer to Section 7.5).

When fire flow storage is to be provided, consult the System Owner guidelines, or refer to the latest edition of *Water Supply for Public Fire Protection* from the Fire Underwriters Survey (FUS). The designer should contact the local FUS office to obtain a copy of a water supply survey for the respective System Owner, should one be available.

The level of fire flow storage may be reduced, accordingly, if the WTP can supply more than the maximum day demand. The designer may also wish to consult the latest edition of the *Design Guidelines for Drinking-Water Systems* from the Ontario Ministry of the Environment (Chapter 8) for an alternative method of establishing fire flow criteria for small systems.

7.4.4 Emergency Storage

During periods of power failure, mechanical or pipeline breakdown or maintenance when use of source water is prevented, there is a need for emergency storage. Emergency storage is the volume of water recommended to meet the demand during maintenance shut-downs or emergency situations, such as source of supply failures (e.g., drought conditions), water quality issues (e.g., algae), watermain failures, electrical power outages, and natural disasters, all of which may be worsened by the impacts of climate change. The WTP may also include emergency storage for small surrounding communities/areas which may rely on municipal water if water quantity and quality issues are encountered due to the impacts of climate change (e.g., low water levels during drought conditions and water quality issues from flood events). The amount of emergency storage included with a particular water system is not set but is typically based on an assessment of risk and desired degree of system dependability.

The designer should consult with the System Owner regarding local emergency storage requirements. Consideration can be given if the System Owner has water use restrictions that can be implemented in emergency scenarios to reduce water demand. The designer should consult with the municipality regarding local emergency storage requirements. If requirements are not clear, identify factors which may influence the need for emergency storage such as frequency and duration of power outages, critical users, and alternate water sources.

In the absence of clear information, 15% of projected average daily design flow can be used, or 25% of peak balancing + fire flow.

7.4.5 Dead Storage

If a storage structure is of a type where only the upper portion of the water provides a useful function, such as maintaining usable system pressure, the remaining lower portion is considered dead storage. Dead storage can be considered useful if the water from the lower portion of the storage structure can be withdrawn by pumps during a fire or other emergency. Where dead storage is present there must be adequate measures taken to circulate the water through the tank to maintain quality and prevent freezing. Unusable dead storage should be avoided wherever possible.

7.4.6 Plant Storage

The designer should recognize the need to calculate, in addition to distribution storage requirements, the requirement for the operation of the WTP (e.g., backwash and domestic use).

7.4.6.1 Clearwell Storage
Clearwell storage should be sized, in conjunction with distribution system storage, to avoid frequent on/off cycling of the treated water pumps. A minimum of two compartments along with adequate measures for circulation should be provided. Clearwells that can be depleted should not be used to achieve the required chlorine CTs. A separate contact tank should be provided to meet the disinfection requirements as per Chapter 5.

7.4.7 Water Storage Facility Design Operating Levels
The Top Water Level (TWL), and location of the storage structures will be determined by the hydraulic analysis undertaken for the design of the distribution system, to result in acceptable service pressures throughout the existing and future service areas. Acceptable pressures under various flow conditions are defined in Chapter 8 which will define acceptable operating levels. Operating bands are shown in in Figure 7.4.

The operating band of the peak balancing volumes should be limited to no more than 9.0 m to stabilize pressure fluctuations within the distribution systems. The bottom of peak balancing volume located at an elevation to achieve minimum design pressures under peak hour flow conditions. The bottom of the fire flow volume operating band should be located at or above an elevation necessary to produce a minimum pressure under a maximum day plus fire flow condition.

7.5 Water Quality
The materials and designs used for treated water storage facilities should provide structural stability and durability as well as preserve the quality of the stored water. Deterioration in water quality is frequently associated with the age of the water. Loss of disinfectant residual, formation of DBPs, and bacterial re-growth can all result from aging of water. As a result, an implicit objective in both design and operation of distribution system storage facilities is the minimization of detention time and the avoidance of volumes of water that remain in the storage facility for long periods. The latest edition of the publication *Maintaining Water Quality in Finished Water Storage Facilities* from the Water Research Foundation should be referenced.

7.5.1 Residence Time
The allowable residence time should depend on the quality of the water, its reactivity, the type of disinfectant used and the travel time before and after the water's entry into the storage facility. A 72-hour residence time is a reasonable guideline. If it is not possible to have sufficient turnover of water in the storage facility, supplemental disinfection of water leaving storage may be required. Mixing systems can help to maintain the quality of stored water and homogeneity of water leaving the reservoir and should be considered in conjunction with supplemental disinfection.

7.5.2 Reservoir Mixing
Mixing should be considered in the design of the water storage facility to ensure a more consistent water quality throughout the facility. Mixing may be accomplished by use of separate inlet/outlet piping, recirculation systems, active mixing systems, and passive mixing systems.

Adequately designed mixing can have the following benefits:

- Reduce the risk of freezing during the winter and excessive warming of the water during the summer.
- Lowers the likelihood of dead zones within the reservoir. This is particularly a concern for standpipes.
- Maintains a more consistent chlorine residual throughout the water column.

Should active or passive mixing systems be considered, the designer is to consider the operating parameters of the storage facility, maintenance, life cycle, and effectiveness.

7.5.3 Chlorine Maintenance

Storage tanks are not typically used to achieve primary disinfection, and careful consideration to the inlet, outlet, baffling, and operating configuration should be given where this arrangement is intended. Disinfectant residual and CT requirements for primary disinfection should be achieved in accordance with the requirements outlined in Section 5.5. Disinfectant boosting systems in the distribution system may be required to provide a continuous disinfection residual leaving storage and /or throughout the system in accordance with regulatory requirements, while achieving all other water quality requirements (i.e., to prevent excessive disinfectant dosing at the point of primary disinfection). These boosting systems are often located at water storage tanks and may provide disinfectant addition at the inlet or outlet of the storage tank as required. The addition of a disinfectant at a storage facility may increase the risk of the formation of DBPs, depending on initial water quality.

7.5.4 Blending of Water Sources

Some water systems use water from two or more sources, with each source having different water quality. The feasibility of the blending of sources should be investigated. The chemical quality of blended water may affect the integrity of the distribution system and could lead to issues with water quality, lower disinfectant residual, and increased corrosion risk (including release of lead ions).

7.6 Location of Distribution Storage

The location of distribution storage is closely associated with the system hydraulics and water demands in various parts of the system. Location of the storage facilities at natural ‘high’ points within the area being served by the water system allows for gravitational advantage and potential considerable cost savings. The site selection process is often also affected by the availability of appropriate land and public acceptance of the structure.

7.6.1 Elevated Storage

Elevated storage includes elevated tanks and the upper portion of water stored within standpipes. Elevated storage facilities that have existed for several years rarely bother the public, however, property owners will often object to a new one being built near their homes. Designs can be very pleasing, and landscaping and colours can be used to minimize or even enhance the visual effect. This may not, however, be enough to overcome the objections of the local community and it may be necessary to build water elevated storage facilities at non-ideal locations from both topographic and hydraulic perspectives. Industrial zones may provide some opportunities, otherwise alternative facilities using above-ground and in-groundwater storage and pumps may be required.

7.6.2 Above Ground & In-Ground Storage Reservoirs

Low level above ground and in-ground storage reservoirs are generally used where a large quantity of water must be stored. A relatively large parcel of land is required to accommodate both the reservoir and the accompanying pump station.

The following are considered minimum requirements:

- The bottom of above-ground reservoirs and standpipes should be placed at the normal ground surface and should be located at a minimum elevation which exceeds the 1-in-100-year flood level including climate change considerations (refer to Chapter 2 for further guidance).
- When the bottom of the storage reservoir must be below normal ground surface, the in-ground reservoir should be placed above the groundwater table. Typically, at least 50% of the water depth should be above grade. Wastewater, drains, standing water, and similar sources of possible contamination must be kept at least 15 m from the reservoir.
- The top of an in-ground reservoir should not be less than 600 mm above normal ground surface. Clearwells constructed under filters may be exempted from this requirement when the total design gives the same protections.

7.7 Facility Requirements

7.7.1 Inlet/Outlet & Baffle Wall

For information on inlet/outlets and baffle walls, see Section 7.5.

7.7.2 Level Control

Adequate controls should be provided to maintain levels in distribution system storage structures. Level indicating devices should be provided at a central location. Key issues are:

- Pumps should be controlled from tank levels with the signal transmitted by telemetry equipment when any appreciable head loss occurs in the distribution system between the source and the storage structure.
- Altitude valves or equipment controls are required to control pump on-off cycles or gravity flow to and from the tank to maintain the system pressures and avoid overflows.
- Overflow and low-level warnings or alarms should be located at places in the community where they will be under responsible surveillance 24 hours a day.
- Changes in water level in a storage tank during daily domestic water demands should be limited to a maximum 9.0 m to stabilize pressure fluctuations within the distribution system.

7.7.3 Overflow

All above groundwater storage structures should be provided with an overflow which is brought down to an elevation between 300 mm and 600 mm above the ground surface, and discharges over a drainage inlet structure or a splash plate. An overflow should not be connected directly to a wastewater or a storm drain. All overflow pipes should be located so that any discharge is visible.

When an internal overflow pipe is used on elevated tanks, it should be located in the access tube. For vertical drops on other types of storage facilities, the overflow pipe should be located on the outside of the structure.

The overflow of a ground-level structure should open downward and be screened with mesh non-corrodible screen installed within the pipe at a location least susceptible to damage by vandalism. Overflows should be located at sufficient elevation to prevent the entrance of surface water. A backflow preventer should be installed on all overflows, on in-ground or low elevation reservoirs.

The overflow pipe should be of sufficient diameter to permit the wasting of water in excess of the filling rate.

Consideration should be given to downgrade receiving areas of overflow water. Adequate surface detention should be provided to prevent soil erosion and to provide safe dissipation of chlorine.

The discharge must not be directed to natural water bodies. Discharge in residential areas should be contained to appropriate and controlled storm water channels.

7.7.4 Drainage of Storage Structures

Water storage structures which provide pressure directly to the distribution system should be designed so they can be isolated from the distribution system and drained for cleaning or maintenance without necessitating loss of pressure in the distribution system. The drain should discharge to the ground surface with no direct connection to a municipal storm drain and should be located at least 300 mm above ground surface.

Water that is drained from storage structures should be dechlorinated prior to discharge to the environment.

7.7.5 Roof Drainage

The roof of the storage structure 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.

7.7.6 Roof & Sidewall

The roof and sidewalls of all structures must be watertight with no opening except properly constructed vents, manholes, overflows, risers, drains, pump mountings, control ports, or piping for inflow and outflow.

- Any pipes running through the roof or sidewall of a treated water storage structure must be welded, or properly gasketed in metal tanks. In concrete tanks, these pipes should be connected to standard wall castings which were poured in place during the forming of the concrete. These wall castings should have seepage rings imbedded in the concrete.
- Openings in a storage roof or top, designed to accommodate control apparatus or pump columns, should be curbed and sleeved with proper additional shielding to prevent the access of surface or floor drainage water into the structure.
- Valves and controls should be located outside the storage structure so that the valve stems and similar projections will not pass through the roof or top of the reservoir.
- The roof of concrete reservoirs with earthen cover should be sloped to facilitate drainage. Consideration should be given to installation of an impermeable membrane roof covering.

7.7.7 Vents

Finished water storage structures should be vented. Overflows should not be considered as vents. Open construction between the sidewall and roof is not permissible. The requirement for vents are as follows:

- They should prevent the entrance of surface water and rainwater.
- They should exclude birds and animals.
- They should exclude insects and dust, as much as this function can be made compatible with effective venting. For elevated tanks and standpipes, 4-mesh non-corrodible screen may be used.
- They should, on ground-level structures, terminate in an inverted U construction with the opening 600 mm to 900 mm above the roof or sod and covered with 24-mesh non-corrodible screen installed within the pipe at a location least susceptible to vandalism.

7.7.8 Frost Protection

All finished water storage structures and their appurtenances, especially the riser pipes, overflows, and vents, should be designed to prevent freezing which may interfere with proper functioning.

7.7.9 Internal Catwalk

All catwalks located over finished water in a storage structure should have a solid floor with raised edges so designed that shoe scrapings and dirt will not fall into the water.

7.7.10 Silt Stop

The discharge pipes from all reservoirs should be located in a manner that will prevent the flow of sediment into the distribution system. Removable silt stops should be provided.

7.7.11 Grading

The area surrounding a ground-level structure should be graded in a manner that will provide positive drainage away from the structure to prevent surface water from standing within 15 m of the structure.

7.7.12 Corrosion Prevention/Reduction

Proper protection should be given to metal surfaces by paints or other protective coatings, by cathodic protective devices, or by both.

- Paint systems should meet the latest edition of *AWWA D102 Coating Steel Water Storage Tanks* and be certified to *NSF/ANSI 61: Drinking Water System Components - Health Effects* and be acceptable to the Regulatory Authority. Interior paint must be properly applied and cured. After curing, the coating should not transfer any substance to the water which will be toxic or cause tastes or odours. Prior to placing in service, an analysis for VOCs is advisable to establish that the coating is properly cured. Consideration should be given to 100% solid coatings.
- Wax coatings for the tank interior should not be used on new tanks. Re-coating with a wax system is discouraged, however, the old wax coating must be completely removed to use another tank coating.
- Cathodic protection should be designed and installed by qualified technical personnel and a maintenance contract should be provided. Refer to the latest editions of *AWWA D104 Automatically Controlled, Impressed-Current Cathodic Protection for the Interior Submerged Surfaces of Steel Water Storage Tanks* and *AWWA D106 Sacrificial Anode Cathodic Protection Systems for the Interior Submerged Surfaces of Steel Water Storage Tanks* for corrosion protection standards for steel reservoirs.

7.7.13 Disinfection

- Finished water storage structures should be disinfected in accordance with the latest edition of *AWWA C652 Disinfection of Water Storage Facilities*. Two or more successive sets of samples, taken at 24-hour intervals, should indicate microbiologically satisfactory water before the facility is placed into operation.
- Disposal of heavily chlorinated water from the tank disinfection process requires dechlorination in accordance with the latest edition of *AWWA C652 Disinfection of Water Storage Facilities* and *AWWA C655 Field Dechlorination* and should be in accordance with the requirements of the Regulatory Authority.
- A disinfection procedure (latest edition of *AWWA C652 Disinfection of Water Storage Facilities* (chlorination method 3, section 4.3)) which allows use of the chlorinated water held in the storage tank for disinfection purposes is recommended where conditions warrant, (i.e., where water supply is not abundant or where large reservoirs would require excessive volumes of water and chlorine).

7.7.14 Water Quality Monitoring

A sampling point should be provided to allow for the monitoring of water quality in water leaving storage. Some regulators require that the water leaving storage be monitored continuously for chlorine residual. A single sampling point on the water leaving the storage may not represent the water supplying the tank or quality or water within the tank. For that reason, multiple sampling sites can be considered and the need for such should be discussed with the System Owner. When selecting multiple sampling sites, consider:

- Configuration of the inlet/outlet piping.
- Storage facility mixing or baffling.
- Type of storage facility (standpipe or reservoir).
- Storage facility operation (inline or floating).

7.7.15 Adjacent Compartments

Finished water must not be stored or conveyed in a compartment adjacent to unsafe water when the two compartments are separated by a single wall.

7.7.16 Basins & Wet Wells

Receiving basins and pump wet wells for finished water should be designed as finished water storage structures.

7.7.17 Standby Power

The necessity for standby power for a storage facility with pump discharge is dependent on whether the normal power is considered secure. In addition, the volume of elevated storage should be assessed when considering the requirements for standby power.

Power supply equipment located outside/above ground are vulnerable to extreme weather events. The impacts of climate change may result in an increased risk of power outages resulting from potential increases in the frequency and intensity of weather events (e.g., hurricanes and other large wind events). Provisions for stand-by power are important to reduce the risk to interruptions to water supply operations and provide resiliency to the impacts of climate change.

7.8 Water Treatment Plant Storage

7.8.1 Backwash Tanks

Backwash tanks should be sized, in conjunction with available pump units and finished water storage, to provide the required filter backwash water. Consideration should be given to the backwashing of several filters in succession.

7.8.2 Clearwell

Clearwell storage should be sized, in conjunction with distribution system storage, to relieve the filters from having to follow fluctuations in water use.

- When finished water storage is used to provide CT for chlorine (see Section 5.5) special attention must be given to size and baffling.
- If used to provide chlorine CT, sizing of the clearwell should include extra volume to accommodate depletion of storage during the nighttime for intermittently operated filtration plants with automatic high service pumping from the clearwell during non-treatment hours.
- A minimum of two clearwell compartments should be provided.
- The overflow pipe should be of sufficient diameter to permit the wasting of water in excess of the filling rate.
- Consideration should be given to receiving areas of overflow water. Adequate surface detention should be provided to prevent soil erosion and to provide safe dissipation of chlorine.
- The discharge must not be directed to natural water bodies. Discharge in residential areas should be contained to appropriate and controlled storm water channels.

7.8.3 Adjacent Compartments

Finished water must not be stored or conveyed in a compartment adjacent to unsafe water when the two compartments are separated by a single wall.

7.8.4 Wet-Wells

Receiving pump wet-wells for finished water should be designed as finished water storage structures.

7.9 Hydropneumatic Tanks

The use of hydropneumatics (pressure) tanks, as storage facilities is preferred for small water supply systems. When serving more than 150 living units, however, ground or elevated storage is recommended in accordance with the sizing requirements as outlined in Section 7.4.

Pressure tank storage is not to be considered for fire protection purposes.

Pressure tanks should meet the latest edition of the *Boiler and Pressure Vessel Code* from the American Society of Mechanical Engineers requirements or an equivalent requirement of provincial and local laws and regulations for the construction and installation of unfired pressure vessels.

7.9.1 Location

The tank should be located above normal ground surface and be completely housed. Refer to Section 9.6 for siting considerations and guidance.

7.9.2 Sizing

The capacity of the wells and pumps in a hydropneumatic system should be at least ten times the average daily consumption rate. The gross volume of the hydropneumatic tank in litres, should be at least ten times the capacity of the largest pump, rated in litres per minute. For example, a 750 L/minute pump should have a 7,500 L pressure tank.

Sizing of hydropneumatic storage tanks should consider the need for chlorine detention time, if applicable.

7.9.3 Piping

The tank should have bypass piping to permit operation of the system while it is being repaired or painted.

7.9.4 Appurtenances

Each tank should have a drain, and control equipment consisting of pressure gauge, water sight glass, automatic or manual air blow-off, means for adding air, and pressure operated start-stop controls for the pumps. In large tanks, where practical, an access manhole should be 600 mm in diameter.

7.10 Security & Safety

7.10.1 Access

Only qualified persons should be allowed to work in water storage facilities.

Finished water storage structures should be designed with reasonably convenient access to the interior for cleaning and maintenance. For in-ground tanks at least two manholes should be provided above the waterline at each water compartment where space permits.

Access manholes in above ground structures should be framed at least 100 mm above the surface of the roof at the opening. For below ground structures access, manholes should be elevated a minimum 600 mm above the top of covering sod.

- Each of the manhole should be fitted with a solid watertight cover which overlaps the framed opening and extends down around the frame at least 50 mm.
- Hinged at one side.
- Have a locking device.

7.10.2 Safety

The safety of employees must be considered in the design of the storage structure. As a minimum, such matters should conform to pertinent laws and regulatory requirements of the area where the reservoir is constructed.

- Ladders, ladder guards, offset balconies, balcony railings, and safety located entrance hatches should be provided where applicable.
- Elevated tanks with riser pipes over 200 mm in diameter should have protective bars over the riser openings inside the tank.
- Railings or handholds should be provided on elevated tanks where persons must transfer from the access tube to the water compartment.
- The design should incorporate easily accessible fall arrest systems for use by employees or emergency response workers for access to the exterior and interior of the structure.

7.10.3 Protection

All finished water storage structures should have suitable watertight roofs which exclude birds, animals, insects, and excessive dust.

Fencing, locks, access manholes, and other necessary precautions should be provided to prevent trespassing, vandalism, and sabotage. The designer should consult the latest edition of the *Water Sector Cybersecurity Risk Management Guidance* from the AWWA.

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Table of Contents

Chapter 8 Transmission & Distribution Systems

Water distribution systems are made up of pipe, valves, and pumps through which treated water is moved from the treatment plant to domestic, industrial, commercial, and other customers. The distribution system also includes facilities to store water (see Chapter 7) meters to measure water use, fire hydrants, and other appurtenances. The major requirement of a distribution system is to supply each customer with a sufficient volume of treated water at an adequate service pressure. Figure 8.1 indicates a typical transmission and distribution system.

8.1 Definitions

The following definitions are considered important for the purposes of this Chapter.

Transmission Main
A transmission main is the pipeline used for water transmission, that is, movement of water from the source to the treatment plant and from the plant to the distribution system.

Transmission mains typically do not have service connections.

Primary Distribution Main
A primary distribution main is a principal supply pipeline within a distribution system. A primary distribution main can also transport water to adjacent distribution networks.

Distribution Main
A distribution main is the local supply pipeline in the distribution system.

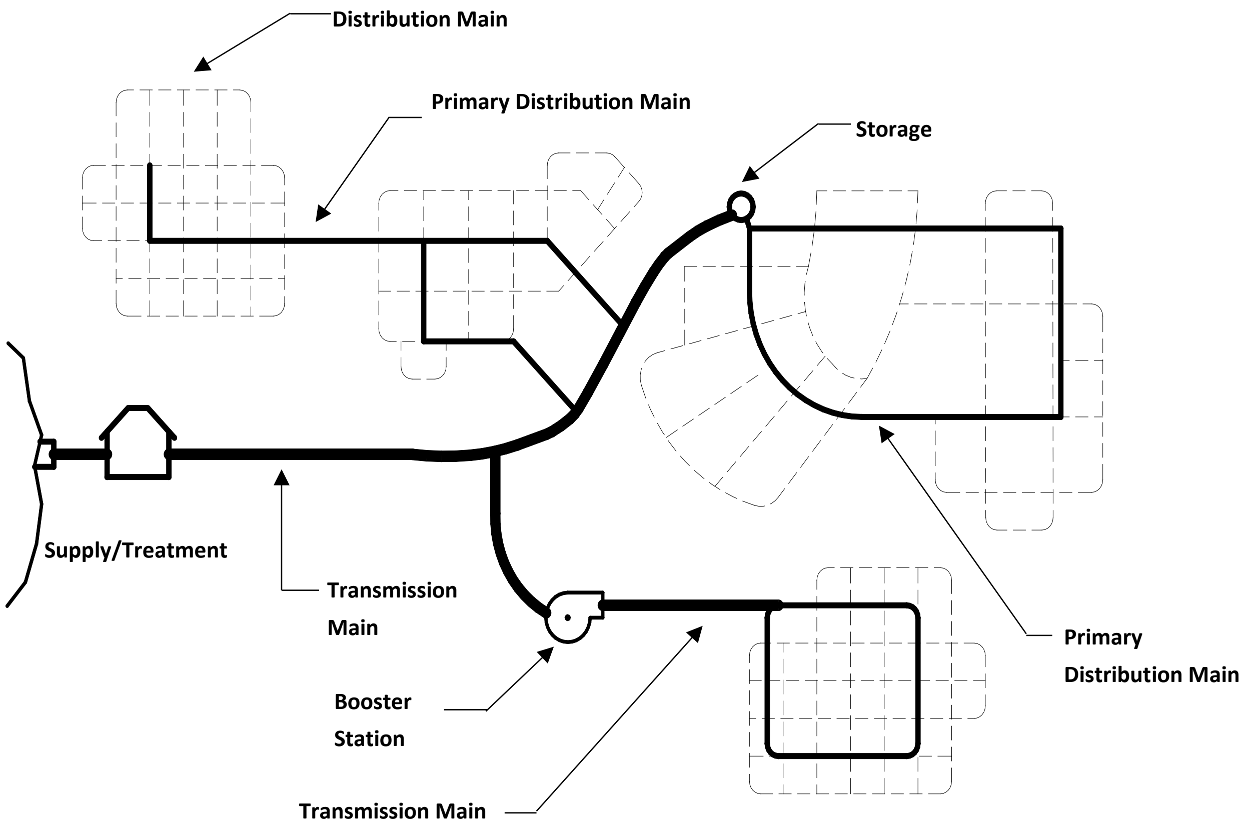

Figure 8.1: Transmission & Distribution Systems

Service Line (Lateral)
A service line is the pipe (and all appurtenances) that runs between the water main and the customer's place of use, including fire lines.

Service Connection
A service connection is the portion of the service line from the System Owner's water main to the curb stop at or adjacent to the street line or the customer's property line.

Water Demands

- Average day demand is the average daily rate of flow of water in a year that must be supplied by the water system to meet customer demands.
- Maximum day demand is the largest daily rate of flow of water in a year that must be supplied by a water system, to meet customer demands.
- Peak hour demand is the largest hourly rate of flow of water in a year that must be supplied by a water system to meet customer demands.
- Minimum hour demand can also be referred to as the night demand. It is the lowest hourly rate of flow of water in a year that must be supplied to meet customer demands.
- Instantaneous peak demand is a short duration, high rate of flow of water that can occur in a water supply system that does not generally include fire flows.

8.2 Materials

There are a variety of materials in use within water transmission and distribution systems. Typical water pipe material used for new construction throughout the Atlantic Provinces include:

- Ductile iron.
- Polyvinyl chloride.
- High Density Polyethylene (HDPE).
- Concrete pressure pipe.

There are other pipe materials (e.g., cast iron) not listed above that are either no longer used for new construction or are only used in specialized cases.

8.2.1 Standards, Materials Selection

Pipe, fittings, valves, and fire hydrants should conform to the latest standards issued by the CSA, AWWA, NSF/ANSI, or National Fire Protection Association (NFPA), and be acceptable to the Regulatory Authority.

The proper selection of water pipe material should take into consideration the following:

- Working pressure rating.
- Surge pressure rating.
- Internal and external corrosion resistance.
- Negative pressure capability.
- Ease of installation.
- Availability.
- Pipe rigidity with regards to trench conditions.
- Ease of repair.

8.2.2 Used Materials

Water mains which have been used previously for conveying potable water may be reused provided they meet the above standards and have been restored practically to their original condition.

8.2.3 Joints

Packing and jointing materials used in the joints of pipe should meet the standards of the CSA, AWWA, and the Regulatory Authority. Pipe having mechanical joints or plain ends in combination with couplings having slip-on joints with rubber gaskets is preferred. Lead-tip gaskets should not be used. Repairs to lead-joint pipe should be made using alternative methods.

Flanged joints should only be used in conjunction with fitting such as valves within a properly constructed chamber.

8.2.4 Corrosion Prevention/Reduction

Special attention should be given first to selecting pipe, valve and fitting materials and applicable coating systems which will protect against both internal and external pipe corrosion. All products should comply with AWWA CSA/ANSI Standards.

For piping, valves and fittings, consideration should be given by the engineer to the potential presence of water; either due to high groundwater conditions, poor drainage, or potential French drain conditions in the trench; chemistry in the surrounding soils such as, but not limited to:

- Aggressive organics or the presence/exposure of salt (NaCl).
- Contact between dissimilar metals.
- The choice of materials.

All of these can contribute to corrosion. Where any of these conditions might exist, the Design Engineer should consider an appropriate corrosion protection system for the piping, valves, and fittings either by encasement (wraps, coatings, etc.) and/or provision of cathodic protection. Consideration should be given for the expected life and future maintenance and/or replacement of the corrosion protection system.

For small copper pipes, sacrificial anodes are recommended.

The design and installation of corrosion protection system should be as per the manufacturer's recommendations and as specified.

8.3 Design Criteria for Transmission & Distribution Systems

8.3.1 Transmission & Distribution Pipelines

The design of water transmission and distribution mains requires special considerations of a number of key elements.

8.3.1.1 Transmission Mains

Transmission mains in water supply systems are typically large diameter, carry large flows under high pressure and are long in length, therefore, the design activities should address:

- Sizing for ultimate future design flows.
- Sizing and layout to ensure adequate supply and turnover of water storage facilities.
- Elimination of customer service take-offs.
- Minimization of branch take-offs to help maintain flow and pressure control.
- Air relief at high points and drain lines at low points.
- Isolation valving to reduce the length of pipe required to be drained in a repair or maintenance shut-down.
- Potential transient pressures.
- Master metering.
- Considerations for climate change (e.g., changes in flood lines and potential increases in freeze-thaw cycles).

8.3.1.2 Primary Distribution Mains

Primary distribution mains typically receive flow from transmission mains or pressure control facilities (booster pumps or pressure reducing valve) and supplies water to one or several local distribution systems as well as services to customers. The primary distribution main provides a significant carrying capacity or flow capability to a large area. Key design activities should address:

- Implementing a minimum "dual" feed system of primary distribution mains to supply large distribution systems.
- Looping and isolation valving to maintain services with alternate routing in the event of repair or maintenance shut-down.

- Area metering.
- Air relief at significant high points.
- Sizing for future extensions.
- Elimination of dead-ends.

Distribution mains typically provide the water service to customers through a network of pipelines feed by the primary distribution mains. Key design activities should address:

- Looping and isolation valving to maintain service with alternate routing in the event of repair or maintenance shut-down.
- Adequate valving to provide an efficient flushing program.
- Elimination of dead-ends.
- Pressure surge relief (requirements can be addressed by storage in the distribution system or other acceptable means).

8.3.1.2.1 Water Demands

The average day demand, maximum day demand, peak hour demand, and minimum hour demand are defined in Section 8.1, and are largely based on the *Design Guidelines for Drinking-Water Systems* from the Ontario Ministry of the Environment. Domestic water demands vary greatly from one water system to another. Depending upon such factors as the presence of service metering, lawn-watering practices, use of bleeders to prevent freezing, water quality, water conservation programs and leakage, daily per capita consumption can vary. Daily consumption data should be derived from system flow data, preferably recorded daily. In the absence of data, a range of 270 to 450 L/(cap·d) for domestic water usage. For design of new systems, an allowance of 350 L/(cap·d) can be used.

Where values for maximum day demand, peak hour demand, and minimum hour (night) demand are not known they can be derived using peaking factors (i.e., applying numerical ratios of the average day demands). Wherever possible, peaking factors based on actual usage records for a given water supply system should be used in the hydraulic analysis of a water transmission and distribution system, however, if such records do not exist or are unreliable, Table 8.1 can be used as a guide.

The peaking factors indicated contained in Table 8.1 (Table 3-1 from the *Design Guidelines for Drinking-Water Systems* from the Ontario Ministry of the Environment) are suitable for use in the hydraulic analysis of a water supply system with a variety of uses (residential/public/commercial/industrial). Water demands and peaking factors for systems containing appreciably large areas of commercial or industrial lands will require an evaluation of water demands based on individual facility users.

Table 8.1: Peaking Factors for Water Supply Systems

Equivalent Population	Minimum Hour Factor	Maximum Day Factor	Peak Hour Factor
500 - 1,000	0.40	2.75	4.13
1,001 - 2,000	0.45	2.50	3.75
2,001 - 3,000	0.45	2.25	3.38
3,001 - 10,000	0.50	2.00	3.00
10,001 - 25,000	0.60	1.90	2.85
25,001 - 50,000	0.65	1.80	2.70
50,001 - 75,000	0.65	1.75	2.62
75,001 - 150,000	0.70	1.65	2.48
Greater than 150,000	0.80	1.50	2.25

For commercial and institutional water demands, in the absence of data, *Design Guidelines for Drinking-Water Systems* from the Ontario Ministry of the Environment provide the allowances for typical water usage in Table 8.2.

Table 8.2: Commercial & Industrial Water Demands

Commercial and tourist areas	28 $m^3/(ha \cdot d)$
Shopping centres (based on total floor area)	2,500 - 5,000 $L/(m^2 \cdot day)$
Hospitals	900 - 1,800 L/(bed·day)
Schools	70 - 140 L/(student·day)
Travel trailer parks (minimum with separate hook-ups)	340 L/(space·day) - 800 L/(space·day)
Campgrounds	225 - 570 L/(campsite·day)
Mobile home parks	1,000 L/(space·day)
Motels	150 - 200 L/(bed-space·day)
Hotels	225 L/(bed-space·day)

Where the average day demand and peaking factors are not defined by the applicable System Owner or Regulatory Authority, additional guideline values can be referenced in the latest editions of the following documents:

- *Modeling, Analysis, and Design of Water Distribution Systems* written by Lee Cesario and published by the AWWA.
- *Design and Construction of Small Water Systems* from the AWWA.
- *Water Distribution Systems Handbook* by Larry W. Mays.
- *M22 Sizing Water Service Lines and Meters* from the AWWA.

8.3.2 Pressure

All transmission mains, primary distribution mains, distribution mains and service mains, including those not designed to provide fire protection, should be sized based on results of a hydraulic analysis of flow demands and pressure requirements.

Transmission and distribution mains should be designed to withstand the maximum working pressure plus pressure surge allowance. Mains should be tested to 1.5 times the working pressure, or to a minimum of 517 kPa (75 psi).

The system should be designed to maintain normal operating pressures 350 to 480 kPa (50 to 70 psi) with a minimum pressure of 275 kPa (40 psi) at ground level at all points in the distribution system. Pressures outside of this range may be dictated by distribution system size and/or topography. The designer should also consider pressure losses within serviced buildings due to the installation of equipment or appurtenances (water meters, backflow preventers, etc.) relative to the minimum operating pressure in the system.

The maximum pressures in the distribution system should not exceed 700 kPa (100 psi) to avoid damage to household plumbing and unnecessary water and energy consumption. When static pressures exceed 700 kPa (100 psi), pressure reducing devices should be provided on mains or service connections in the distribution system.

Fire flow residual pressure should be maintained at 150 kPa (22 psi) at the flow hydrant and should be a minimum 140 kPa (20 psi) within the system, for the design duration of the fire flow event.

8.3.3 Maintaining Water Quality

The following is an excerpt of Section 10.1.1 and 10.1.3 of the *Design Guidelines for Drinking-Water Systems* from the Ontario Ministry of the Environment (2019):

"The report of the Walkerton Commission includes the following definition: "A high-quality distribution system is reliable, providing a continuous supply of potable water at adequate pressure. Reservoirs within the system balance pressure and cope with peak demands, fire protection, and other emergencies without causing undue water retention, while looped watermains prevent stagnation and minimize customer inconvenience during repairs. Since water quality declines with the length of time the water remains in the system, and the rate of decline depends partly on the attributes of the distribution system, a high-quality system has as few dead ends as possible and maintains adequate flow and turnover. The designer should strive to achieve these objectives."

"Water distribution systems should be designed to provide a balance between hydraulic water supply needs and water quality. Water quality issues are categorized as microbiological (e.g., bacteria, regrowth, nitrification), chemical/physical (e.g., disinfection by-products, lead and copper, maintenance of secondary disinfectant residual) or aesthetic (e.g., colour, taste, odour). Many water quality issues have a direct potential public health impact."

"Water quality deteriorates through interactions between the pipe wall and the water, and reactions within the bulk water itself. Depending on the retention time in the system, water flow, treated water quality, pipe materials and condition and deposited materials (e.g., sand, iron, manganese), the water quality will change to a greater or lesser extent. Therefore, water age, a function of system design, water demand and system operation, is a major factor in water quality deterioration within the distribution system. Systems should be designed to maximize turnover and to minimize retention times and water age. Careful consideration should be given to distribution main sizing, providing for multidirectional flow, adequate valving for distribution system control and provisions for flushing and occasional "swabbing". In addition, positive pressure must be maintained at all times to prevent intrusion of contaminants. The designer should consult references such as the AWWARF Guidance

Manual for Maintaining Water Quality in the Distribution System (Project #357), 2000 and the United States Environmental Protection Agency (USEPA) document Distribution System White Papers".

8.3.4 Diameter

The diameter of mains should be sized based on a hydraulic analysis and allowable velocities. The minimum nominal diameter of pipe should be as follows:

- 200 mm for primary distribution mains (300 mm is recommended).
- 150 mm for distribution mains.
- 150 mm for service mains providing fire protection.
- 100 mm for service mains not providing fire protection.

Consideration should be given to water quality deterioration arising from potential oversizing of the water mains. Oversizing of water mains may be due to accommodating future buildout or accommodating relatively large fire flows in a small distribution system. In some cases, it may be necessary to evaluate the provision of separate pipes for fire and potable supplies to maintain water quality.

8.3.5 Velocity

The maximum design velocity for flow under maximum day conditions for transmission mains, primary distribution mains, distribution mains and service mains should be 1.5 m/s. The maximum fire flow velocity should be 3.0 m/s.

Flushing devices should be sized to provide a flow that provides a minimum cleansing velocity of 0.8 m/s in the water main being flushed.

8.3.6 Dead Ends/Looping Requirements

Water distribution systems should be designed to exclude any dead-ended primary distribution mains, and distribution mains unless unavoidable. Appropriate tie-ins (loops) should be made wherever practical.

Looping may help to address water quality concerns with dead end mains for which there is low demand, however, a hydraulic analysis should be undertaken to determine if adequate turnover is achieved should looping be added.

Where dead-end mains occur, they should be provided with a fire hydrant if flow and pressure are sufficient, or with an approved flushing hydrant or blow-off for flushing purposes. Flushing device should not directly connect to any wastewater system.

8.3.7 Fire Protection

All transmission mains, primary distribution mains and distribution mains, including those designed to provide fire protection, should be sized based on a hydraulic analysis to be carried out to determine flow demands and pressure requirements. The minimum size of water main for providing fire protection and serving fire hydrants should be 150 mm diameter.

When fire protection is to be provided, system design should be such that fire flows and facilities are in accordance with the requirements of the appropriate latest edition of *Water Supply for Public Fire Protection* from the Fire Underwriters Survey as well as the latest edition of *M31 Distribution System Requirements* for Fire Protection from the AWWA.

8.3.8 Fire Pumps

NFPA 20 Standard for the Installation of Stationary Pumps for Fire Protection covers the selection of stationary pumps and installation of pumps supplying water for private fire protection. Items include:

- Water supplies.
- Suction.
- Discharge.
- Auxiliary equipment.
- Power supplies.
- Electric drive and control.
- Internal combustion engine drive and control.
- Steam turbine drive and control.
- Acceptance tests and operation.

Refer to Chapter 6 for additional discussion on pumping facilities.

Stored water may be required to meet the demand for fire protection for a given duration. A reliable and safe method of replenishment would be required (see Chapter 7).

8.3.9 Drain/Flushing Devices

Drain/flushing devices should be placed at significant low points in the transmission system. The drain/flushing devices are required to accommodate flushing during construction, and after a watermain break to drain the pipe for repair.

Where flushing devices are to be installed, they are to be designed in accordance with the requirements of the latest edition of *AWWA C651 Disinfection Water Mains* and due care with respect to de-chlorinating, exit velocity of water during flushing (potential erosion/scour), minimum separation distance from nearest watercourse, storage, etc.

Flushing device should not be directly connected to any wastewater system.

8.3.10 Air Relief & Vacuum Valves

Air relief and vacuum valves should be installed, in a chamber, at significant high points in the transmission system and at other such locations as required for efficient operation of the water system (see the latest edition of *M51 Air Valves: Air Release, Air/Vacuum & Combination* from the AWWA).

8.3.11 District Metered Areas

Large utilities and/or upgrades to existing water distribution systems may benefit from the use of District Metered Areas (DMA).

A DMA is a discrete area of a water distribution network where the water volume provided to the area is monitored and compared to the total water volume of the metered individual users located within the area. A comparison of the total water provided (single or multiple inlet DMAs) and total water consumed (multiple individual meters) over a specific time frame provides the System Owner the opportunity to audit the system and implement controls to minimize water loss, if required.

A DMA may be created temporarily by closing boundary valves so that it remains flexible to changing demands, or permanently by disconnecting pipes to neighbouring areas.

The ACWWA promotes the use of DMAs as a best practice.

8.3.12 Crossing Obstacles

Due to geography, parallel services, etc., there will be a variety of physical obstacles which can result in watermain crossing obstacles. Considerations include, but are not limited to, the following:

- Road crossings.
- Wastewater sewer crossings.
- Surface water crossings.
- Horizontal drillings.

8.3.12.1 Road Crossings

It is recommended for all new water mains crossing existing roads and all new roads crossing existing water mains that there is:

- A minimum cover of 1.5 m from the top of the pipe.
- Backfill method and material are approved.
- Drainage is adequate.
- Ditches crossing water mains should provide minimum cover of 1.5 m or insulate the watermain for frost protection.

8.3.12.2 Wastewater Sewer Crossings

For water mains crossing sewer mains, see Section 8.7 for clearance and separation requirements.

8.3.12.3 Surface Water Crossings

Surface water crossings, whether over or under water, require special considerations. The Regulatory Authority should be consulted before final plans are prepared.

The pipe should be adequately supported and anchored, protected from damage and freezing, and accessible for repair or replacement.

The 1-in-100-year flood lines including climate change considerations should be determined (refer to Chapter 2 for further guidance).

A minimum ground cover of 600 mm should be provided over the pipe. Consideration should be given to the potential for water-course bottom to change as a result of scour or dredging. When crossing watercourses which are greater than 4.5 m in width, the following should be provided:

- The pipe should be of special construction, having flexible, restrained, or welded watertight joints.
- Valves should be provided at both ends of water crossings so that the section can be isolated for testing or repair.

- Valves should be easily accessible, not subject to flooding, and should be within a properly constructed chamber.
- Permanent taps should be made on each side of the valve within the manhole to allow insertion of a small meter to determine leakage and for sampling purposes.

8.3.12.4 Horizontal Drillings

Other methods of installation of watermains crossing obstacles or in deep installations include horizontal drilling/boring and installing pipe sections in protective sleeves.

8.3.13 Bedding

Bedding material and methodology should be done in accordance with specifications from local jurisdiction and should be no less than as recommended by the pipe manufacture. Pipe and fittings must not be laid when the trench bottom is frozen, under water or when trench conditions or weather are unsuitable. Material removed from the trench should not be used as a bedding material.

8.3.14 Cover

All water mains should be covered with sufficient earth or other insulation to prevent freezing. If this is not possible, insulation around the pipe is required. In addition, there is a requirement to have sufficient cover over water mains to minimize mechanical loading (see Section 8.3.12.1). It is also recommended that maximum allowable depth be specified.

8.3.15 Thrust Restraint

All tees, bends, plugs and hydrants should be provided with reaction blocking, tie rods or restrained joints designed to prevent movement.

In situations where a watermain installation is above deep fills or parallel to a deep wastewater main, consideration should be given to using restrained joints.

8.3.16 Pressure & Leakage Testing

All types of installed pipe should be pressure tested and leakage tested in accordance with the latest edition of *AWWA C600 Installation of Ductile-Iron Mains and Their Appurtenances*, or as required by provincial or local authorities.

8.3.17 Disinfection

All new, cleaned, or repaired water mains should be disinfected in accordance with the latest edition of *AWWA C651 Disinfection Water Mains*. The specifications should include detailed procedures for the adequate flushing, disinfection, disposal of chlorinated water, and microbiological testing of all water mains. In an emergency or unusual situation, the disinfection procedure should be discussed with the Regulatory Authority.

8.3.18 Commissioning

Following successful testing and disinfection of watermains, the new system should be commissioned with due consideration of resulting pressure and flow changes and other parameters that may be experienced within the water supply system.

8.4 Trenchless Technologies

Traditional construction methods for the installation, replacement, or rehabilitation of underground utilities such as watermains and sewers require extensive excavation and surface disruption. Trenchless technologies is an umbrella term for a variety of construction techniques and methods that significantly reduce excavation and surface disruption. Trenchless technologies offer the ability to install, replace, or rehabilitate buried infrastructure while reducing the disruption to the surrounding community, environment, and other utilities located in the vicinity.

There are varying levels of structural enhancement that can be provided by trenchless rehabilitation techniques; from non-structural linings to fully structural linings. Non-structural enhancements are typically used to stop leaks (e.g., I&I), enhance system hydraulics or water quality, or provide corrosion protection. Fully structural linings, on the other hand, provide a complete replacement to the host pipe system upon completion.

Trenchless technologies are particularly popular in urban areas where there is a high density of underground utilities and/or vehicular and pedestrian traffic. Trenchless technologies also offer advantages for crossing transportation corridors, waterways, and environmentally sensitive areas.

The trenchless technology industry is an advancing field with new or modified methods for trenchless construction continually under development. Some of the most common trenchless technologies are listed as follows:

Trenchless Installation Methods

- Tunnelling.
- Directional drilling.
- Pipe ramming.
- Pipe jacking.
- Auger boring.

Trenchless Replacement/Rehabilitation Methods

- Slip lining.
- Pipe bursting.
- Cured-in-Place-Pipe (CIPP) liners.
- Sprayed in Place Pipe (SIPP) liners.
- Grouting.

As the technologies available are constantly advancing and changing, the list above simply provides a sample of the commonly used practices. The use of trenchless technologies should be considered in comparison to traditional open-cut methods for the replacement, installation and/or rehabilitation of underground utilities on a case-by-case basis.

Further information can be found in the latest edition of *M28 Rehabilitation of Water Mains* from the AWWA.

8.5 Hydrants

All fire hydrants and flush hydrants should be of 'self draining' dry-barrel type. All fire hydrants should conform to the latest edition of *AWWA C502 Dry-Barrel Fire Hydrants*.

Watermains not designed to carry fire flows should not have fire hydrants connected to them. Properly identified flushing hydrants, however, may be used as outlined in Section 10.4.5.

8.5.1 Location & Spacing

Fire hydrants should be provided at each street intersection and at intermediate points between intersections as recommended by the latest edition of *Water Supply for Public Fire Protection* from the Fire Underwriters Survey. In the absence of clear guidance hydrant spacing may range from 100 to 175 m depending on the area being served and in accordance with FUS requirements.

Flushing hydrants or devices are recommended for systems which are not capable of providing fire flow and for dead-ended watermains and areas where the degradation of water quality may be possible due to low consumption/flow conditions. Flushing devices should be sized to provide flows which will give a velocity of at least 0.8 m/s in the watermain being flushed. No flushing device should be directly connected to any wastewater system.

8.5.2 Valves & Nozzles

Fire hydrants should have a bottom valve size of at least 125 mm, one 113 mm pumper outlet, and two 63 mm outlets.

Outlet and nozzle sizes should be standardized throughout the water distribution system.

Specific requirements should be coordinated with the local fire authority.

8.5.3 Lead

The fire hydrant lead should be minimum of 150 mm in diameter. Shut-off valves should be installed in all hydrant leads. The flushing hydrant lead should be sized for the intended flowrate.

8.5.4 Drainage

The designer should refer to the local Regulatory Authority having jurisdiction for hydrant drainage requirements. When allowed, the ‘self draining’ dry-barrel type hydrant with drains ports not plugged should have gravel pit or dry well provided at the base, unless the natural soils will provide adequate drainage. When required by the Regulatory Authority having jurisdiction, or in areas having high water tables and water will rise above the hydrant drain ports, or at sites with a known risk of contamination, the ports should be plugged. Appropriate measures should be taken to ensure drainage of the hydrant barrel (pumping or other suitable means) to prevent damage.

Attention must be given to drainage of sub-surface hydrant chambers, and only where unavoidable, should pumping chambers dry be specified. Where this is required, the hydrants must be clearly marked as non-draining.

Hydrant drains should not be connected to or located within 3.0 m of wastewater main or storm drains.

8.6 Valve & Metering Chambers

8.6.1 Chamber Construction

Chambers for air relief and vacuum valves, flow monitoring/measuring devices and pressure reducing valves should be:

- Constructed to provide a watertight structure with easy and safe access.
- Designed to include watertight gaskets where a pipe passes through a chamber wall; flexible rubber “A-Lok” type for cast-in-place concrete or mechanical expansion insert type for pre-cast concrete.
- Insulated to ensure adequate frost protection.
- Include gravity or pump drainage.

8.6.2 Air Relief & Vacuum Valves Chambers

Air relief and vacuum valves should be installed, in a chamber, at significant high points in the distribution system and at other such locations as required for efficient operation of the water system.

Automatic air relief valves should not be used in situations where flooding of the manhole or chamber may occur.

The open end of an air relief pipe from automatic valves larger than 50 mm diameter should be extended at least 2.5 m above grade and provided with a screened and downward-facing elbow. The pipe from a manually operated valve should be extended to the top of the air relief chamber.

8.6.3 Flow Measurement & Meter Chamber

Chambers containing flow monitoring/measurement devices should be located at off-road locations where feasible.

8.6.4 Pressure Reducing Valve Chambers

Pressure reducing valve chambers should be designed and constructed to provide:

- By-pass capability.
- Isolation valves on the upstream and downstream piping for the pressure reducing valve.
- Upstream and downstream pressure gauges.

8.6.5 Chamber Drainage

Chambers should be drained, if possible, to the surface of the ground where they are not subject to flooding by surface water, or to underground absorption pits. Climate change should be considered when determining flood risks (refer to Chapter 2 for further guidance). Drains should be equipped with a backflow prevention device and screening to prevent the entry of insects, birds, and rodents.

In areas where high groundwater levels are evident, above water table chambers should be considered.

8.7 Separation Distances to Wastewater & Storm Sewers

The following factors should be considered in providing adequate separation:

- Materials and type of joints for water and wastewater pipes.
- Soil conditions.
- Service and branch connections into the water and wastewater mains.
- Compensating variations in the horizontal and vertical separations.
- Space for repair and alterations of water and wastewater mains.
- Off-setting of pipes around manholes.

The requirements of the *Atlantic Canada Wastewater Guidelines* from Atlantic Canada Water and Wastewater Association should be referenced.

8.7.1 Parallel Installation

Water mains should be laid at least 3.0 m horizontally from any existing or proposed wastewater/pipe/manhole. The distance should be measured edge to edge. In cases where it is not practical to maintain a 3.0 m separation, the Regulatory Authority may allow deviation on a case-by-case basis, if supported by data from the Design Engineer. Such deviation may allow installation of the water main closer to a sewer, provided that:

- The water-main is laid in a separate trench.
- Or on an undisturbed earth shelf located on one side of the sewer.
- At such an elevation that the bottom of the water main is at least 300 mm above the top of the sewer, or as required by the Regulatory Authority.

8.7.2 Crossings

Water mains crossing sewers should be laid to provide a minimum vertical distance of 450 mm between the outside of the water main and the outside of the sewer. This should be the case where the water main is either above or below the sewer with preference to the water main located above the sewer. At crossings, above or below, one full length of water pipe should be located so both joints will be as far from the sewer as possible. Special structural support for the water and/or sewer pipes may be required.

8.7.3 Force Mains

There should be at least 3.0 m horizontal separation between watermains and sanitary sewer force mains. When crossing, the watermain should be above the force main with a vertical separation of a minimum 450 mm at the crossing.

The Regulatory Authority should be contacted in instances where existing infrastructure does not allow for the watermain to be placed above the force main at the required separation.

8.7.4 Manholes

A watermain should not pass through or come in contact with any part of the sewer manhole.

8.7.5 Other Sources of Contamination

Design Engineers should exercise caution when locating water mains at or near certain sites such as WWTPs or industrial complexes. On site wastewater disposal facility including absorption fields must be located and avoided. The engineer should establish specific design requirements for locating water mains near any source of contamination and coordinate planned activities with the Regulatory Authority.

8.7.6 Exceptions

The Regulatory Authority must specifically approve any variance from the above requirements when it is impossible to obtain the specified separation distances. Where sewers are being installed and the above requirements cannot be met, the sewer materials should be waterworks grade 1,000 kPa (150 psi) pressure rated pipe or equivalent and should be pressure tested to ensure water tightness.

8.8 Cross Connection Control

8.8.1 Cross Connection Control Program

Backflow prevention devices should be installed on consumer service connections in accordance with the latest edition of the *National Building Code of Canada* from the National Research Council of Canada. Backflow prevention arrangement design and device selection should be in accordance with latest editions of *CSA B64.10 Selection and installation of backflow preventers / Maintenance and field testing of backflow preventers*.

System Owners should consider the adoption and enforcement of cross connection control as a best practice to protect public health. When a project includes the design of service connections, the System Owner should be contacted to determine if a cross connection control program exists so that the appropriate backflow prevention device can be selected.

8.9 Water Services & Plumbing

8.9.1 Plumbing

Water services and plumbing should conform to relevant local and/or provincial plumbing codes, or to the latest edition of the *National Building Code of Canada* from the National Research Council of Canada. Solders and flux should be lead free.

8.9.2 Consumer Connections (Lateral & Curb-Stops)

All consumer connections (laterals) should conform with the following:

- Minimum cover 1.6 m.
- Maximum cover 2.0 m.
- Minimum 300 mm horizontal and vertical separation distance from gravity sewer pipes.
- Minimum 450 mm vertical separation when crossing above a sewer pipe.
- Minimum separation distance of 3.0 m from outdoor fuel tank.
- Minimum separation from wastewater disposal field of 6.0 m.
- The designer should also refer to the System Owner specifications for service lateral sizes as billing may be based online size. Typical single family residence connections should be minimum 20 mm copper or 25 mm HDPE pipe. Larger sizes may be required depending on length of lateral and grade elevations. Refer to latest edition of *M22 Sizing Water Service Lines and Meters* from the AWWA.
- Only lead-free solder and flux should be used.
- Maximum velocity of flow should not exceed 4.5 m/s.
- There should be no joint between the curb stop and the building, if possible.
- A shut-off valve (curb-stop) should be fitted on the street side of the property boundary.

- An approved metering device should be fitted.
- Backflow prevention devices, when required, should be installed after metering device.
- Shut-off valves should be installed before the metering device.
- Pressure reducing valves to be installed as required before metering device.

For replacement of existing lead service lines, the designer should contact the System Owner and refer to the latest edition of *AWWA C810 Replacement and Flushing of Lead Service Lines*.

8.9.3 Service Meters

Each service consumer connection should be individually metered with an approved metering device.

8.9.4 Bulk Water Loading Stations

Bulk water loading stations present special problems since the fill line may be used for filling both potable water vessels and other tanks or contaminated vessel. To prevent contamination of both the public supply and potable water vessels being filled, the following principles should be met in the design of bulk water loading stations:

- A reduced pressure principle backflow prevention device should be installed on all watermains supplying water loading stations.
- The piping arrangement should prevent contaminant being transferred from a hauling vessel to other subsequently using the station.
- Hoses should not be contaminated by contact with the ground.
- A loading station should be designed to provide access only to authorized personnel.
- Access to a loading station should be strictly controlled to minimize water safety and security concerns.

8.9.5 Water Quality Monitoring Stations

Dedicated water monitoring stations may be required within a water distribution system to collect water samples as part of the approved water quality monitoring program. The need for, and the proposed locations of sampling stations, should be discussed with the Regulatory Authority and the System Owner. Permanent water quality sampling stations should be designed for cold climates and provide freeze protection for the area for which it is installed.

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Table of Contents

Chapter 9 Operation & Maintenance

9.1 General

Operation and maintenance manuals are specific to each project and should be produced for each project prior to commissioning.

Individual equipment will primarily be governed by the manufacturer's specifications for operation, maintenance, and repair, and should be included in the O&M manual.

The O&M manual should be revised and updated as part of any major system improvement, including rehabilitation of any part or whole of existing infrastructure and the addition of new infrastructure.

The System Owner should retain a current copy of the O&M manual at head office, and at individual facilities, for immediate access by the water system personnel.

The O&M manuals should contain pertinent information on the normal day to day O&M of the facility, program schedules, descriptions of routine tasks and means to assess the system for vulnerabilities and damages, including those that may be attributed to the impacts of climate change, throughout the asset life. Consult your Regulatory Authority for specific requirements.

Operations manuals should include up to date SOPs and CPs. Consult your Regulatory Authority for specific requirements associated with O&M documents.

9.2 Surface Water Source Facilities

9.2.1 Water Quality Documentation

Water quality monitoring, recording, and reporting should be in accordance with the requirements of the Regulatory Authority. The manuals should include the procedures outlining the monitoring, recording, and reporting requirements.

9.2.2 Operational Requirements

Operational requirements of an O&M manual for surface water sources should include, but not be limited to, the following:

- Water volume measurement.
- Water level measurement.
- Pump performance monitoring.
- Control valves.
- Record keeping.
- Schedule for review of data by qualified personnel.
- Diagnosis of problems.
- Notification requirements if there is a water quality problem.

9.2.3 Maintenance Requirements

Maintenance requirements for an O&M manual for surface water sources should include, but not be limited to, the following:

- Cleaning of screens.
- Cleaning of reservoirs and impoundments.
- Pump maintenance (see Section 9.4).
- Wet well cleaning.

9.2.4 Documentation

Documentation to be included in the O&M manual should include, but not be limited to, the following:

- Water levels and bathymetric data.
- Watershed boundary mapping.
- Watershed management and emergency spill response plans.
- Information on backup supply (if any).
- Cleaning frequencies.
- Impoundment and reservoir specifications.
- Screen specifications.
- Pump specifications (see Section 9.4).
- Standard operating procedures and CPs.

9.3 Groundwater Source Facilities

9.3.1 Water Quality Documentation

Water quality monitoring, recording, and reporting should be in accordance with the requirements of the Regulatory Authority. The manuals should include the procedures outlining the monitoring, recording, and reporting requirements.

9.3.2 Operational Requirements

Operational requirements of an O&M manual for groundwater sources should include, but not be limited to, the following:

- Water volume measurement.
- Water level measurement (production and monitoring wells).
- Submersible pump performance monitoring.
- On-off cycling of production wells.
- Sampling from monitoring wells.
- Control valves.
- Record keeping (including hydrograph).
- Schedule for review of data by qualified personnel.
- Diagnosis of problems.
- Notification requirements if there is a water quality problem.

9.3.3 Maintenance Requirements

Maintenance requirements for an O&M manual for groundwater sources should include, but not be limited to, the following:

- Purging of production wells.
- Production well screen, or stabilizer screen cleaning and development.
- Monitoring well purging, cleaning, and development.
- Submersible pump maintenance.
- Disinfection.

For manufactured components (e.g., valves and meters) the preventative maintenance program should follow the manufacturer's specifications.

9.3.4 Documentation

Documentation to be included in the O&M manual should include, but not be limited to, the following:

- Well log.
- Static water level from pumping test and pumping water levels.
- Initial step testing results for comparison with current well condition/performance.
- Well specifications (depth, diameter, stabilizer, screen slot, setting, and type).
- "As-built" well log showing relative positions of pump, screen, stabilizer, casing, etc.
- Datum point from which all well measurements are made (e.g., top of casing).
- Log of operating water level, flowrate, and pump monitoring information.
- Standard operating procedures and CPs.

9.4 Pumping Facilities

9.4.1 Operational Requirements

Operational requirements in the O&M manual for pumping facilities should include, but not be limited to, the following:

- Pump operating range.
- Operation of pumps at reduced flows.
- Priming.
- Final checks before starting pumps.
- Starting and stopping procedures for pumps.
- Auxiliary services on standby pumps.
- Restarting pumps after power failure.
- Record keeping.
- Monitoring devices (gauges and meters).
- Dehumidification.
- Drainage.
- Schematic of pump controls and monitoring devices.
- Power supply schematic.
- Overall SOPs.
- Contingency plans.

9.4.2 Maintenance Requirements

Maintenance requirements for an O&M manual for pumping facilities should include, but not be limited to, the following:

- Daily observation of pump operation.
- Lubrication specifications.
- Semi-annual inspection.
- Annual inspections.
- Complete overhaul.
- Spare parts.
- Record keeping.
- Diagnosis of problems.
- Out of service/lock-out procedure.

9.5 Water Treatment Plants

9.5.1 Water Quality Compliance Requirements

Water quality compliance monitoring, recording, and reporting should be in accordance with the requirements of the Approval/License/Permit to Operate and documented separately from the O&M manual.

9.5.2 Water Quality Operational Requirements

Water quality operational requirements of an O&M manual for WTPs should include, but not be limited to, the following:

- Raw and treated water volume measurement.
- Water level and pressure measurements (where applicable).
- Monitoring of online temperature, pH, and individual filter effluent turbidity.
- Meter calibration.
- Sample collection and analysis.
- Laboratory jar testing procedures.
- Chemical receiving and preparation/mixing of day tanks.
- Chemical ordering.
- Adjustment of chemical feed rates.
- Changing of chlorine cylinders.
- Chlorine residual monitoring.
- Monitoring of filter head loss.
- Surface wash, backwashing and filter scraping.
- Media regeneration and/or filter ripening (if applicable).
- Clean-in place and pressure decay tests (membrane systems).
- Sludge level measurements and sludge removal (if necessary).
- Residuals treatment.
- Sludge dewatering.
- Schedule for review of data by qualified personnel.
- Diagnosis of problems.

9.5.3 Maintenance Requirements

Maintenance requirements of an O&M manual for WTPs should include, but not be limited to, the following:

- Daily, semi-annual, and annual inspections and testing procedures.
- Cleaning intervals and procedures.
- Preventative maintenance requirements.
- System overhaul intervals and procedures.
- Recommended spare parts inventory.
- Record keeping requirements.
- Out of service/lock-out procedures.
- General facility maintenance instructions.

Maintenance items should include, but not necessarily be limited to, the following systems:

- Online meters, monitors, level transmitters, pressure gauges, etc.
- Pumping systems.
- Heating, ventilation, and air conditioning systems.
- Backup generators.
- Laboratory equipment.
- Chemical feed systems.
- Flocculation systems.
- Filter media.
- Process tankage.
- Membrane and pre-treatment systems.
- Valves, actuators, and appurtenances.
- Residuals treatment systems.
- Dewatering systems.
- Wastewater sewer systems.
- Storm sewer systems.
- Service water systems.

Where maintenance and/or servicing of any of the above items are beyond the capability of the operator, the manual should indicate as such and should provide the appropriate contact information for servicing of that particular part and/or system.

9.5.4 System Documentation

Documentation requirements to be specified in the O&M manual should include, but not be limited to, the following:

- Plant detailed design drawings and specifications.
- Process diagram.
- Water volume data.
- Required water quality monitoring data and chain-of custody forms.
- Level and pressure data.
- Up-to date spare-parts inventory.
- Record of inspections, testing, and servicing for required systems.
- Upsets, problems, and corrective action taken.

- Impacts and damages to existing infrastructure and treatment processes (including those which may be attributed to the impacts of climate change).
- Maintenance schedules.
- Backup of all electronic information.

9.6 Treated Water Storage Facilities

9.6.1 Operation & Maintenance Requirements

Operational and maintenance requirements in the O&M manual for treated water storage facilities should include, but not be limited to, the following:

- Regular inspection.
- Temporary removal from service:
  - Draining.
  - Cleaning.
  - Repairs (including material specification).
  - Disinfection.
- Return to service.
- Monitoring devices (gauges and meters).
- Record keeping.

9.6.2 Cold Weather Operation

Treated water storage tanks can be severely affected by periods of cold weather, and it is essential that cold weather O&M and emergency procedures be addressed by the O&M manual.

9.7 Transmission & Distribution Systems

9.7.1 Operation & Maintenance Requirements

Operational and maintenance requirements in the O&M manual for transmission and distribution systems should include, but not be limited to, the following:

- Inspection.
- Valve exercising.
- Cleaning and flushing.
- Disinfection.
- De-chlorination and discharge of super chlorinated water.
- Repairs including emergencies and material specification.
- Transient pressure protection.
- Monitoring devices (e.g., gauges and meters).
- Record keeping.
- Preventative maintenance.
- System mapping.
- Leak detection and survey.

9.8 Small Water Supply Systems

The nature of small water supply systems requires an O&M manual with a focus on key issues.

Individual components of the system can be considered as units with operator requirements clearly listed, including compliance monitoring, and specialized maintenance/repair requirements. Most requirements are governed by manufacturers specifications and scheduling, which should be carried out by recognized/certified outside contractors.

The small water supply system O&M manual should include, but not be limited to, the following:

- Water source.
- Intake.
- Pumping facility (if applicable).
- Water volume.
- Treatment.
- Disinfection.
- Water storage.
- Distribution system.
- Compliance monitoring.
- System protection (including automated systems, alarms, and response times).
- Operator training and supervision.
- Operator/contractor safety.
- Documentation.
- Scheduling of combined operating and maintenance activities.

9.9 Safety

The O&M manual should address issues of worker safety, including, but not be limited to, the following:

- Working in slippery and wet conditions.
- Working in confined spaces.
- Working at elevated heights.
- Protective clothing and equipment.
- Safety harness operation.
- Traffic/work zone control.
- Ladders.
- Ventilation.
- Minimum safe lighting.
- Minimum number of workers required for specific tasks.
- Lifting heavy objects.
- Procedures for excavation.
- Operator/contractor training.
- Operator/contractor certification.
- Safety devices, including alarms.
- Out of service/lock-out procedure.

9.10 Overall Documentation

Documentation should be available for regular inspections, emergency servicing, or rehabilitation of the facilities. The documentation should be available in an easily accessible location at each facility and at the System Owner's head office.

The documentation should include, but not be limited to, the following:

- Operation and maintenance manuals for the facility and individual equipment.
- Name and phone numbers of System Owner/responsible engineer.
- Name and phone number of facility supervisor.
- Description and schematic of facility and monitoring devices.
- Regular power supply information.
- Backup power supply information.
- Instructions for system shut-down.
- Location of as-built drawings.

9.11 Operator Training Scheduling

A program for operator training should be developed and included in the O&M manual. The program should include reference to required periodic refresher courses.

The operator in direct charge of the system should be responsible for ensuring the schedule is implemented and followed.

9.12 Supervisory Control & Data Acquisition Monitoring

Where appropriate, the O&M manual should address SCADA monitoring.

All SCADA systems and components should be maintained as per the manufacture's specifications. All SCADA components that fail should be repaired or replaced on a timely basis.

A capability of manually checking SCADA data should be incorporated into all SCADA systems. SCADA measurements should be checked against manual measurements (e.g., pressure, flow values, etc.) on a regular basis to confirm the SCADA system is operating properly.

9.13 Security

The O&M manuals should address security and protection of various facilities, including, where appropriate, but not limited to the following:

- Authorized access.
- Protection of the public from potential hazards within the facilities.
- Protection of water sources against contamination from negligence, accident, vandalism, terrorism, etc.
- Protection of water distribution system against contamination from negligence, accident, vandalism, terrorism, etc.
- Protection of equipment from theft and vandalism.

9.14 References

American Water Works Association. *AWWA G430-14(R20) Security Practices for Operation and Management*. AWWA Standard, New York, 26 Oct. 2020. <https://engage.awwa.org/PersonifyEbusiness/Store/Product-Details/productId/87153630>.

Federation of Canadian Municipalities and the National Research Council. *InfraGuide: National Guide to Sustainable Municipal Infrastructure*. Ottawa, 2006. <https://fcm.ca/en/resources/mamp/infraguide-national-guide-sustainable-municipal-infrastructure>.

Health Canada, Water and Air Quality Bureau, Healthy Environments and Consumer Safety Branch. *Guidelines for Canadian Drinking Water Quality - Summary Table*. Government of Canada, Ottawa, ON, Sept. 2020. <https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/water-quality/guidelines-canadian-drinking-water-quality-summary-table.html >.

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Chapter 10 Small Water Supply Systems

10.1 General

The requirement of these Guidelines is generally focused on the provision of a central water supply system servicing urban and suburban areas. Other areas, however, may also have requirements for a central water supply system, but generally cannot benefit from the economies of scale provided with the construction of a large-scale project. This can preclude the development or extension of a central water supply system, because the capital and operating costs may be prohibitive for the System Owner and/or the customer.

It is recognized that a small water supply can provide an acceptable level of service to customers. The system should be designed to a standard that is equivalent to municipal water systems, especially in terms of quantity and quality for normal consumption. The conditions for individual small water supplies, however, may differ significantly from municipal systems, and from each other, therefore, strict adherence to these Guidelines as outlined in the previous chapters may not always be possible.

This section is, therefore, included to provide guidance in the design of small water supply systems.

10.2 Outline of a Small Water Supply System

Typical candidates for a small water supply include established communities and new small developments.

Established communities may consist of a community or village core with small lots and high housing density, and/or sprawling areas with large lots and low housing density.

A small water supply system may be required to service an established community because existing individual groundwater supplies have quality and/or quantity problems. Alternatively, an established community using a central source of water may require additional treatment processes, and/or a new central supply.

A small water supply system may be required to service a new development because the proposed development density precludes the use of individual wells. In addition, the cost of individual wells may be prohibitive. Typically, new developments on a small water supply system may include, but not be limited to, the following:

- Clusters of rental recreational cottages.
- Condominium projects.
- Mobile home parks.
- Small residential communities.
- Campgrounds.

The definition of a small water supply system may vary between Regulatory Authorities; however, they typically can be defined by the number of service connections as follows:

- Very small water system (5 to 14 service connections).
- Small water system (15 to 150 service connections).

General features of a small water supply system include, but are not limited to, the following:

- Limited system redundancy.
- Small diameter piping (i.e., less than 150 mm diameter, without fire protection hydrants).
- Operation and maintenance duties may be performed by part time staff, or contractors.
- Technologies used often need to be relatively simple.

The Regulatory Authority should be contacted to determine site specific requirements for a small water system.

10.3 Approval Requirements

The approval requirements of small water systems are similar to the approval requirements of a municipal system and, therefore, the process outlined in Chapter 1 should be followed.

System Owners planning a small water supply system should consult with the Regulatory Authority to discuss the scope of the project and to determine the regulatory requirements.

10.4 Water Use Requirements

It is essential that the WTPs should be designed such that the source of supply, treatment equipment, transmission main, water distribution mains, and storage components are capable of meeting maximum and peak hour demands without overtaxing the source or resulting in excessive pressure loss in the distribution system. When available, average, maximum and peak demands should be based on existing flow data.

The impacts of climate change may include changes in water use patterns, such as an increased water demand during hot days or overall seasonal increases (e.g., during hotter summer months). Water demands may increase uses such as hydration, recreation, and irrigation purposes. These uses may translate into increases in daily demands which can put significant strain on small systems.

10.4.1 Average Use

The projected average water use demand, if not known, should be estimated from reliable records of present consumption in similar facilities serviced by water meters.

Historically, design values for average domestic water use have ranged from 270 to 450 L/cap·d.

Small system communities that have commercial users must be reviewed in detail to resolve problems associated with high variant system demand and additional per capita water use rates may need to be developed.

The above values represent the average flow over 24 hours. They do not reflect the maximum day and peak hour demands in the system that will exceed the average value by a significant amount.

10.4.2 Maximum Day Demand

Maximum day demand is the maximum amount of water supplied to the system on any given day within a calendar year and is the minimum flow for which a small water system should be designed. As with municipal water systems it may be possible to derive a value for maximum day demand, based on a small water system of similar size and consumer characteristics, in an adjacent or nearby development.

In the absence of reliable data, the maximum daily flow may be calculated on the basis that the Average Daily Flow (ADF) occurs over an 8-hour period. This equates to a maximum day factor of three times average day.

10.4.3 Peak Hour Demand

As with maximum day demand, it may be possible to derive this value, based on nearby or adjacent developments with similar characteristics. In the absence of actual data, however, the peak hour demand may be determined by taking the ADF divided by 24 hours and multiplying it by the appropriate peak rate factor obtained in Table 10.1 (based on *Table 3-3: Peaking Factors for Drinking-Water Systems Serving Fewer than 500 People* in the *Design Guidelines for Drinking-Water Systems* from the Ontario Ministry of the Environment (2019*)*. As evident from the Table, as the number of connections decline, the peaking facing increases significantly. Designers should consider this when estimating flows for situations where there are less than 10 connections.

Table 10.1: Peak Factors for Small Water Supply Systems

Dwelling Units Serviced	Equivalent Population	Night Minimum Hour Factor	Maximum Day Factor	Peak Hour Factor
10	30	0.1	9.5	14.3
50	150	0.1	4.9	7.4
100	300	0.2	3.6	5.4
150	450	0.3	3.0	4.5
167	500	0.4	2.9	4.3

10.4.4 Outdoor Use

Where applicable, an allowance for outdoor use of water (lawn watering, car washing) should be made. It should be assumed that a maximum of 25% of the homeowners would be using an outdoor tap at any one time at the rate of 20 L/minute for 1 hour per day. (This allowance is not required when the distribution system is designed to provide fire protection).

10.4.5 Fire Protection

By definition, a small water system is not normally designed to provide fire protection, and, therefore, will not include fire hydrants. Flushing hydrants, however, should be included, and should be clearly identified as being limited to flushing, not fire protection.

10.5 Source of Supply

The Design Engineer should demonstrate that an adequate quantity of water is available to meet the demands of the small water supply system. Chapter 3 should be reviewed for additional information on sources of supply.

The impacts of climate change may result in changes in water use patterns, such as increased demands during hot days and throughout the summer months. This may translate into increased water demand for uses such as hydration, recreation, and irrigation. Smaller systems generally will experience these fluctuations in water demands to a higher degree than larger systems. In addition, periods of low flows or low water levels may coincide with periods of increased demand (i.e., drought conditions occur predominately during the summer and early autumn months). For that reason, CPs for community water conservation to ensure an adequate quantity of water is continuously available should be explored.

10.5.1 Surface Water

Subject to the source and the requirements of the Regulatory Authority, a hydrology study by a professional hydrologist may be required to confirm the availability of water.

The reliable yield of the source, after the flow has been regulated by seasonal balancing storage, should be adequate to supply the maximum day demand during moderate dry periods. A moderate dry period should be determined based on the site setting, growth projections for the population and considerations for climate change (e.g., potential increases in the frequency of occurrence of drought conditions which may limit water supply). Refer to Chapter 2 and Chapter 3 for further guidance.

10.5.1.1 Impounding Reservoirs

Impounding reservoirs should be designed to minimize the deterioration of raw water quality. This is done by minimizing contact with organic material, (grass, peat, trees, etc.) avoiding shallow water areas, and embankment erosion. Refer to Chapter 3 for further guidance.

10.5.1.2 Intakes

Intake works should be designed to optimize water quality, minimize maintenance and adverse environmental impacts, and not be affected by low flows and impacts of climate change. They should not obstruct the passage of vessels in navigable waters.

Intakes should be sized to the ultimate capacity of the small water supply system to limit disturbance to the aquatic environment. Screens should be easy to clean and designed to meet requirements of DFO regulations.

River intakes should be sited in a stable reach of the river channel, in sections where erosion or deposition will not endanger the works, and in such a way that the natural regime of the river will not be disturbed.

Submerged intake pipes in rivers and lakes should be graded to prevent accumulation of gasses and be adequately anchored and buried. Provision should be made to remove sediment from the pipe by incorporating a back-flushing device.

Intake works should be protected against unauthorized persons and contamination from domestic, industrial, or other harmful wastes or runoff. The intake works should be reasonably accessible in all seasons and should be protected from accumulation of ice.

10.5.1.3 Raw Water Pumps

When raw water is supplied by pumping, at least two pumping units should be installed. With the largest pump out of service, the remaining pump should be capable of maintaining maximum day demand within the small water supply system.

Pumping facilities should be designed to maintain the sanitary quality of the pumped water. Pumping stations should be above ground and protected from flooding, including climate change, and additional climate change impacts.

Operation of the pumps should be regulated by utilizing high- and low-level sensing devices located in the treated water storage reservoir.

The operation or pumps in a constant pressure system should be regulated by pressure switches.

10.5.2 Groundwater

Wells should be located, constructed, tested, and disinfected in accordance with Chapter 3, or as required by the Regulatory Authority. A hydrogeology study is recommended to ensure water availability.

The well should be protected from possible sources of contamination with respect to land use adjacent to the well and the recharge area of the well.

The well should be protected from climate change impacts (e.g., potential increases in flood risk, contaminate transport, etc.). Refer to Chapter 3 for further guidance.

A well protection plan may be required by the Regulatory Authority.

10.5.2.1 Number of Wells

Where more than 20 homes are served, at least two production wells should be used, each being capable of providing the maximum daily demand. Both wells should be online and alternating in use.

If the individual wells are not capable of providing the maximum day demand, at least 1 day's storage should be provided.

Where less than 20 homes are serviced, and/or only one well is used, it is recommended that a spare replacement pump be available.

10.6 Water Treatment

All drinking water should meet applicable drinking water standards and/or guidelines.

Surface water and GUDI, where applicable, will require treatment as per the surface water treatment requirements.

Groundwater may require treatment to address specific individual health or aesthetic based water quality parameters to meet drinking water standards and guidelines.

Allowances for water loss required for in-plant use should be considered.

It is recognized that redundancy requirements in small water systems may be cost-prohibitive. The System Owner, in this regard, may present innovative options to the Regulatory Authority for consideration. In addition, management plans, SOPs, and contingencies should be in place to deal with the reduced capacity and water quality maintenance requirements.

The Regulatory Authority may consider system specific exceptions and may require the provision of emergency water storage and/or emergency shut-down of the water system or part of the system in the event of a treatment system malfunction.

The provision of water storage at a suitable elevation may negate some redundancy requirements.

10.6.1 Treatment of Surface Water

The water quality investigation should include all health and aesthetic parameters in the latest edition of the *Guidelines for Canadian Drinking Water Quality - Summary Table* from Health Canada.

Where applicable, the pre-design investigation should evaluate the treatability of the water using laboratory testing. Chapter 3 outlines the requirements.

The basic components for water treatment of surface water are outlined in Chapter 4 and consists of the following:
- Pre-sedimentation.
- Coagulation and flocculation.
- Clarification.
- Filtration.
- Disinfection.

Proprietary treatment equipment may be considered for treatment of surface water.

10.6.1.1 Disinfection of Surface Water

All surface water sources and GUDI supplies should be disinfected (Section 10.6.3).

10.6.2 Treatment of Groundwater

The water quality investigation should include all health and aesthetic parameters in the latest edition of the *Guidelines for Canadian Drinking Water Quality - Summary Table* from Health Canada.

Proprietary treatment units will typically be used.

In all cases the treatment requirements for each site should be directed by the respective Regulatory Authority.

10.6.2.1 Disinfection of Groundwater

Barring system specific exceptions, groundwater should be disinfected (as discussed in Section 10.6.3). In all cases the disinfection requirements for each site should be directed by the respective Regulatory Authority.

10.6.3 Methods of Disinfection

Chlorination is the recommended method of disinfection for a small water supply system, as it provides a measurable residual in the distribution system. The presence of a measurable chlorine residual is typically an indication that the bacteriological quality of the water is acceptable.

The use of a hypochlorination system is the preferred method of chlorination for small water supply system because it is easy to operate and maintain.

Hypo-chlorination may be accomplished with a sodium or calcium hypochlorite solution. The facilities should include a cool, dark, dry, clean, above ground and vented area for the storage and for the use of hypochlorite disinfectant. The facilities should also include covered make-up and feed solution tanks.

The use of gas chlorination facilities is not recommended. Gas chlorination should be restricted to water systems where qualified operators are available to operate and maintain the equipment on an ongoing basis, and who are trained and equipped to handle any emergency.

Requirements for chlorine CT and free chlorine residuals must be considered when planning and locating the disinfection facilities.

Ultraviolet disinfection may be used for primary disinfection. Ultraviolet systems do not provide a residual and as such, a secondary disinfectant such as chlorine should be provided.

Novel or alternative disinfections may be considered for use for small water supply systems, however, may require additional review by Regulatory Authorities prior to approval.

10.7 Auxiliary Power

An auxiliary power supply may not be feasible for a small water supply system. In the event of a prolonged power outage, options include hauling water or the provision of a mobile generator.

The impacts of climate change include a potential increased frequency and severity of storm events and watershed disturbances across Atlantic Canada. In some regions, this may translate to an increased risk of power outages and disruption to water supply operations and restricted site access. The provision of auxiliary power is encouraged to be implemented for water supply systems.

10.8 Water Storage

Finished water storage facilities should have sufficient capacity to balance the fluctuations in domestic demands and minimize pump start/stop cycles. This storage should be reliably available, preferably by gravity. If site conditions preclude gravity flow, a secondary pumping system will be required.

The impacts of climate change may result in periods of decreased water availability or supply system disruptions. Provisions should be made for bulk water connections to storage facilities to ensure continued storage and supply of water to the distribution system during those periods. Refer to Section 8.9.4 for further guidance.

10.8.1 Storage Capacity

Storage should be provided for balancing and emergency use. Unless otherwise determined by engineering studies storage to control pumps, balance fluctuations in domestic demand, and stabilize pressures should not be less than 25% of maximum day demand. Also, emergency storage should not be less than 25% of maximum day demand.

In instances where the yield of the source is limited, a minimum 1-day storage is recommended. Where applicable, an allowance should also be made for backwash water requirements.

10.8.2 Water Storage Materials

Water storage facilities for small water supply systems are typically constructed from pre-cast or cast-in-place concrete, fibreglass, or steel.

10.8.3 Treated Water Pump

Where water is provided from a treated water storage tank, at least two high lift pumps should be provided. Each pump should be capable of delivering a minimum of the design maximum day demand at the desired pressure.

To deliver the peak hour water demand it may be necessary to operate more than a single pump.

10.8.4 Acceptable Pressure

Pressures within a small rural supply system should generally be maintained between 275 to 420 kPa (40 to 60 psi).

10.9 Pressure Tanks

Pressure (hydro-pneumatic) tanks are normally used as a means of providing pump control, but not for providing balancing and emergency storage. There are, however, occasions, for small rural water supply systems, when pressure tanks can be used to provide balancing and emergency storage. Authorization from the Regulatory Authority should only be given upon receipt of an acceptable detailed design from a professional engineer.

10.10 Water Distribution System

10.10.1 Material

The selection of pipe material for waterlines in a small water supply system should be carried out as per the recommendations in Section 8.2.

10.10.2 Distribution System Piping Diameter

The distribution system piping diameter should be sized to provide adequate pressures and velocities at peak hour demand. Refer to Section 8.3. Diameter piping less than 150 mm is often used for small water systems.

10.10.3 Pressure Rating

The minimum recommended pressure rating for piping in a small water system should be based on manufacturer's specification. A typical rating for a small water system network is 1,100 kPa (160 psi).

10.10.4 Velocities

Velocities in the water distribution system should be a maximum of 1.5 m/s.

10.10.5 Service Connections

Service connections should be a minimum 19 mm diameter. Refer to the latest edition of *M22 Sizing Water Service Lines and Meters* from the AWWA for further guidance.

10.10.6 Water Meters

It is preferred that individual water meters be installed at all customers. Where this is not feasible, a master water meter should be located at the source.

10.10.7 Hydrants

Fire hydrants should not be connected to small rural water supply systems that are not designed for fire flows.

Flushing hydrants or flushing devices are recommended for small water supply systems that are not designed for fire flows. Flushing devices should be sized to provide flows of at least 0.8 m/s.

10.10.8 Individual Home Booster Pumps

Individual home booster pumps should not be connected to a small water system unless specifically authorized.

10.11 Monitoring Requirements

Monitoring and reporting requirements, where it is the responsibility of the System Owner, should be outlined by the Regulatory Authority in the Approval/License/Permit to Operate.

The monitoring program should be carried out in compliance with sampling and analysis requirements outlined in the Approval/License/Permit to Operate.

In instances where monitoring is the responsibility of a Regulatory Authority, reporting will be the responsibility of the Regulatory Authority and/or laboratory.

Continuous monitoring and record keeping will provide valuable information on site specific changes or impacts to infrastructure or operations (e.g., water quality and yield) over the lifetime of the asset. Records should be reviewed on a minimum 5-year basis to assess possible changes, including identifying possible impacts of climate change, and adaptation efforts to reduce site specific risks.

10.12 Facility Classification & Operator Certification

It is recommended that operators of small water supply systems be thoroughly trained in all aspects of the O&M of the water supply system and provided with all necessary manuals and system documentation.

Some jurisdictions have adopted regulations that makes facility classification and operator certification mandatory while others strongly recommend operator certification. Where applicable, the regulations require all water treatment and water distribution personnel to be certified and require that an operator with a certification level equivalent or greater to the facility classification be in direct responsible charge.

The Regulatory Authority should be consulted regarding specific requirements.

10.13 Easements, Statutory Rights of Way, & Restrictive Covenants

An easement should be provided when any part of a small water supply system is to be located on privately owned land (other than service connections). The easement should be registered in favour of the water supply system authority in perpetuity. The minimum practical width of easement should be 6.0 m.

10.14 References

American Water Works Association. *M22 Sizing Water Service Lines and Meters*. Third Edition. AWWA, 2014. <https://engage.awwa.org/PersonifyEbusiness/Store/Product-Details/productId/44766350>.

Health Canada, Water and Air Quality Bureau, Healthy Environments and Consumer Safety Branch. *Guidelines for Canadian Drinking Water Quality - Summary Table*. Government of Canada, Ottawa, ON, Sept. 2020. <https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/water-quality/guidelines-canadian-drinking-water-quality-summary-table.html >.

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Appendix A

Additional Considerations for Pre-design & Final Design Reports

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Appendix A

Additional Considerations for Pre-design & Final Design Reports

Table 1.1 in these Guidelines provides a checklist of water supply system components that typically should be included in a Pre-design Report. The requirements can be determined by the System Owner(s) by indicating which components are applicable to the project and serve to determine the contents for a specific project to be submitted to the Regulatory Authority for review. The Pre-design Report shall include a screening-level assessment and risk assessment, as described in Chapter 2, to incorporate climate change considerations into the project.

The following provides a list of specific tasks that may be required under each of the selected water supply components.

A.1 Pre-design Report

Surface Water Supply Source:

- Sites considered and reasons for selection.
- Location and physical setting of watershed.
- Watershed ownership and management issues.
- Watershed area.
- Safe yield including climate change considerations.
- Existing and potential sources of contamination.
- Raw water quality (historic, existing, and future including climate change considerations).
- Proposed intake location (vertical and horizontal (including climate change considerations)).
- Impound requirements (including climate change considerations to ensure water availability during periods of drought).
- Flow maintenance requirements.
- Other water use and withdrawal rates.
- Identify key stakeholders or other users.
- Intake security.
- Additional climate change considerations.

Groundwater Supply Source:

- Regulations on groundwater extraction.
- Potential environmental impacts by the groundwater extraction (e.g., nearby domestic wells, stream flow, saltwater intrusion, climate change considerations, etc.).
- Sources of data.
- Sites considered and reasons for selection.
- Location and physical setting of aquifer.
- Land ownership and land use.
- Aquifer protection and management issues including considerations for the impacts of climate change.
- Availability of water (peak vs. safe use and competing uses in areas) including considerations for the impacts of climate change.
- Summary of source exploration (test well depths, location, pumping data).
- Description of hydrogeology:
  - Topography and drainage.
  - Location of existing well(s)/well field(s) and water supplies.
  - Raw water quality.
  - Existing and potential sources of contamination (including historical site data (e.g., abandoned dumps and industrial sites) and climate change considerations).
  - Surficial hydrogeology.
  - Bedrock hydrogeology.
  - Descriptions of pumping and observation wells.
  - Aquifer and aquitard properties.
  - Safe aquifer yield including climate change considerations.
  - Existing and future water budget in watershed/catchment scale (e.g., water supply and demand in the watershed).
  - Well head completion details.
  - Water levels including climate change considerations.
  - History of well maintenance and monitoring.
  - Regulations on groundwater extraction.
  - Potential environmental impacts by the groundwater extraction (e.g., nearby domestic wells, stream flow, saltwater intrusion, and climate change considerations).

Water Treatability:

- Fluctuations in raw water quality, including potential climate change impacts on raw water quality.
- Water quality parameters that exceed limits.
- Disinfection by-product formation potential.
- Treatment requirements.
- Bench-scale tests.
- Pilot scale tests.
- Treated water quality.
- Impacts on the water distribution system.

Raw Water Storage Reservoir:

- Natural storage.
- Engineered storage.

Raw Water Transmission Main:

- Pumping/pressure reduction requirements.
- Capacity of main.
- Pipe material.
- Routing considerations.
- Soil conditions.
- Groundwater level elevation.
- Contaminated sites.

Water Treatment Plant:

- Location (including climate change considerations).
- Plant sizing.
- Design life.
- Basic treatment concept:
  - Number of process trains.
  - Custom made or package plant.
- Treatment processes.
- Capacity of treatment units.
- Hydraulic grade line through plant.
- Method of solids removal:
  - Sedimentation.
  - Filtration (membrane direct).
  - Dissolved air flotation.
- Filter system type (slow, rapid, pressure, membrane).
- Filtration area and rates.
- Filter media type.
- Filter redundancy.
- Backwash type (air, scour, etc.).
- Backwash rates.
- Filter-to-waste capacity.
- Process waste disposal.
- Sanitary wastewater disposal.
- Primary and secondary disinfection processes.
- Disinfection equipment, housing, and redundancy.
- Contact time factor and log inactivation credits.
- Chemicals used.
- Chemical feeder capacity and ranges.
- Chemical containment and storage.
- Corrosion control.
- Water quality monitoring.
- Storage requirements (including climate change considerations).
- Integration of new facilities in existing system.
- Future expansion/modifications possibilities.
- Security.
- NFPA classifications.
- Automation and instrumentation.

- Process control and compliance monitoring.
- High lift pumping/pressure reduction.
- Emergency power.
- Personnel space requirements (e.g., lab and maintenance).
- Solid waste management.
- Facility classification.
- Office, washroom, and kitchen facilities.
- Safety (eyewash stations).

Treated Water Quality:
- Monitoring:
  - Operational parameters.
  - Compliance parameters.
    - Health related parameters.
    - Aesthetic related parameters.

Treated Water Transmission Main:
- Redundancy (single or twinned).
- High lift pumping.
- Hydraulic analysis.
- Ultimate production capacity of WTP.
- Existing capacity and available storage.
- Future connection requirements.
- Pressure reduction.
- Air release.
- Line valves.
- Surge analysis.
- Maximum and minimum operating pressures.
- Residential fire flow requirements.
- Residential/industrial/commercial fire flow requirements.
- Minimum fire flow residual pressures.
- Maximum pipeline velocity.
- Maximum day demand factors.
- Water quality monitoring stations.
- Drainage procedures (including de-chlorination, when required).
- Route location.
- Topographic survey.
- Land and easement acquisitions.
- Existing services (power, sanitary, storm water, communication cables, and gas).
- Geo-technical survey requirements.
- In-ground control chambers.
- Above ground control chambers.
- In-ground meter chambers.
- Above ground meter chambers.

Other considerations:

- Erosion and sedimentation measures (including climate change considerations).
- Traffic control.
- Unsuitable material in excavation.
- Soil corrosiveness.
- Contaminated soils.
- Groundwater elevation (including climate change considerations).
- Depth of frost.

Acceptable pipe material

- AWWA standards for pipe material based on pressure and geotechnical conditions.

Treated water storage:

- Siting/location (including climate change considerations).
- Sizing.
- Flow through or floating configuration.
- Top water elevation.
- Lowest operating water level.
- Peak balancing/fire/emergency storage.
- Water quality control (age, mixing/destratification, chlorine, DBPs, biofilm, etc.).
- Elevated storage.
- Ground level storage.
- Re-chlorination requirements.
- Monitoring (water quality, pressure, flows, etc.).
- Security issues:
    - Contamination.
    - Potential for vandalism.

Water distribution system:

- Extent of the distribution system.
- General distribution system data:
    - Pipe material.
    - Pipe age.
    - Pipe diameter.
    - Maximum velocity.
    - Groundwater elevation (including climate change considerations).
    - Separation from sewers.
    - Valve placement.
    - Hydrant requirements.
    - Water service lateral material.
    - Pressure zones and related valves or pumps.
    - Hydraulic grade line analysis.
    - Surge analysis.
    - Water loss considerations.
    - Stream crossings.

- Age related water quality issues:
  - Dead end mains.
  - Chlorine residual concerns.
  - Disinfection-by-product concerns.
  - Nitrification concerns.
  - Biofilm growth and bacterial regrowth.
  - Impact of treatment process on distribution system and mitigative measures.
- Adequacy of firefighting capacity.
- Watermain upgrade/replacement requirements.
- Domestic water only vs. fire flow.
- Cross connection control program requirements.

Additional Key Components

- Water Demand Projections:
  - Population trends, development trends, serviceable boundaries, and the potential for commercial and/or industrial zoning should be used to project future average and maximum daily demands, including fire flows where applicable. Projections should be realistic and may incorporate a plan for expanding the plant. Length of forecasted parameters will depend on the System Owners.
  - Impacts of climate change should be considered and addressed, including the potential for diminished source water yields and changes to water demands.
  - Water loss should be considered, and where appropriate, efforts should be made to establish a program to reduce water loss.
  - The construction of a new WTP or the extension of an existing system will require an estimate of the future population within the service area. Appropriate planning personnel should be consulted as part of this exercise, and particular attention is required to zoning designations to determine where commercial and/or industrial uses may be developed in the future.

- Design Criteria:
  - The quantity of water at the source shall be adequate to meet the maximum projected water demand of the service area as shown by calculations for both the current and future safe yield (including climate change considerations). Current safe yield may be calculated using droughts of record while future safe yield may be calculated (including climate change considerations). The selection of safe yield for approval application is further described in Section 3.1.1 of these Guidelines. Minimum drought conditions may be 1-in-10-year, 1-in-50-year, and 1-in-100-year return events or other scenarios as required. Permitting of source water withdrawal varies by province and is considered the governing practice in this regard. This includes requirements which may be imposed at a federal level. The detailed protocols and standards necessary to obtain withdrawal approvals are beyond the scope of this document.
  - The water transmission, distribution, and storage infrastructure should be designed to provide the required flows and pressures for the range of demand expected.
  - The design criteria used in the evaluation of the options should be outlined in the Pre-design Report and include all climate change considerations.
  - Water infrastructure design should include/consider materials and designs that are resilient to extreme weather events including climate change impacts.

- Site Selection of Treatment Plant:
  - Site selection of a large water supply component such as a WTP and/or a water storage reservoir will require consideration of a variety of factors, including:
    - Water quality if more than one source is available.
    - Location of source of supply.
    - Location of plant (including climate change considerations).
    - Land ownership issues for existing and future expansion.
    - Security issues.
    - Proximity to developed areas.
    - Hydraulic integration of the new plant into the existing system.
    - Proximity to sensitive areas (including protected watersheds).
    - Flood concerns (including climate change considerations).
    - Fire hazard concerns.
    - Geotechnical considerations.
    - Transmission and distribution system upgrade requirements.
    - Energy requirements (including climate change considerations).
    - Available disinfectant CT to first customer.
    - Proximity to sanitary sewer and residual disposal.
    - Proximity to power services (including climate change considerations).
    - Telecommunications (including climate change considerations).
    - Access road requirements (including climate change considerations).
    - Environmental ERPs if chlorine gas is included.
    - Site topography and drainage (including climate change considerations).
    - Site maintenance.
    - Land for drying beds, lagoons, etc. for waste streams (including climate change considerations).

- Conceptual Layout of WTP:
  - The selection of a preferred site, the selection of a water treatment process and ancillary equipment, and the assessment of the hydraulic impact on the transmission and distribution system, will allow for development of the conceptual layout of the required WTP.
  - The concept layout of the WTP should include, where applicable, consideration of the following functional aspects of the plant layout:
    - Number of process trains.
    - Provisions for future plant expansion.
    - Provisions for expansion of the plant waste treatment and disposal facilities (if on-site).
    - Access road (including climate change considerations).
    - Site grading and drainage (including climate change considerations).
    - Driveways and parking areas (including climate change considerations).
    - Chemical delivery access (including climate change considerations).
    - Chemical storage and feed equipment requirements.
    - Provision for power (including climate change considerations).
    - Provisions for stand-by power (including climate change considerations).
    - Adequate shop space and storage.
    - Laboratory facilities.
    - Seismic considerations.
    - Sanitary wastewater and residual disposal requirements (including climate change considerations).

- Ancillary Equipment and Infrastructure:
  - In addition to the major treatment process units, the development of a WTP will require consideration of ancillary process such as:
    - Types of disinfectant.
    - Requirements for alternative disinfectant.
    - Types of chemicals required.
    - Corrosion control requirements.
    - Fluoridation.
    - Environmental ERPs if chlorine gas is included.
    - Waste treatment.

- Route Selection of Transmission Mains:
  - The evaluation of a route of a transmission main should include land and easement acquisition requirements. Where options are evaluated, future connections and existing services should be identified.

- Site Selection of Water Storage Reservoirs:
  - The TWL and the location of a floating or flow-through water storage reservoir should be selected to result in acceptable service pressure and water quality throughout the distribution system under all demand conditions (including climate change considerations). Acceptable pressures are discussed in Chapter 8.

- Cost Estimates:
  - The concept development of major infrastructure should allow for a Class C cost estimate of the project to be carried out.
  - A Class C estimate is based upon concept plans and an outline of design systems of the intended project. This concept represents one solution of the design problem but not necessarily the eventual solution to the design problem. This estimate is based on completion of all work necessary to begin the preliminary design.
  - The Class C estimate must be based on knowledge of site conditions adequate to enable the identification of site related risks and the development of corresponding contingency costs that are sufficient to making the correct investment decision.
  - The Class C estimate is more detailed than a Class D estimate (which would be an order of magnitude estimate based simply on a statement of requirements) and less defined than a Class B estimate (which would be based on the completed preliminary design drawings).
  - Estimates of capital cost should include a breakdown of major components divided according to construction discipline, as well as specific allowances for:
    - Engineering services.
    - Pilot testing.
    - Contingencies.
    - Costs of additional evaluations.
  - The Divisions of the National Master Specification (NMS) are recommended as a best practice for dividing construction disciplines.

- Estimates of annual operating costs should include the following:
  - Chemicals.
  - Heat and power.
  - Maintenance.
  - Labour.
  - Security.
  - Monitoring and testing.
  - Source water protection.
  - Other utilities (e.g., phone, internet, etc.).
  - Ongoing training costs.

- Alternate Treatment:
  - Where alternate treatment processes are being evaluated, a NPV analysis or life cycle costing should be carried out on the applicable processes, using a minimum 20-year period, to select the most cost-effective option for the System Owner. Both capital and operating costs should be taken into consideration when conducting the evaluation.

A.2 Design Report

Table 1.2 in these Guidelines provides a checklist of WTP components that typically should be included in a Design Report. The requirements can be determined by the System Owner by indicating which components are applicable to the project and serve to determine the contents for a specific project to be submitted to the Regulatory Authority for review. The identification and prioritization of climate change risks to the project should be completed in the pre-design phase. The results of the screening-level assessment and risk assessment will guide the incorporation of climate change resiliency strategies into detailed design. All components of the project which incorporate climate change considerations should be clearly stated in the Design Report.

The following provides a list of specific tasks that may be required under each of the selected WTP components.

General Information:

- Existing water works infrastructure.
- Identification of area serviced.
- Name of System Owner (contact person, address, telephone, email).
- Climate change resiliency strategies incorporated into design.

Extent of the Water System:

- Extent of area to be serviced.
- Provisions for future extensions.

Soil, Groundwater, and Geotechnical Conditions:

- The character of the soil through which watermains are to be laid.
- Foundation conditions prevailing at sites of proposed structures.
- The potential for acid rock conditions.
- The approximate elevation of groundwater in relation to subsurface structures (including climate change considerations).
- De-watering provisions if necessary.

Water Demands:

- A description of the population trends as indicated by available records, and the estimated population which will be served by the proposed WTP or expanded system.
- Present water consumption and the projected average and maximum daily demands.
- Status of fire flow demand and fire flow storage.
- Present and/or estimated yield of the sources of supply.
- Unusual occurrences and/or major commercial or industrial demands.

Hydraulic Analyses:

- Based on flow demands and pressure requirements.
- Fire flows, when fire protection is provided by the WTP and distribution system, meeting the recommendations of the Insurance Advisory Organization or other similar agency for the service area involved.

Sources of Water Supply:

Describe the proposed source of water to be developed, the reasons for the selection, and provide information as follows.

For surface water sources, include, but not be limited to:

- Area of watershed.
- Location of intake (including climate change considerations).
- Source water surface area and volume (including major tributaries).
- Current and future safe and maximum yield (including climate change considerations).
- Other users of the source.
- Factors that may affect the source (including climate change considerations).
- Maximum flood level including climate change considerations, together with approval for safety features of the spillway and dam from the appropriate Regulatory Authority.
- Description of the watershed noting any existing or potential sources of contamination that may affect water quality, such as:
  - Highways.
  - Railroads.
  - Chemical facilities.
  - Agricultural uses (including climate change considerations).
- Summarized quality of the raw water with special reference to fluctuations in quality, and changing meteorological conditions (including present, historic, and projected changes including climate change considerations).
- Source water protection issues or measures that need to be considered or implemented.
- Fish maintenance requirements.
- Ice conditions.
- Evidence that applicant has approval to withdraw water.
- Additional climate change considerations.

For groundwater sources, including, but not limited to:

- Climate change considerations.
- Regulations on groundwater extraction.

- Saltwater intrusion.
- Distance to nearest watercourse.
- Groundwater under the direct influence of surface water assessment.
- Safe and maximum yield for each production well and for the entire well field.
- Evaluation of impacts to yields of other aquifer users, where applicable.
- Locations of the production well(s) and monitoring well(s), and elevation of wells with respect to surroundings.
- Hydrogeological conceptual model showing the probable hydrogeological character of formations through hydrogeology of the area in which the source is to be developed.
- Hydrogeological conditions affecting the site.
- Hydrogeological and environmental impact by the proposed well/well field, such as:
  - Anticipated interference between proposed and existing wells.
  - Stream flow reduction by the proposed extraction.
  - Saltwater intrusion.
- Estimation of capture area and pumping radius of influence for production wells.
- Summarized quality of the raw water with special reference to fluctuations in quality, changing meteorological conditions, etc. (including present, historic, and projected changes including climate change considerations).
- Summary of groundwater exploration, test well depth, method of construction, depth and length of casing/liner and screen, pumping test rates and their duration, groundwater levels, and specific yield.
- Sources of possible contamination and their risks.
- Wellhead completion method (vault, pitless adaptor, etc.).
- Wellhead protection measures being considered.
- Evidence that applicant has approval to withdraw water.

Design Criteria of WTPs:
Confirm that the design criteria used conforms to the requirements of the Regulatory Authority. It is recommended that the design criteria include, but not be limited to, the following:

- Intake size, type, and location relative to depth of water column (including climate change considerations).
- Intake velocity.
- Screening type and location.
- Coagulation/flocculation process.
- Solids separation process.
- Surface and/or solids loading rates.
- Chemical feed systems and feed rates.
- Filter system type (slow, rapid, pressure, membrane, etc.).
- Filter media specifications.
- Number of filters and redundancy.
- Filtration area and rate.
- Number of treatment trains.
- Process specific parameters (pH, temperature, TOC, colour, turbidity, etc.).
- Disinfection process.
- Algal treatment strategy.
- Corrosion control strategy.
- Disinfection equipment redundancy.
- Disinfection by-product formation potential.

- Contact time values and details.
- Log inactivation credits for bacteria, protozoa, and viruses.
- Storage allowance or requirements.
- Filter-to-waste.
- Backwash requirements:
  - Treatment considerations.
  - Proposed disposal method.
  - Location.
  - Chemical, physical, and biological characteristics.
  - Volume.
  - Applicable discharge regulations.
  - Aluminum background in receiving water and other parameters such as pH, hardness, etc.
  - Final disposal.
  - Possible impact and uses of receiving waters.
- Additional climate change considerations.

Automation:
Provide a list of instrumentation and automated systems, as well as supporting data outlining automatic equipment, and the overall operations strategy for the plant. Note that manual override and alarms must be provided for any automatic controls.

Operations During Construction:
Where applicable, the submission should contain a program for keeping the existing water works facilities in operation during construction of additional facilities to minimize interruption of service.

If applicable, consideration should be given to increased water quality monitoring (process and compliance) and to increased staff requirements during construction. Should it be necessary to take existing systems out of operation, a shut-down schedule that will maintain a safe supply of water to the users. System Owners should be prepared to submit a request for approval from the Regulatory Authority.

Appendix B

Factors for Choosing Climate Change Information

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Appendix B

Factors for Choosing Climate Change Information

In this Appendix, many of the concepts discussed in Chapter 1 are applied specifically to choosing climate information. A list of factors that drive the selection of climate information is presented in this Appendix.

B.1 Asset – Climate Interactions

A major factor for choosing climate information are the asset-climate interactions:

- **Interactions**: the asset-climate interaction(s) (i.e., impacts) being assessed are what drive the need for specific climate information. Which variables, and what aspects of the variables or indices are relevant, depends on the how the asset or program has been or will be impacted by climate change. The list of relevant interactions depends on **what is being impacted** (the asset or program). For example, a yield study likely needs to examine dry weather, whereas a water quality study may be concerned with high-intensity precipitation. Furthermore, wastewater discharge limits described in the plant's Approval/License/Permit to Operate would consider both dry and wet weather flows. While the 1-in-50-year wind is relevant for buildings, changes in average monthly winds are not directly applicable. The list of relevant interactions also depend on **what is causing the impact** (climate change). Such as the geographic context, topography, proximity to the coast, microclimate, vegetation, geology, etc. For example, permafrost may need to be considered in Labrador, but is not applicable in Prince Edward Island.

B.2 Assessment

The following are factors for choosing climate information based on the characteristics of assessment:

- **Budget/Timeline**: in some cases, compromises are made due to the assessments' practical constraints. For example, while a yield assessment would ideally be informed by hydrological or hydrogeological impact modelling, trends can be approximated, with caveats, from precipitation information.
- **Type of Input Required**: the assessment type may dictate the format or other characteristics of the climate information required. For example, flood modelling that is based on the 1-in-100-year storm requires climate information on the projections for future precipitation rates (e.g., increase from 200 mm by 30% to 260 mm), whereas a risk assessment based on the probability of the existing 1-in-100-year storm requires climate information on the projected increased frequency of such an event (e.g., 0.01 annual exceedance probability becomes 0.015).

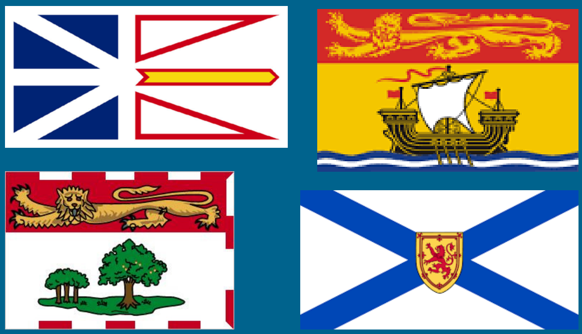
- **Projection Horizons**: as described in Chapter 2, projection horizons or timelines are chosen based on the remaining useful life of the program or asset being assessed. Sources of uncertainty are relevant to different timescales, which means that different types of climate information may be required depending on the projection horizon. For short projection horizons (e.g., 10-year lead times), the natural climate variability may dominate and can even hide the climate change signal. For that reason, climate risk in these time periods needs to consider variability based on historical measured information or certain types of climate model ensembles.
- **Risk Tolerance and Uncertainty Characterization**: infrastructure types have different risk tolerances. For a dam, a risk assessor may want to understand how the 95th percentile of climate model projections for drought may affect desiccation cracking in the structure. The best practice to characterize uncertainty is to use more than one emissions scenario and a range of projections from an ensemble of climate models. For some variables, more than one projection method is also warranted. Using the median of a modelling ensemble, however, ignores the potential risk of higher or lower projections. This may be sufficient for a non-critical asset, with a higher risk tolerance than a critical asset.
- **Precision Level**: assessments vary widely in the degree of precision required. Some risk assessments are more qualitative, and they require a general trend or degree of change to assign climate changes as low, medium, high, or a binned score from 0 to 5. The anticipated impact on results also dictates the precision level required for certain variables. For example, a 5˚C change in water temperature may be irrelevant to the planned design, in which case literature may be sufficient.
- **Geographic Scale**: whether an assessment is conducted for a single locality, or at a larger scale (e.g., province-scale) will influence the type of climate information that is relevant. There is also a practical aspect, for example, obtaining gridded projection data may be warranted for a larger assessment in order to visualize geographic variability in projections.

B.3 Climate Information

The following are factors for choosing climate information based on the characteristics of climate information sources:

- **Source Recognition**: only sources of climate information vetted by experts should be used, such as Environment and Climate Change Canada. It is important that the methodologies have been well validated (tested) and that metadata is available.
- **Methodology Assumptions**: sources of information should be used within the confines of their assumptions. For example, the *IDF_CC Tool* from the Western University Canada assumes that the relationship between daily and sub-daily precipitation is unchanged in the future, and the method should only be used in conjunction with other approaches.
- **Updated Methodology**: climate science moves at a fast pace. Emissions scenarios, modelling ensembles, and post-processing techniques are regularly updated and improved. Unless it cannot be avoided, it is important not to use sources of climate information that have been superseded. Using older information could mean it is outdated and will have an impact on the design process.
- **Available Variables**: the variables required for an assessment will dictate the sources of climate information. Temperature and precipitation are the two variables which are the are most readily available from climate models. That said, projections for changes in frequency and/or intensity of hurricanes are better obtained from literature.
- **Available Indices**: only certain indices are available from data portals and past literature. If an assessment requires a specific infrastructure-related threshold, it may be necessary to calculate the projection by post-processing daily projection timeseries.

- **Available Ensemble**: sources of information must have a sufficient ensemble size. It is inadequate to use projections from only a few climate models.
- **Uncertainty Characterization**: not all sources of climate information report on the range of possible projections (e.g., percentiles). For example, literature for sea-level rise projections may report only the median of the model ensemble. Especially for assessments with a low risk tolerance, it is important to obtain projections where uncertainty characterization is also available.
- **Resolution**: not all climate information sources will provide the spatial and temporal resolution needed for an assessment. For example, the ensemble of downscaled GCMs on ClimateData.ca has daily projections only, and it cannot inform sub-daily precipitation extremes.
- **Projection Horizon**: not all sources are available for all projection horizons. Some indices from data portals may have been pre-calculated on certain tri-decades. Historical sources of information obviously do not provide information on future projection periods.



ATLANTIC CANADA
WATER & WASTEWATER ASSOCIATION
American Water Works Association
Atlantic Canada Section
Water Environment Federation
the water quality people

Consultant

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Peer Review

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