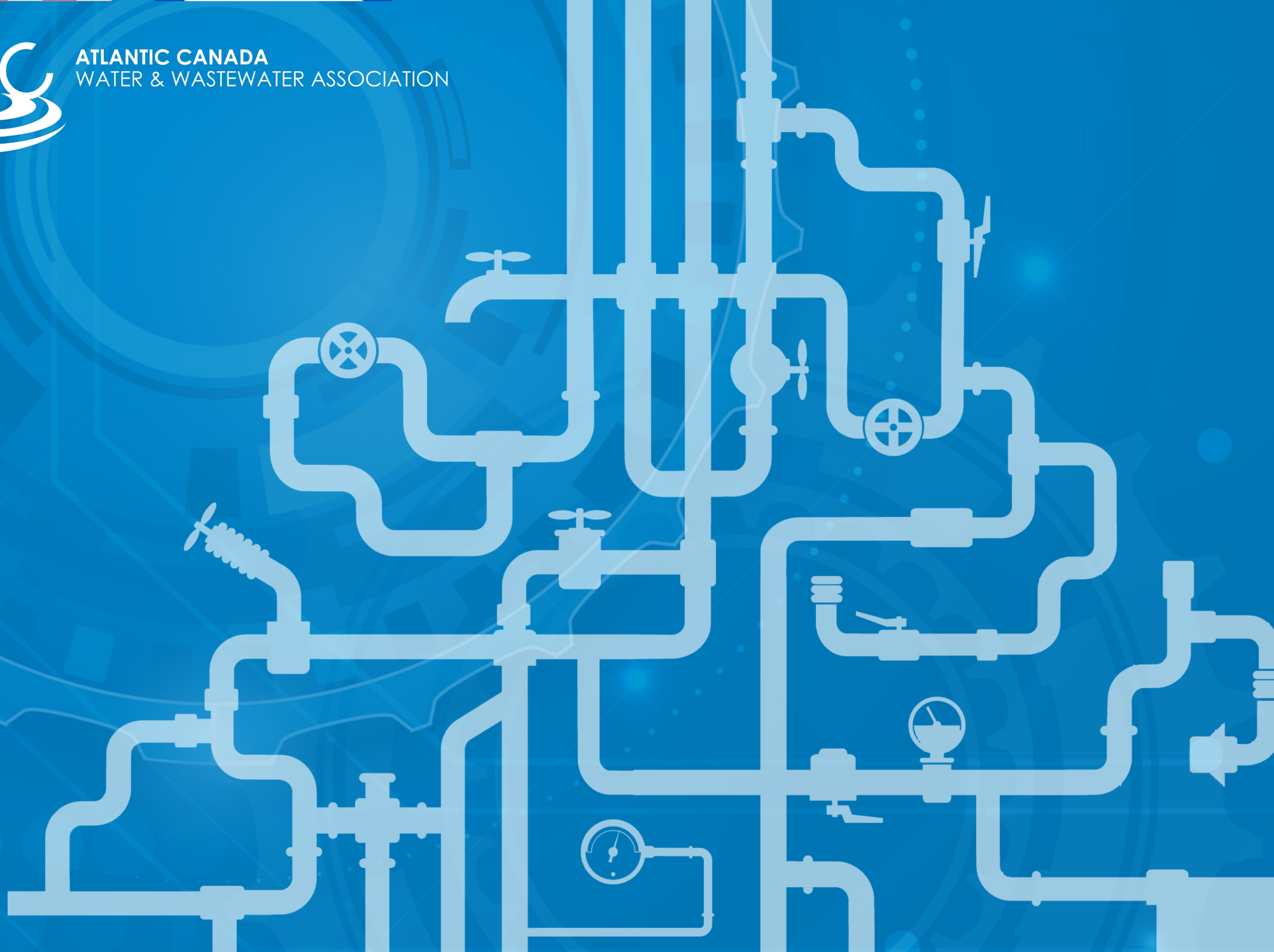
Atlantic Canada Water Supply Guidelines | Draft 2, March 2020

ATLANTIC CANADA
WATER & WASTEWATER ASSOCIATION



ACWWA Water Supply Guidelines Draft 2 – Stakeholder Notification

The ACWWA Water Supply Guidelines Draft 2, March 2020, has been forwarded to the Project Committee for review. The document is still very much in draft form, and is being made available for stakeholder review and input. Please note the following:

1. Definitions for average day demand, maximum day demand, and peak day demand, etc. are provided in several chapters. Final definitions, and location of the terms, will be provided in consultation with the Project Committee.

2. Chapter 2 Climate Change is a new chapter and introduces the topic to the industry. The chapter includes significant narrative to illustrate context, and the format is not finalized. An option to be discussed with the Project Committee is that the Climate Change chapter may be broken up into a chapter and an appendix.

3. The location for references are not finalized.

4. The sections on cyanobacteria and corrosion control are not complete. Both topics are subjects of considerable evolving design practice, and are being developed in isolation.

5. Cross references to sections are highlighted as they are not completed.

6. The use of 1 in n return events and references to consideration of climate change/impacts are highlighted as they require discussions with the Project Committee.

Please contact the undersigned if you have any comments or questions on the Draft. A "markup" PDF copy of the Draft is available on request should a stakeholder wish to review the edits to the 2004 document.

Please provide comments by August 28, 2020.

CBCL

Willard D'Eon, MPH, P.Eng. | Process Engineer

c. 902-499-0159 | willardd@cbcl.ca

Purpose and Use of Guidelines

Purpose

The purpose of the Atlantic Canada Water Supply 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). The update includes revisions to technical requirements and a section on the consideration of climate change for the design of climate resilient infrastructure. A companion document, the Atlantic Canada Wastewater Guidelines, was updated in coordination with these guidelines.

The document should be considered a companion to the *Atlantic Canada Wastewater Systems Guidelines (2020).*

The guidelines are intended to be used in the evaluation of water supply and treatment projects, and for the design and preparation of plans and specifications. The guidelines will suggest limiting values for items upon which an evaluation of such plans and specifications may be made by regulatory authorities, and will establish, as far is practical, a best practice.

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

Funding

Funding for the updates to the Guidelines was provided by Natural Resources Canada under the Building Regional Adaptation Capacity and Expertise (BRACE) program, a five-year (2017-2022), $18 million 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.

Funding from NRCan matched financial and/or in-kind contributions 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).

The Project Committee included representatives from the above as follows:

- 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: Sylvie Morton, P.Eng.
- Newfoundland and Labrador: Deneen Sprackling, P.Eng.
- Nova Scotia: John Lam, P.Eng.
- Prince Edward Island: Morley Foy, P.Eng

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

Climate Change

Understanding climate change and its impacts on water supply (and wastewater) infrastructure is an important and complex reality for utilities in Atlantic Canada. Utilities are anticipated to encounter both challenges and opportunities related to addressing the impacts of projected future 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 utility has its own unique set of priorities and finite resources. As such, when one combines these factors, it becomes evident that each region within Atlantic Canada will be impacted by climate change differently.

Given regional differences in Atlantic Canada, there is limited value in presenting detailed site-specific climate change parameters, indices, and adaption design processes in this guideline. Instead, this guideline aims 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. This guideline document will focus on climate change adaptation instead of climate change mitigation. Where possible, the guideline will identify opportunities to reduce energy consumption and demand in water supply operations to limit human-induced greenhouse gas emissions.

The guidelines serves as a foundational introduction to climate change adaptation for water utilities in Atlantic Canada and will highlight the linkages between changing climate and the planning, design and operations of infrastructure managed by water and wastewater utilities. A new introductory Climate Change chapter aims to deliver a comprehensive overview for the strategies available to gather climate change information, assess impacts and risks, and to implement effective adaptation planning. Throughout the guideline, 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 the Manual are advised that requirements for specific issues such as filtration, equipment redundancy, and disinfection are not uniform among the Atlantic Canada provinces, and that the appropriate regulator should be contacted prior to, or during, an investigation to discuss specific key requirements.

Approval Process

This Guideline has been prepared for use in the design of infrastructure for water supply systems in Atlantic Canada. Every effort has been made to ensure that the manual is consistent with current technology and environmental considerations. The approval and permit process outlined in these guidelines is general in nature and is meant to be an overview only. Proponents 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, etc., and/or contacts may be accessed as follows:

- *New Brunswick Environment and Local Government.*
- *Newfoundland and Labrador Municipal Affairs and Environment.*
- *Nova Scotia Department of Environment.*

- Prince Edward Environment, Water, and Climate Change.

Innovation

The Water Supply Guidelines are not intended to limit innovation on the part of proponents. Where the designer can show that alternate approaches can produce the desirable results, such approaches may be considered for approval.

Definition of Terms

The terms used in the Guidelines reflect generally used definitions in the water industry. Users are referred to the American Water Works Association (AWWA) "Drinking Water Dictionary" 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 implementation of new systems. Not all of these issues are easily categorized and addressed as a guideline. 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 the Manual are encouraged to review AWWA and CWWA policy/position papers at the following:

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

Reference Material

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

List of references
End of chapters?
End of Guidelines?

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 the documents should be forwarded to the following:
????

Contents

Chapter 1 Approval Requirements and Procedures ... 7
1.1 General Overview ... 7
1.2 Pre-Consultation ... 9
1.3 Pre-Design (Technical) Report ... 9
1.4 Detailed Design Submissions ... 18
1.5 Approval/Permit to Construct ... 23
1.6 Post Construction Report/Certificate of Compliance ... 23
1.7 Approval/Permit to Operate ... 24
1.8 Monitoring and Recording Requirements ... 24
1.9 Reporting Requirements ... 24
1.10 Facility Classification and Operator Certification ... 24
1.11 Owner Responsibility ... 24
1.12 Regulator Responsibility ... 25
Chapter 2 Incorporating Climate Change in the Design of Drinking Water Infrastructure ... 28
2.1 Introduction to Climate Change Adaptation in this Guideline ... 28
2.2 Scope of Climate Change Adaptation in this Guideline ... 29
2.3 Climate Change Projections for Use by Practitioners ... 29
2.4 Global and National Climate Change Trends ... 33
2.5 Projected Climate Change in Atlantic Canada ... 35
2.6 Climate Change Impacts on Drinking Water Infrastructure Design ... 39
2.7 Identifying Climate Risks to Drinking Water Infrastructure ... 44
2.8 Adaptation to Climate Change in Drinking Water Infrastructure ... 51
2.9 Key Climate Change Indices and Parameters for Consideration ... 54
2.10 Sources of Climate Data ... 55
2.11 References ... 58
Chapter 3 Source Water Development ... 64
3.1 General ... 64
3.2 Surface Water ... 64
3.3 Groundwater Supply ... 67
3.4 Source Water Protection ... 79
Chapter 4 Design of Water Treatment Facilities ... 85
4.1 Design Basis ... 85
4.2 Site Selection ... 85

4.3 Layouts 88
4.4 Piping & Instrumentation Diagrams and Plant Control 89
4.5 Stand-by Power 89
4.6 Chemical Feed Facilities 89
4.7 Plant Facilities 95
4.8 Laboratory Facilities 95
4.9 Monitoring 96
4.10 Operations and Safety 97
4.11 Facility Construction 98
4.12 Labeling and Colour Coding 99
4.13 Remote Operation of Facilities 100
4.14 Other Considerations 100
Chapter 5 Design of Water Treatment Processes 106
5.1 Presedimentation and Screening 106
5.2 Coagulation/Flocculation Process 106
5.3 Clarification 108
5.4 Filtration 112
5.5 Disinfection 124
5.6 Softening 130
5.7 Aeration 131
5.8 Iron and Manganese Control 134
5.9 Fluoridation 137
5.10 Stabilization and Corrosion Control 139
5.11 Taste and Odour Control 141
5.12 Cyanobacteria 142
5.13 Waste Handling 142
5.14 Emerging Technologies 148
Chapter 6 Pumping Facilities 151
6.1 Facility Types 151
6.2 Facility Construction 152
6.3 Pumps 154
6.4 Booster Pumps 156
6.5 Automatic and Remote Controlled Stations 157
6.6 Appurtenances 157
6.7 Electrical 158
6.8 Safety Precautions 159

6.9 Station Monitoring 159
Chapter 7 Treated Water Storage Facilities 163
7.1 General 163
7.2 Definitions 163
7.3 Materials of Construction 165
7.4 Storage Requirements 166
7.5 Water Quality 169
7.6 Location of Distribution Storage 170
7.7 Facility Requirements 171
7.8 Water Treatment Plant Storage 174
7.9 Hydropneumatic Tanks 174
7.10 Security/Safety 175
Chapter 8 Transmission and Distribution Systems 179
8.1 Definitions 179
8.2 Materials 181
8.3 Design Criteria – Transmission and Distribution Systems 182
8.4 Hydrants 187
8.5 Valve and Metering Chambers 188
8.6 Separation Distances to Sanitary and Stormsewers 189
8.7 Cross Connection Control 190
8.8 Water Services and Plumbing 190
Chapter 9 Operation and Maintenance 193
9.1 General 193
9.2 Surface Water Source Facilities 193
9.3 Groundwater Source Facilities 194
9.4 Pumping Facilities 195
9.5 Water Treatment Facilities 195
9.6 Treated Water Storage Facilities 197
9.7 Transmission and Distribution Systems 197
9.8 Small Water Supply Systems 198
9.9 Safety 198
9.10 Overall Documentation 199
9.11 Operator Training Scheduling 199
9.12 SCADA Monitoring 199
9.13 Security 199

Chapter 10 Small Water Supply Systems 202
10.1 General 202
10.2 Outline of a Small Water Supply System 202
10.3 Approval Requirements 203
10.4 Water Use Requirements 203
10.5 Source of Supply 204
10.6 Water Treatment 205
10.7 Auxiliary Power 207
10.8 Water Storage 207
10.9 Pressure Tanks 208
10.10 Water Distribution System 208
10.11 Monitoring Requirements 209
10.12 Facility Classification and Operator Certification 209
10.13 Easements, Statutory Rights of Way, and Restrictive Covenants 209

Appendices

A References???

Chapter 1 Approval Requirements and Procedures ... 7

1.1 General Overview ... 7

1.1.1 Summary of Approval Process ... 7

1.2 Pre-Consultation ... 9

1.3 Pre-Design (Technical) Report ... 9

1.3.1 Contents of a Pre-Design Report ... 10

1.3.2 Pre-Design Evaluation ... 15

1.3.2.1 Water Demand Projections ... 15

1.3.2.2 Design Criteria ... 16

1.3.2.3 Climate Change Consideration ... 16

1.3.2.4 Site Selection of Treatment Facility ... 16

1.3.2.5 Conceptual Layout of Treatment Plant ... 16

1.3.2.6 Ancillary Equipment and Infrastructure ... 17

1.3.2.7 Route Selection of Transmission Mains ... 17

1.3.2.8 Site Selection of Water Storage Reservoirs ... 17

1.3.2.9 Cost Estimates and Financing ... 17

1.4 Detailed Design Submissions ... 18

1.4.1 Plans ... 19

1.4.2 Technical Specifications ... 20

1.4.3 Design Brief ... 20

1.4.3.1 General Information ... 20

1.4.3.2 Extent of Water System ... 20

1.4.3.3 Soil, Groundwater, and Geotechnical Conditions ... 20

1.4.3.4 Water Demands ... 20

1.4.3.5 Hydraulic Evaluations of Transmission and Distribution Systems ... 21

1.4.3.6 Sources of Water Supply ... 21

1.4.3.7 Design Criteria for Water Treatment Plants ... 22

1.4.3.8 Automation ... 22

1.4.3.9 Requirements for Operation during Construction ... 22

1.4.4 Review of Design Submission ... 22

1.5 Approval/Permit to Construct ... 23

1.6 Post Construction Report/Certificate of Compliance ... 23

1.7 Approval/Permit to Operate ... 24

1.8 Monitoring and Recording Requirements ... 24

1.9 Reporting Requirements 24
1.10 Facility Classification and Operator Certification 24
1.11 Owner Responsibility 24
1.12 Regulator Responsibility 25

Chapter 1 Approval Requirements and Procedures

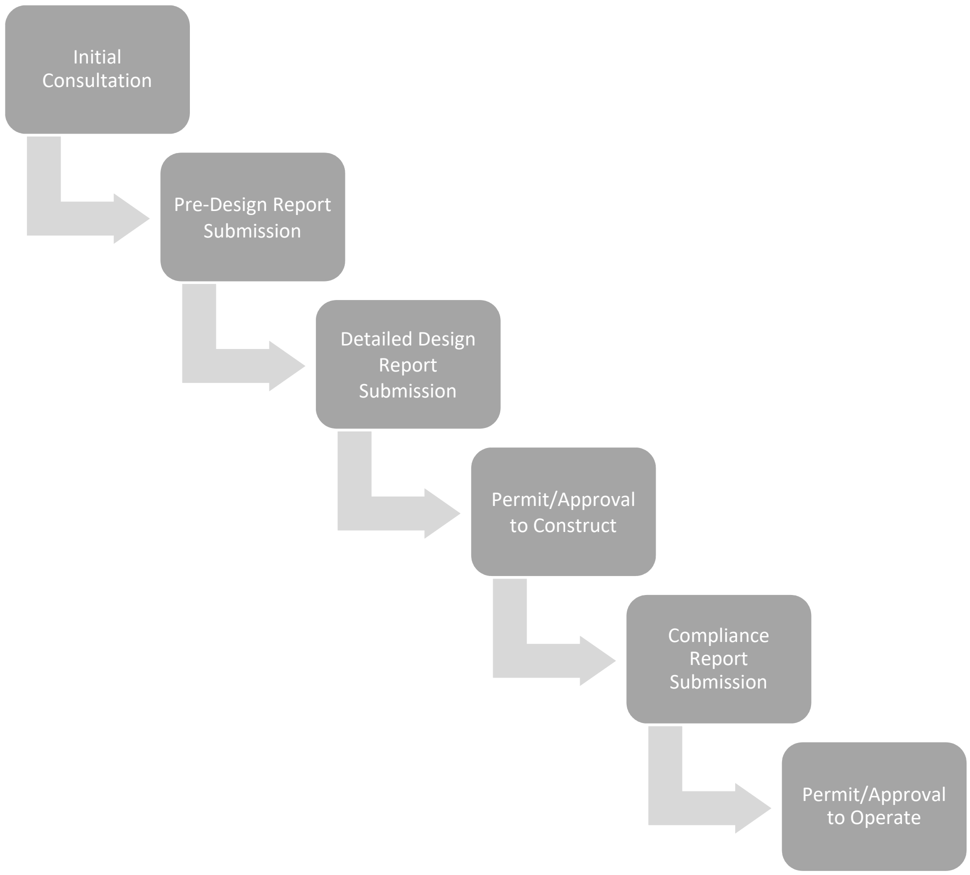
1.1 General Overview

The approval process for water supply, treatment and distribution varies from province to province, and can include multiple overlapping agencies. In all cases, a project proponent should seek early clarification from the respective province as to whether an approval for construction, modification, or operation will apply to a portion or all of a project before the project is advanced. In some cases, an approval is needed for the vertical assets (e.g., water treatment plant, 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 Owner, or Owner's Designate 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 before proceeding with construction. Determination of an overall regulatory roadmap of a given project is beyond the scope of this manual. The guidelines which follow are intended to guide the design stages associated only with public water supply infrastructure. In general, early consultation with the regulatory authorities is recommended in the project planning stages.

1.1.1 Summary of Approval Process

The approval process can be a multi-step procedure, and varies from province to province. It is recommended that early consultation be conducted with all involved parties including the Owner, design team, regulators, and other key stakeholders. Throughout the project, regular consultation and status review meetings should be continued through the concept, design, approval, and construction stages. The general approach for approaching a project regulatory process is shown on the following chart and expanded upon in the following sections. It is recognized, however, that not all steps are required in each project, or in each province.



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

The pre-design report should be submitted to the regulator, with a request for comments or “concept approval.” **Acceptance of a pre-design report (in any form) from a regulator, however, 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 regulator prior to the planned start of the construction or modification project. The plans, specifications and supporting documentation should be stamped with the seal and signature of a Professional Engineer that is licensed to practice in the Province of application. The application should be submitted to the regulatory agency and should be signed by the owner, or where authorization is provided, a person representing the owner.

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

An “Approval/Permit to Construct” should 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 Owner until the official "Permit/Approval to Construct” has been issued by the regulator.**

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

After the submission of the Post-Construction Report/Certificate of Compliance, the regulator may provide an “Approval/Permit to Operate" if all aspects of the project are acceptable.

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

The expiry date of the approval/permit and the terms for renewal should be indicated by the regulator.

1.2 Pre-Consultation

Proponents planning a water supply project should consult with the regulator to discuss the scope of the project 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 climate change impact, required for the Project;
- Identification of key timelines associated with the review process;
- Identification of key stakeholders that should be involved in the process.

1.3 Pre-Design (Technical) Report

A pre-design report should be considered as good engineering practice even when not required by the regulator.

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

- Water supply sources;
- Pump-house infrastructure;
- Water treatment systems;
- 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 climate change issues, if applicable, and to determine options for upgrade, improvement, 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:

- The municipality, utility, private developers or industry, for a project description, including findings, conclusions, cost estimates, financing requirements and recommendations;
- Designers, to establish the overall scope of design and for the arrangement, capacity, and type of components to be designed;
- The regulator for evaluation of environmental impacts, for examination of process operations, for verifying compliance with Water Treatment Standards, and for the issuance of a “Concept Approval” 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; and
- News media for description of the project.

The pre-design investigation may provide a “screening’” opportunity to determine if the project requires an assessment and/or registration under the respective Environmental Assessment Act, or if climate change impacts are a concern. The respective provincial regulator should be contacted to determine specific requirements.

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

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:

All projects:

- 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;
- Assess alternate options of resolving the limitations in an effort to meet the long term goals which have been identified;
- Identify geotechnical issues;
- Identify climate and climate change risks;
- Identify the long term goals of the work being considered;
- 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 agencies;
- Identify all waste streams/emissions from project;
- Identify impacts of the environment on the project;

- Identification of utility or private developers (name, address, telephone);
- Include a map of project site to show the following:
  - Property boundary and ownership;
  - Area of new development/ area of existing development
- Environmentally sensitive areas (e.g., watercourse, wetland)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;
- Determination of service area;
- Determination of equivalent service population;
- Summary of water consumption data;
- Future population and water consumption projections;
- Include future climate change scenario projections, including risks to quantity and quality of water as well as maintenance of built assets;
- Maintenance and operation requirements;
- Evaluation of options;
- Preliminary cost estimates of options;
- Concept plan of recommended options; and
- Any other requirements of the regulator.

Possible inclusions:

- Historical and projected future climatic conditions; sources of data
- Probability and severity of impacts from climate change
- Adaptation/resiliency measures/options
- Monitoring of adaptation/resiliency measures

Surface Water Supply Source:

- Sites considered and reasons for selection;
- Location and physical setting of watershed;
- Climate change impacts;
- Watershed ownership and management issues;
- Watershed area;
- Safe yield (winter and summer);
- Existing and potential sources of contamination;
- Raw water quality;
- Proposed intake location (vertical and horizontal);
- Impound requirements;
- Flow maintenance requirements;
- Other water use and withdrawal rates;
- Intake location; and
- Intake security.

Groundwater Supply Source:

- Include future Climate Change scenarios
  - Climate change scenarios and impacts on groundwater supply;
- 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;
- Availability of water (peak versus safe use, plus competing uses in areas); and
- 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 such as abandoned dumps, industrial sites, etc.;
- Surficial hydrogeology;
- Bedrock hydrogeology;
- Descriptions of pumping and observation wells;
- Aquifer and aquitard properties;
- Safe well yields;
- Safe aquifer yield;
- Existing and future water budget in watershed/catchment scale, e.g. water supply and demand in the watershed;
- Well head completion details;
- Water levels; and
- History of well maintenance and monitoring.

Water Treatability:
- Fluctuations in raw water quality;
- Water quality parameters that exceed limits;
- Trihalomethane (THM) formation potential;
- Treatment requirements;
- Bench-scale tests;
- Pilot scale tests;
- Treated water quality; and
- Impacts on the water distribution system.

Raw water storage reservoir:
- Natural storage; and
- Engineered storage.

Raw water transmission main:
- Pumping/pressure reduction requirements;
- Capacity of main;
- Pipe material;
- Routing considerations;
- Soil conditions;
- Groundwater level elevation; and
- Contaminated sites.

Water treatment facility:
- Location, with consideration of climate change impact;
- Plant sizing;
- Design life;
- Basic treatment concept:

  - Number of process trains;
  - Custom made or package plant.
- Treatment processes;
- Capacity of treatment units;
- Hydraulic gradeline through plant;
- Method of solids removal:
  - Sedimentation;
  - Dissolved air flotation.
- Filter system type (slow, rapid; pressure, membrane);
- Filtration area and rates;
- Filter media type;
- Filter redundancy;
- Backwash type (air, scour);
- Backwash rates;
- Process waste disposal;
- Sanitary wastewater disposal;
- Disinfection process;
- Disinfection equipment, housing, and redundancy;
- CT factor;
- Chemicals used;
- Chemical feeder capacity and ranges;
- Chemical containment and storage;
- Corrosion control;
- Water quality monitoring;
- Storage requirements;
- Integration of new facilities in existing system;
- Future expansion / modifications possibilities;
- Security;
- Automation and instrumentation;
- Process control and compliance monitoring;
- High lift pumping / pressure reduction;
- Emergency Power;
- Personnel space requirements (i.e., lab and maintenance);
- Solid waste management; and
- Facility classification.

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 treatment plant;
  - 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 pipe line velocity;
- Maximum day demand factors;
- Water quality monitoring stations;
- Drainage procedures (including dechlorination, when required);
- Route Location;
- Topographic survey;
- Land and easement acquisitions;
- Existing services (power, sanitary, stormwater, communication cables, 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;
  - Traffic control;
  - Unsuitable material in excavation;
  - Soil corrosiveness;
  - Contaminated soils;
  - Groundwater elevation;
  - Depth of frost.
- Acceptable pipe material (AWWA Standards for pipe material based on pressure and geotechnical conditions).

Treated water storage:

- Siting/Location, with consideration to climate change impact;
- Sizing;
- Top water elevation;
- Lowest operating water level;
- Baffling/water circulation (water quality issues);
- Elevated storage;
- Ground level storage;
- Rechlorination requirements;
- Monitoring;
- 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;
  - Separation from sewers;
  - Valve placement;
  - Hydrant requirements;
  - Water service lateral material;
  - Pressure zones and related valves or pumps;
  - Hydraulic gradeline analysis;
  - Surge analysis;
  - Water loss considerations;
  - Cross connection control program; and
  - Stream crossings.
- Age related water quality issues:
  - Dead end mains;
  - Chlorine residual concerns;
  - THM concerns;
  - Nitrification concerns;
  - Biofilm growth and bacterial regrowth; and
  - Impact of treatment process on distribution system.
- Adequacy of fire fighting capacity;
- Watermain upgrade/replacement requirements;
- Domestic water only versus fire flow; and
- Cross connection control program requirements.

1.3.2 Pre-Design Evaluation

The following sections describe additional details of key components in a pre-design evaluation. Not all topics are relevant to every project but where applicable, these sections should guide the type of information detailed during pre-design.

1.3.2.1 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, for a 20 year period. Projections should be realistic, and may incorporate a plan for expanding the facility.

Impacts of climate change should be considered and addressed, including the potential for diminished source water yields.

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 water system 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 in an effort to determine where commercial and / or industrial uses may be developed in the future.

1.3.2.2 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 using droughts of record, 1:10, 1:50 and 1:100 year return events or other scenario 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 federally. 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.

Water infrastructure design should include/consider materials/designs that are resilient to extreme weather events

1.3.2.3 Climate Change Consideration

The proposed infrastructure upgrades and/or modifications should undergo a risk assessment to determine the need for immediate or future actions necessary to establish climate resilient design outcomes.

1.3.2.4 Site Selection of Treatment Facility

Site selection of a large water supply component such as a water treatment plant 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 facility and climate change considerations;
- Land ownership issues;
- Security issues;
- Proximity to developed areas;
- Hydraulic integration of the new facility into the existing system;
- Proximity to sensitive areas;
- Flood concerns;
- Fire hazard concerns;
- Geotechnical considerations;
- Transmission and distribution system upgrade requirements;
- Energy requirements;
- Available disinfectant contact time to first customer;
- Proximity to sanitary sewer;
- Proximity to power services;
- Access road requirements;
- Site topography and drainage; and
- Site maintenance.

1.3.2.5 Conceptual Layout of Treatment Plant

The selection of a preferred site, the selection of a water treatment process train 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 water treatment plant.

The concept layout of the treatment plant 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;
- Site grading and drainage;
- Driveways and parking areas;
- Chemical delivery access;
- Chemical storage and feed equipment requirements;
- Provision for power;
- Provisions for stand-by power;
- Adequate shop space and storage;
- Laboratory Facilities; and
- Facility sanitary wastewater disposal requirements.

1.3.2.6 Ancillary Equipment and Infrastructure
In addition to the major treatment process units, the development of a water treatment plant will require consideration of ancillary process such as:
- Type of disinfectant;
- Requirements for alternative disinfectant;
- Types of chemicals required;
- Corrosion control requirements;
- Fluoridation; and
- Waste treatment.

1.3.2.7 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.

1.3.2.8 Site Selection of Water Storage Reservoirs
The top water level and the location of a floating or flow-through water storage reservoir should be selected to result in acceptable service pressure throughout the distribution system under all demand conditions. Acceptable pressures are discussed in Chapter 8 - Transmission and Distribution Systems.

1.3.2.9 Cost Estimates and Financing
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).

In addition, where alternate treatment processes are being evaluated, a net-present-worth 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 utility. Both capital and operating costs should be taken into consideration when conducting the evaluation.

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; and
- Costs of additional evaluations.

The Divisions of the National Master Specification are recommended as 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 (i.e., phone, internet); and
- Ongoing training costs.

1.4 Detailed Design Submissions

The owner or authorized representative must prepare and submit an application and detailed design documents to the regulator for approval. The application should be signed by the owner, or where authorization is provided, a person representing the owner.

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

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

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

- Design brief;
- Design plans;
- Specifications;
- Quantities and cost estimates; and
- Other information as required by the regulator.

1.4.1 Plans

All plans for water works should bear a title showing the name of the owner, the location of the project, the project name, the scale in appropriate units, the north point, date, the name of the engineer, and signed registration seal(s).

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.

Detail 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. Components should include if applicable, but not be limited to:

- Site and key plan;
- Streets or areas to be serviced;
- Areas where the new system will connect to the existing system, and connection details;
- Stream crossings, providing profiles with elevations of the stream bed and the normal and extreme high and low water levels;
- Details of underwater crossings, and methods used to prevent pipe breakage and discharge of chlorinated water into the watercourse, in aerial or underwater crossings;
- Profiles having clearly indicated and appropriate horizontal and vertical scales;
- Location and size of the property to be used for the source water development with respect to known references such as roads, streams, section lines, or streets;
- Topography and arrangement of present or planned wells or structures, with appropriate contour intervals;
- Elevations of the highest known and projected flood level (if applicable), floor of the structure, upper terminal of protective casings and outside surrounding grade, Geodetic elevations, reference;
- Plan and profile drawings of well construction, showing diameter and depth of drill holes, casing and liner diameters and depths, grouting depths, elevations and designation of geological formations, water levels and other details to describe the proposed well completely;
- Location of all existing and potential sources of pollution which may affect the water source or underground treated water storage facilities, including historical land uses to account for abandoned landfills or industrial sites;
- Size, length, and identity of sewers, drains, and watermains, and their locations relative to facility structures;
- Schematic flow diagrams and hydraulic profiles showing the flow through various facility units;
- Piping in sufficient detail to show flow through the facility, including waste lines and floor drains;
- Locations of all chemical storage areas, feeding equipment, points of chemical application, and spill containment details;
- All appurtenances, specific structures, equipment, water treatment plant waste disposal units and points of discharge having any relationship to the plans for watermains and/or water works structures;
- Locations of sanitary or other facilities, such as lavatories, showers, toilets, and lockers;
- Locations, dimensions, and elevations of all proposed plant facilities;
- Locations of all sampling taps, draw-off points, and on-line monitoring;
- Adequate description of any features not otherwise covered by the specifications;
- Architectural drawings;
- Mechanical drawings;
- Electrical drawings;
- P & ID drawings; and
- Miscellaneous details.

1.4.2 Technical Specifications

Complete technical specifications for the construction of impoundment structures, intakes, pumping stations, wells, water treatment plants, 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, 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; and
- Operating tests for the completed works and component units. (It is suggested that these performance tests be conducted at design load conditions wherever practical).

1.4.3 Design Brief

The Design Brief 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 regulator to refer to the pre-design report.

The design brief should present, where applicable, the following information:

1.4.3.1 General Information

General information on:

- Consideration of climate change impacts;
- Existing water works infrastructure;
- Identification of area serviced; and
- Name of owner/utility (contact person, address, telephone).

1.4.3.2 Extent of Water System

The extent of the water works system should include:

- Extent of area to be serviced, Consideration of climate change impacts; and
- Provisions for future extensions.

1.4.3.3 Soil, Groundwater, and Geotechnical Conditions

Soil, groundwater, and geotechnical conditions including a description of:

- The character of the soil through which watermains are to be laid;
- Foundation conditions prevailing at sites of proposed structures;
- The approximate elevation of groundwater in relation to subsurface structures; and
- De-watering provisions if necessary.

1.4.3.4 Water Demands

- A description of the population trends as indicated by available records, and the estimated population which will be served by the proposed water supply system 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; and

- Unusual occurrences and/or major commercial or industrial demands

1.4.3.5 Hydraulic Evaluations of Transmission and Distribution Systems

- Hydraulic analyses based on flow demands and pressure requirements;
- Fire flows, when fire protection is provided by the water supply and distribution system, meeting the recommendations of the Insurance Advisory Organization (IAO) or other similar agency for the service area involved.

1.4.3.6 Sources of Water Supply

Describe the proposed source of water supply to be developed, the reasons for the selection, and provide information as follows:

For surface water sources, include, but not be limited to:

- Climate change considerations;
- Area of watershed;
- Source water surface area and volume;
- Safe and maximum yield;
- Other users of the source;
- Factors that may affect the source;
- Maximum flood level, together with approval for safety features of the spillway and dam from the appropriate reviewing authority;
- Description of the watershed, noting any existing or potential sources of contamination (such as highways, railroads, chemical facilities, agricultural uses) that may affect water quality;
- Summarized quality of the raw water with special reference to fluctuations in quality, changing meteorological conditions, etc.;
- 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; and

For Groundwater sources, include, but not be limited to:

- Climate change considerations;
- Safe and maximum yield for each production well and for the entire wellfield;
- Locations of the production well(s) and monitoring well(s), and elevation of wells with respect to surroundings;
- Probable hydrogeologic character of formations through Hydrogeology of the area in which the source is to be developed;
- Hydrogeologic 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;
- 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.;
- Summary of groundwater exploration, test well depth, and 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;
- Well head completion method (vault, pitless adaptor);
- Wellhead protection measures being considered; and
- Evidence that applicant has approval to withdraw water.

1.4.3.7 Design Criteria for Water Treatment Plants

The design brief for a water treatment plant should confirm that the design criteria used conforms to the requirements of the regulator. It is recommended that the design criteria include, but not be limited to, the following:

- Intake size, type and location;
- 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);
- Filter media specifications;
- Number of filters;
- Filtration area and rate;
- Number of treatment trains;
- Process specific parameters (TOC, colour, turbidity);
- Disinfection process;
- Disinfection equipment redundancy;
- Disinfection by-products formation potential;
- CT values and details;
- Storage allowance or requirements; and
- Backwash requirements:
    - Proposed disposal method;
    - Location;
    - Chemical, physical and biological characteristics;
    - Volume;
    - Applicable discharge regulations;
    - Aluminum background in receiving water;
    - Final disposal; and
    - Possible impact on receiving waters.

1.4.3.8 Automation

Provide a list of instrumentation and automated systems, as well as supporting data outlining automatic equipment, and the overall operations strategy for the facility. Note that manual override and alarms must be provided for any automatic controls.

1.4.3.9 Requirements for Operation during Construction

Where applicable, the submission should contain a program for keeping the existing water works facilities in operation during construction of additional facilities so as 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 should be prepared and submitted for approval to the regulator.

1.4.4 Review of Design Submission

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

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 agencies. The plans, specifications and supporting documentation should be stamped with the seal and signature of a Professional Engineer that is licensed to practice in the Province of application. The application should be signed by the owner, or where authorization is provided, a person representing the owner.

The regulator should review the application to determine if it conforms with policies, standards, regulations, or guidelines. During the review of the application, the regulatory agency may request oral or additional written information on the project. If requested information is not received, the regulator may declare the application incomplete, and advise the applicant of such.

1.5 Approval/Permit to Construct

An “Approval/Permit to Construct” should be issued by the regulator after the design application has been reviewed and found to be satisfactory. **The proposed works should not be undertaken by the proponent until the official "Permit/Approval to Construct” has been issued.**

The Approval/Permit will provide the owner with the authority to proceed with construction of the particular project.

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

1.6 Post Construction Report/Certificate of Compliance

A "Post-Construction Report/Certificate of Compliance" should be provided at the completion of the project. The report should contain all information regarding major changes, if any, from the approved plans or specification made during construction. These major changes include any deviations, which affect capacity, flow or operation of units.

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 water treatment plant 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 requirements;
- Confirmation that the plant and its’ components, watermains, and reservoirs have been properly disinfected prior to being placed in use;
- Confirmation that a cross-connection survey has been performed and cross connections have not been found;
- Confirmation that all components and chemicals are NSF compliant;
- Indication that as-built drawings, operation and maintenance manuals, and any other relevant documentation have been provided to the owner/operator and/or other body if required by the regulatory

agency; and

- Confirmation that operator certification is consistent with provincial requirements.

In the event that specific information cannot be confirmed when the report is proposed, a plan outlining the time frame to comply should be submitted.

1.7 Approval/Permit to Operate

When applicable, the regulator should provide an “Approval/Permit to Operate" or equivalent document.

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

The expiry date of the approval/permit and the terms for renewal should be indicated by the regulatory agency.

1.8 Monitoring and Recording Requirements

Monitoring and recording requirements by the applicant would be outlined, as applicable, by the regulator in the Approval/Permit to Operate.

The monitoring program should be carried out in compliance with sampling and analysis requirements outlined in the “Approval/Permit to Operate”.

Any monitoring carried out by a regulatory agency does not relieve the system owner of their responsibility related to this function. The system owner maintain responsibility for all aspects of the system.

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 and Operator Certification

Some provinces have adopted regulations that make 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 regulator should be consulted regarding specific requirements.

1.11 Owner Responsibility

The 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/Permit to Operate”.

In provinces that do not have mandatory facility classification and operator certification, 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 Regulator Responsibility

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

Chapter 2 Incorporating Climate Change in the Design of Drinking Water Infrastructure 28

2.1 Introduction to Climate Change Adaptation in this Guideline 28

2.2 Scope of Climate Change Adaptation in this Guideline..29

2.3 Climate Change Projections for Use by Practitioners..29

2.3.1 Global and Regional Climate Models 30

2.3.2 Use of Global and Regional Climate Models in Design and Adaptation Planning............31

2.3.3 Updates and Climate Data Evolution 31

2.3.4 Managing Uncertainty in Climate Change Data 32

2.4 Global and National Climate Change Trends...33

2.5 Projected Climate Change in Atlantic Canada 35

2.5.1 Temperature...36

2.5.2 Precipitation 37

2.5.3 Sea Level Rise 38

2.5.4 Storm Activity 39

2.6 Climate Change Impacts on Drinking Water Infrastructure Design 39

2.6.1 Altered Precipitation Quantity, Form, and Timing 40

2.6.2 Changes to Seasonal Water Flow Patterns 41

2.6.3 Warmer Surface Water Temperatures...41

2.6.4 Rising Sea Levels 41

2.6.5 Impact on Groundwater Resources 42

2.6.6 Incidence of Drought 42

2.6.7 Water Quality 43

2.6.8 Design Philosophy to Incorporating Climate Change Impacts 43

2.6.9 Defining Extreme Events 44

2.7 Identifying Climate Risks to Drinking Water Infrastructure 44

2.8 Adaptation to Climate Change in Drinking Water Infrastructure 51

2.8.1 Adaptation Strategies...51

2.8.2 Specific Adaptation Examples 52

2.8.2.1 Water Collection Adaptations 52

2.8.2.2 Increase Reservoir Capacity 53

2.8.2.3 Adaptation to Drought 53

2.8.2.4 Water Intake Relocation... 53

2.8.2.5 Assessment of Water Sources and Ecosystem Protection Adaptations 53

2.8.2.6 Higher Loads of Organic Matter 54

2.8.2.7 Water Distribution Adaptations ... 54
2.9 Key Climate Change Indices and Parameters for Consideration ... 54
2.10 Sources of Climate Data ... 55
2.10.1 Climate Risk Atlas of Canada ... 55
2.10.2 Canadian Centre for Climate Modelling and Analysis ... 56
2.10.3 The Intergovernmental Panel on Climate Change (IPCC) ... 56
2.10.4 Canadian Institute for Catastrophic Loss Reduction ... 57
2.10.5 Canadian Extreme Water Level Adaptation Tool (CAN-EWLAT) ... 57
2.11 References ... 58

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

2.1 Introduction to Climate Change Adaptation in this Guideline

Understanding climate change and its impacts on drinking water infrastructure has become an important and necessary consideration for utilities in the Atlantic Region of Canada. The topic of climate change itself is complex, let alone within the context of planning, designing and operating drinking water infrastructure. Utilities are anticipated to encounter both challenges and opportunities related to addressing the impacts of projected future climate change. It is anticipated that impacts from climate change will vary widely across the Atlantic Region due to the size and diversity of the region. There are also significant regional economic and demographic differences, where every utility has its own unique set of priorities and finite resources. As such, when one combines these factors, it becomes evident that each region within Atlantic Canada will be impacted by climate change differently.

Defining Climate Change

The Intergovernmental Panel on Climate Change (IPCC) defines climate change as “a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes, or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.”

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.”

Historical and projected trends point to the need for Atlantic Canada to adapt its existing and future drinking water infrastructure in order to minimize the social and economic costs associated with severe weather and longer term climate change trends. This guideline will specifically focus on adaptation, where the information contained within this guideline is intended to assist in the development of adaptation strategies during the planning, design and operational stages for a utility in the drinking water sector.

Note: This guideline document will focus on climate change adaptation instead of climate change mitigation. Climate change mitigation is an approach to reduce the human-induced greenhouse gas emissions that are released into the atmosphere and limit the extent of future climate change. Where possible, the guideline will identify opportunities to reduce energy consumption and demand in drinking water operations to limit human-induced greenhouse gas emissions. In general, utilities should seek opportunities to reduce energy use and consumption, as it can be both economical and serve to limit future climate change impacts.

Given regional differences in Atlantic Canada, there is limited value in presenting detailed site-specific climate change parameters, indices, and adaption design processes in this guideline. Instead, this guideline aims 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.

Within this context, it is important to recognize that improvements in the scientific community's understanding of our changing climate is ongoing. The capacity of powerful computational models and scientific methods to represent multiple climate and ocean processes has significantly improved since the early 2000s. As models continue to resolve a higher number of processes more accurately; new datasets, better post-processing of climate projections, and new data portals will become available. It is encouraged for practitioners using this guideline to maintain awareness of evolution in climate data and science, and if possible, regularly review newly distributed climate change data. Practitioners are encouraged to regularly engage with climate change scientists or professionals, and to collaborate with such experts when responding to new risks and opportunities during the adaptation planning process, from preliminary stages through to operations.

2.2 Scope of Climate Change Adaptation in this Guideline

The guidelines serves as a foundational introduction to climate change adaptation for drinking water utilities in Atlantic Canada. Adaptation planning is not a new for utilities, and should not be considered a separate effort from day-to-day operations. Adaptation strategies that provide multiple benefits can be integrated into current asset management, permit compliance, emergency response planning, capacity development and other decision-making processes at utilities (EPA, 2015). It is important to consider many different options to develop a comprehensive adaptation plan that satisfies the utility needs without overstretching resources. In many cases, adaptation options can also address issues related to budget, aging infrastructure and other concerns, in addition to providing greater resilience to climate impacts. As such, climate change adaptation strategies may provide benefits such as more sustainable and efficient operations, cost savings, maintenance of adequate water supply and quality and the reduction of greenhouse gas emissions.

Adaptation: refers to initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist such as, anticipatory and reactive, private and public, and autonomous and planned, to name a few (ICLR, 2012).

Climate and weather of Atlantic Canada vary spatially (across regions) and temporally (from one season to the other). Significant socioeconomic differences exist across the region. Some communities have more capacity to adapt to the impact of climate change, whereas other communities have less diversified economies, limited economic resources and limited access to services. The design, materials, size and maintenance of infrastructure systems can reflect these differences between communities and, as a result, different communities can be affected differently by climate change (J. Boyle, M. Cunningham, J. Dekens, 2013). It is therefore important to recognize that each community will develop a climate adaptation strategy for its drinking water infrastructure which is uniquely suited to the needs, resources and environment in which it operates.

The ensuing sections will highlight the linkages between changing climate and the planning, design and operations of infrastructure managed by drinking water utilities. Each section in the chapter will build on prior sections to deliver a comprehensive overview for the strategies available to planners, designers and regulators to gather climate change information, assess impacts and risks, and to implement effective adaptation planning. Throughout the guideline, 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 drinking water facility.

2.3 Climate Change Projections for Use by Practitioners

To use climate change projections, practitioners should understand where climate data comes from, what general assumptions are made in generating this data, and for what application(s) the data is valid. This section aims to provide the users of this guideline with a brief background in how climate data is generated, and the difference between outputs such as a climate parameter, and index. In particular, users should understand the uncertainties which are associated with climate data, and how to manage the rapidly evolving availability of climate change data for planning, design and operations of drinking water infrastructure.

2.3.1 Global and Regional Climate Models

Future climate change projections and trends are typically determined using climate models. Climate models divide the earth into small grid cells, which vary in size. Within each of these grid cells a series of equations are resolved to simulate atmospheric, oceanic, and other physical processes. Each of the grid cells in the model are linked to one another, and together they create a model domain, or geographic area. There are over thirty (30) Global Climate Models (GCMs) which are owned by leading scientific institutions around the world. These models require significant computing power to simulation future global climate scenarios using greenhouse gas (GHG) emission scenarios as their inputs. Emission scenarios represent possible GHG emission patterns over the 21st century from anthropogenic emission sources. These scenarios represent different futures based on the amount of GHG emitted globally, and account for shifting patterns in global population, future technology, alternative energies, policies, and conflict(s). There are currently four industry standard scenarios, called Representative Concentration Pathways (RCP), that have been established by the Intergovernmental Panel on Climate Change (IPCC). These are commonly known as:

- **RCP 2.6** - Assumes that GHG emissions stay consistent until 2020 when they begin to decline until 2100, where average global warming is limited to approximately ~2.0 °C in this time period.
- **RCP 4.5** – A future with relatively ambitious emissions reductions where CO2 emissions increase only slightly before a decline commences around 2040, where average global warming is limited to approximately ~2.4 °C by 2100.
- **RCP 6.0** - A future where CO2 emissions stabilize, where average global warming is limited to approximately ~2.8 °C by 2100.
- **RCP 8.5** – A future with no implementation of policy changes to reduce emissions, and thus increasing GHG emissions in to the future, where average global warming is anticipated to increase by ~4.3 °C by 2100.

All global climate model projections can suffer from so-called 'systematic biases' when they are used to analyze local-scale climates. Moreover, GCM datasets are generally calculated at fairly coarse spatial resolutions (>1° lat/lon, or more than 100 km x 100 km in southern Canada) that further impacts the value of the original GCM data for studying local climate changes. Therefore, to improve the utility of GCM projections for local-scale analyses of climate change, scientists employ various types of systematic bias-correction and spatial downscaling techniques (CAoC, 2019).

Generally, bias correction and downscaling are done at the same time. Bias correction/downscaling comes in two flavours: dynamic and statistical. The purpose of both types is to remove systematic bias within the data, as much as possible, and to convert the coarse-resolution GCM data into higher-resolution data (with data points closer together than in the original model output).

Global Climate Model (GCM) outputs can be focused onto smaller areas by using a process referred to as "downscaling". This is the methodology applied in the **Canadian Climate Atlas**, a publically available web-tool which provides regionally downscaled climate data for practitioners and decisions makers across Canada.

Regional Climate Model (RCM) output in Canada, is can be extracted from the Canadian model, **CanRCM4**, which is driven by global climate models. Data can be extracted from the **Canadian Centre for Climate Modelling and Analysis.**

Note: It is recommended to adopt RCP 4.5 and RCP 8.5 scenarios when assessing climate change risks and impacts. More than one emission scenario is often used to cover the uncertainty related to the future path that the humanity will take to manage emissions.

2.3.2 Use of Global and Regional Climate Models in Design and Adaptation Planning

Global and regional climate models are often limited in both their computational and theoretical ability to capture the complexity of the climate system. Therefore, they must use a large number of approximations. Further, climate models are subject to variability and uncertainty that can result in overestimates or underestimates of predicted values based on the numerical methods in the equations or the model resolution. The use of a single model solution can be considered as one possible future while the median of many models' solutions is considered to be the most unbiased representation of the future. This approach for managing model uncertainty and variability is called ensemble modeling.

The decision to use data from either GCMs, RCMs, downscaled data from GCMs, or a combination of these sources, should be made in consultation with a trained climate scientist or professional knowledgeable in the field of climate change data. Significant differences may exist in the data generated by the methods listed, let alone the ensemble of models selected for the analysis, and therefore the implications in choosing data sources can result in meaningful impacts in the design and decision making processes. As a starting point it is recommended to consult carefully curated tools and methods publically available through the Canadian Centre for Climate Modelling and Analysis and the Canadian Climate Atlas.

Note: Certain climate phenomena are not well captured by climate models. Examples include: lightning, freezing rain, wind gusts, hurricane, tornado, blizzard, acid rain, shortwave (UV) radiation, and air quality. In this case, it is recommended to consider how the factors that affect these phenomena are changing. Such an assessment should be completed by a climate scientists or experts familiar with studying climate trends and correlations.

Typically, the outputs of GCMs and RCMs include standard climate parameters like temperature, precipitation, humidity, snow, and wind. Indices are calculated from these parameters to provide detailed and meaningful projections that can be used by decision-makers. The terms climate parameter and index have different interpretations in climate science and impact science. For the purposes of this manual, the definitions of climate parameter and index will be characterized by:

Parameter: Influence the properties of a climate system and refers to direct measurement or climate model outputs such as temperature, pressure or precipitation.

Index: A calculated value that can be used to describe the state and the changes in the climate system, for example, the number of summer days and tropical nights, or the maximum length of a wet spell.

There are many types of indices which can be generated from climate parameters, a range of values (i.e. daily temperature ranges), threshold-based parameters, and minimum and maximum parameters such as the length of dry or wet spells. Some indices require a combination of parameters, such as humidity which involves both precipitation and temperature. Users of this guideline should consider whether they are seeking a climate parameter, or index extrapolated from climate parameters.

2.3.3 Updates and Climate Data Evolution

Climate science is an evolving discipline, where new data, models and projections are regularly published. As these data become available, the projections adopted by a utility in its design or planning process should not be presumed outdated. Uncertainties in climate data, such as GHG emission trends, are evolving. For this reason, it is worthwhile to monitor new projections and compare them to those used in a design, adaptation planning, or operational plans. If new projections differ substantially from prior projections, it may be warranted to revisit a project climate risk assessment or adaptive capacity assessment of infrastructure, policies, or programs.

Some impact and risk assessments do not directly apply precise climate information; rather interpret and act on trends which are less likely to change drastically. For this reason, regular maintenance checks of the projections are a good practice, particularly when a new RCP is established, or a climate framework is updated by the global scientific community.

Note: A schedule can be created to evaluate updates to climate change data, as it pertains to critical aspects of existing operations; or rather proactively when the data is required for a new project or decision making process.

2.3.4 Managing Uncertainty in Climate Change Data

A great deal of uncertainty surrounds the timing, nature, direction and magnitude of localized climate impacts. It can be a challenge for utilities to navigate such uncertainty when working to address climate change impacts in planning, design and operations of drinking water infrastructure. In particular, it may be difficult to balance climate-related action with current obligations, which requires maintaining service affordability while developing the financial, managerial and technical capacity to meet future needs (EPA, 2015).

While reviewing, compiling or using climate data, practitioners and users of this guidelines should be acutely aware that there are many sources of uncertainty within available climate data. Examples include, but are not necessarily limited to natural variability, scenario uncertainty, and scientific uncertainty attributed to varying future scenarios of greenhouse gas emissions and the imperfect capacity of global climate models. Uncertainty related to natural variability is significant in the short term whereas predictions associated with each emission scenario diverge over the long term, lessening the significance of uncertainty associated with natural variability. Therefore, the relevance of each source of uncertainty depends on the time horizon of interest, and the relative significance of these sources of uncertainty changes with the expected remaining useful life of a policy, program, or asset.

Based on scientific analysis of climate model projections, the IPCC assessed the likelihood of future trends in climate extremes and concluded that globally "*It is very likely that hot extremes, heat waves and heavy precipitation events will become more frequent*" (Solomon et al., 2007). While it is not possible to state with exact certainty how or when climatic conditions will change in the decades to come in Atlantic Canada, it is projected that there will be continued "*increases in the occurrence of heat waves, forest fires, storm-surge flooding, coastal erosion, and other climate-related hazards*" in Atlantic Canada, according to Natural Resources Canada (2007). These regional Atlantic Canada trends and associated levels of uncertainty are consistent with global climate trends.

A table below summarizes the likelihood of future trends for climate extremes in Canada, as per the Institute for Catastrophic Loss Reduction (ICLR, 2012). In this table the user of this guideline can gain a better appreciation of the certainty or uncertainty associated with various projected climate indices and parameters for extreme weather and climate events.

Phenomenon and Direction of Trend	Likelihood that trend occurred in 20th Century (Typically Post-1960)	Likelihood of Future Trends for the 21st Century Based on Projections using IPCC Scenarios
Warmer and fewer cold days and nights over most land areas	Very likely	Virtually Certain
Warmer and more frequent hot days and nights over most land areas	Very likely	Virtually Certain

Warmer spells / heat waves: frequency increases over most land areas	Likely	Very likely
Heavy precipitation events: frequency increases over most areas	Likely	Very likely
Area affected by drought increases	Likely in some regions since 1970s	Likely
Increased incidence of extreme high sea level (excludes tsunamis)	Likely	Likely

Notes: Changes in frequency of coldest and hottest days and nights refer to the coldest or hottest 10%. Extreme high sea level depends on average sea level and on regional weather systems. It is defined here as the highest 1% of hourly values of observed sea level at a station for a given reference period. Changes in observed extreme high sea level closely follow the changes in average sea level.

Models will continue to improve over time, especially as computational capabilities are advanced. However, there is always some uncertainty that is “irreducible”. Some models favor certain processes over others, and therefore the models themselves are a source of uncertainty. Using an ensemble of climate models, is one of the best ways to mitigate the uncertainty in climate projections. This uncertainty is then framed within the presentation of the data plots and graphs, for decision makers to consider when using the climate projections. As previously advised, these data plots and graphs which incorporate uncertainty should be interpreted by a professional trained in climate science and adaptation within the context of infrastructure planning, design and operations.

Note: Managing uncertainty over a broad range of projections is recommended. To implement this into practice, a risk assessment can be used. Such an assessment provides context over the full range of climate projections and assists in determining what future scenario is appropriate for further application(s) such as adaptation planning, resilience assessments, design standards, environmental assessments and long range planning.

Uncertainty should not prevent drinking water utilities from taking action now with regards to potential climate change impacts. For some utilities, it is not an option to wait and see or take no action. In fact, the cost of inaction may be greatly underestimated and can be offset by taking preventative action today. Building climate considerations into everyday utility decision making is a current necessity because utility investments are often capital intensive, long-lived and can require long lead times to ensure system reliability and maintenance of desired service levels.

2.4 Global and National Climate Change Trends

It has been widely demonstrated and acknowledged that anthropogenic-induced Green House Gas (GHG) emissions are the primary factor contributing to global increases in average temperatures (Bush & Lemmen, 2019). Figure 1 depicts the changes of global mean temperature and carbon dioxide emissions (as the main anthropogenic source of global warming) from 1880 to 2017 (NASA GISS, NOAA NCEI, ESRL). Based on this and other analyses, the IPCC in its 2007 full assessment concluded that the “warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.”(Solomon et al 2007).

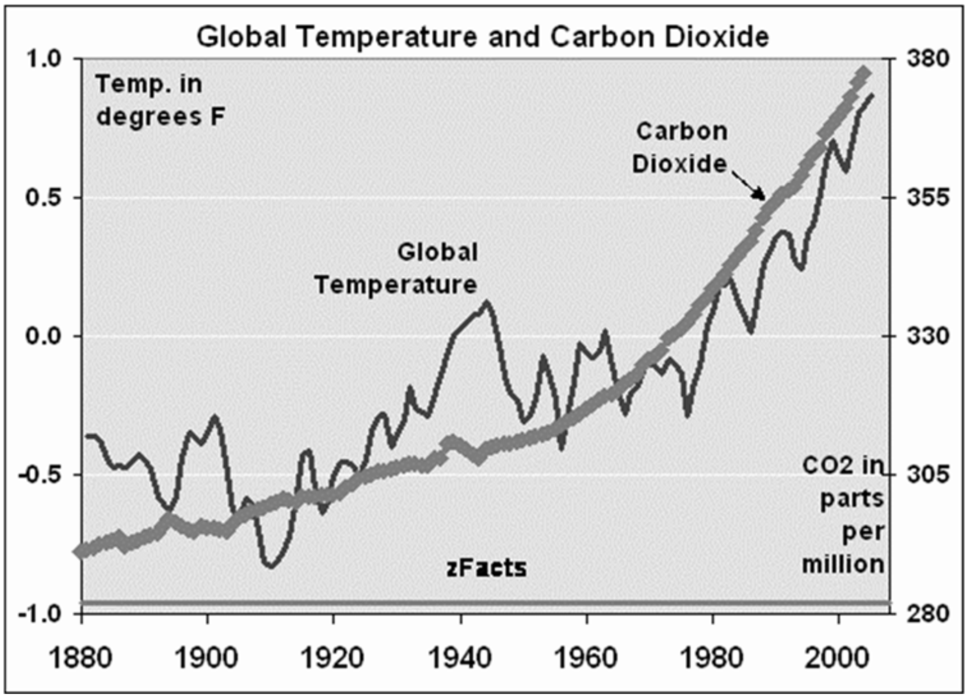


Figure 2.1. Global temperature and Carbon Dioxide during 1880-2010

In the general, the following global trends are widely accepted and anticipated:

- **Temperature**: One of the key factor driving climate change, and subsequent other climatic variables (e.g. precipitation, humidity, snow, wind etc.), is projected to increase globally by 3.7°±1°C by the end of 21st century.
- **Precipitation**: Increases in atmospheric temperature results in more moisture holding capacity (about 7% per each degree Celsius of warming), and consequently results in greater rates of rainfall (i.e. extreme rainfall) (Attema, Loriaux, & Lenderink, 2010; Bush & Lemmen, 2019).

Although more extreme rainfall is projected globally, It does not necessarily mean more flooding in that flooding is a complex system that is dependent on more factors than only rainfall (Sharma, Wasko, & Lettenmaier, 2018). Global temperature increase can also result in longer growing season length, more warm nights and heat waves as well as slightly fewer frost days (Bush & Lemmen, 2019). On the other hand, global warming leads to increase in the number of dry days; however, it does not necessarily mean longer and more frequent droughts because of the same complexity associated with flooding (Bush & Lemmen, 2019).

Relative to global trends, Canada is, on average, warming at twice the global rate (Bush & Lemmen, 2019). Canada's vast land coverage and wide variety of climates also means that climate changes at varying rates across the country. For example, some impacts from climate change are more pronounced in northern latitudes, relative to Canada's more populated regions along its southern latitudes. The observed temperature changes over Canada between 1948 and 2016 show a statistically significant increase of 1.7°C Canada-wide and 2.3°C over Northern Canada (Bush, E.; Lemmen, 2019). This spatial variance of climate projections even exists in Atlantic Canada, and must therefore be carefully considered by designers, regulators and operators.

Seasonal temperature has been increasing across Canada for all seasons, although winter has experienced the highest rates of warming, specifically in Northern Canada (Bush, E.; Lemmen, 2019; Li et al., 2018a). Canadian average temperature (over all seasons) is projected to keep increasing to more than 6°C by the end of 2100

(Kharin et al., 2013; Li et al., 2018b; Bush & Lemmen, 2019). That would bring longer growing season and more cooling degree-days[1] as well as fewer heating degree-days[2]. In other words, warm events are projected to become warmer and cold events, less cold (Bush & Lemmen, 2019). Moreover, the Atlantic Ocean Temperature has been increasing for the last century and is projected to continue increasing, where again, winter has the greatest rate of ocean temperature increase (Abeysirigunawardena, Smith, & Taylor, 2011; Agilan, Resources, & 2017, n.d.; Agilan & Umamahesh, 2017; Bush, E.; Lemmen, 2019).

The observed temperature increase in Canada has the causal effect of early springs, projected to start between 0.6-1.6 weeks earlier per decade (depends on the locations) throughout 21st century. Furthermore, summer time is projected to extend by as much as 2 weeks per decade until late 21st century (Bush & Lemmen, 2019).

Average annual precipitation varies across Canada from 200mm in the far north to 3000mm on the west coast. Annual mean precipitation has also been increasing in Canada (larger increase over Northern Canada), and is projected to continue increasing during the 21st century t, with the exception of summers where mean precipitation is projected to decrease (specifically over Southern Canada) (Li et al., 2018b; Vincent, Zhang, Mekis, Wan, & Bush, 2018). As noted previously, the frequency and intensity of extreme precipitation is projected to increase over the entire Canada (Bush, E.; Lemmen, 2019; Li et al., 2018a).

Although snow cover is a complex hydroclimatic variable and needs multiple variables to be taken into consideration (Bush & Lemmen, 2019), observations over the past 34 years (1981-2015) have detected a decrease across all of Canada by 5% to 10% across seasons(Brown & Braaten, 1998; Mudryk et al., 2018). Temperature increases are projected with a high level of confidence, and therefore a decrease in overall national snow cover is also highly likely throughout the entire year (winter has the largest decrease notably for southern Canada). On the other hand, maximum seasonal snow water equivalent, which is a measurement of snowpack and defined as the amount of water contained in a snowpack, is projected to decrease cumulatively by 15% to 30% of the baseline over 2020 to 2050; noted that Atlantic Canada and British Columbia are projected to have the greatest decrease in snow water equivalent (Mudryk et al., 2018; Sospedra-Alfonso & Merryfield, 2017).

Sea Ice Concentration's (SIC) data during 1981-2015 found SIC reduction over Canadian waters throughout the entire seasons (noted that SIC is strongly associated with temperature), with greatest reduction over eastern Canadian waters in winter and spring at a rate of 8% per decade. Due to the strong dependence between temperature and SIC and increase temperature projection, SIC is projected to continue decreasing over entire Canadian waters, notably the Maritimes in winters (Mudryk et al., 2018), as demonstrated by the decreasing ice-pack in the Gulf of Saint Lawrence along the PEI and New Brunswick coastline

2.5 Projected Climate Change in Atlantic Canada

To indicate the magnitude of changes expected across the Atlantic Region of Canada, the Climate Atlas of Canada (CAC, 2019) published in July 2019 may be consulted. It is anticipated that the Atlas will be updated regularly in the coming years. For the most recent and up-to-date information and data, readers of this manual are referred to the CAR data portal directly.

The Climate Atlas of Canada used 24 statistically downscaled (Bias Correction with Constructed Analogues and Quantile mapping, Version 2; BCCAQv2) Global Climate Models (daily data with spatial resolution of 10*10 km)

[1] An index to measure the need of cooling the buildings

[2] An index to measure the need of heating the buildings

under Representative Concentration Pathways (RCP hereafter) 4.5 and 8.5 (which show the medium and high emission scenarios, respectively).

2.5.1 Temperature

According to CAR, Nova Scotia (NS) is the warmest province of Atlantic Canada with annual average temperature of 6.4°C during 1976-2005 (the baseline) followed by Prince Edward Island (PEI) with 5.9°C, New Brunswick (NB) with 4.5°C and Newfoundland and Labrador (NL) with -1°, respectively. Annual average temperature is projected to increase by 4.3°C (±1.45) in NB, 4.3°C (±1.75) in NL, 3.8°C (±1.5) in NS and 4.2°C (±1.55) in PEI by 2080s under RCP8.5, respectively. The projections show that it is very likely (more than 50% probability) that winter average temperature of NS become above 0°C by 2080s under RCP8.5 (table 1), which results in potential earlier and higher rate of snow melting.

Table 2.1. Historical and projected (10th percentile) median (90th percentile) temperature (°C) of Atlantic Canada

		New Brunswick			Newfoundland & Labrador		
		1976-2005	2021-2050	2051-2080	1976-2005	2021-2050	2051-2080
Temperature	Annual	**4.5**	(5.4) **6.6** (7.9)	(7.4) **8.8** (10.3)	**-1**	(-0.2) **1.1** (2.5)	(1.6) **3.3** (5.1)
	Spring	**2.9**	(2.9) **4.8** (6.9)	(4.6) **6.8** (9.2)	**-3.5**	(-3.7) **-1.7** (0.5)	(-2.1) **0.2** (3)
	Summer	**1.7**	(17.5) **19** (20.4)	(19.3) **21.2** (23)	**11.4**	(11.6) **13.2** (14.7)	(13.2) **15.1** (17.1)
	Fall	**6.7**	(7.2) **8.7** (10.3)	(9) **10.7** (12.4)	**2**	(2.5) **3.9** (5.3)	(4.1) **5.8** (7.5)
	Winter	**-8.8**	(-8.8) **-6.4** (-3.9)	(-6.2) **-3.8** (-1.5)	**-14**	(-13.7) **-11.1** (-8.2)	(-11) **-8.1** (-5.4)

		Nova Scotia			Prince Edward Island		
		1976-2005	2021-2050	2051-2080	1976-2005	2021-2050	2051-2080
Temperature	Annual	**6.4**	(7.1) **8.2** (9.6)	(8.8) **10.2** (11.8)	**5.9**	(6.7) **8** (9.4)	(8.6) **10.1** (11.7)
	Spring	**3.8**	(3.8) **5.5** (7.4)	(5.4) **7.4** (9.5)	**3.1**	(3) **4.9** (7)	(4.9) **6.9** (9.2)
	Summer	**16.7**	(17.1) **18.6** (20.1)	(18.8) **20.6** (22.6)	**17.4**	(17.7) **19.3** (21)	(19.5) **21.5** (23.6)
	Fall	**8.9**	(9.3) **10.8** (12.3)	(11) **12.7** (14.3)	**8.7**	(9.1) **10.6** (12.3)	(10.9) **12.6** (14.3)
	Winter	**-4.1**	(-4.1) **-2.1** (0.1)	(-2.1) **0.1** (2.2)	**-5.7**	(-5.7) **-3.4** (-1)	(-3.4) **-1** (1.2)

Aside from the intensity of extreme events, the frequency of extreme events is projected to increase in Atlantic Canada. The number of tropical nights, which is defined as the annual number of days whose minimum temperature is more than 20°C, has been a rare event in Atlantic Canada that almost never happened in NS, NL and NB. However, the number of tropical nights is projected to increase significantly (except NL) so that PEI is projected to have 22 tropical nights (±17) followed by NS and NB with 11 nights (±11 and ±10) and NL with only 1.5 nights (±1.5) by 2080s, respectively. On the other hand, the number of extremely hot days, which is defined as number of days whose average temperature is more than 30°C, is projected to increase in Atlantic Canada.

NB, as the province with the most number of extremely hot days (5 days a year) during the baseline, is projected to have 30 (±15) extremely hot days by 2080s, while PEI and NS have experienced 1 extremely hot day annually over the baseline and they are projected to experience 21 (±17) and 16(±13) days by 2080s, respectively. However, the trend of extreme event frequency in NL, with no extremely hot days during baseline, is not as fast as other provinces of Atlantic Canada and NL is projected to have 3(±3) extremely hot days a year by 2080s (table 3).

Table 2.2. Historical and projected (10th percentile) median (90th percentile) tropical nights, extremely hot and cold days of Atlantic Canada

	New Brunswick			Newfoundland & Labrador		
	1976-2005	2021-2050	2051-2080	1976-2005	2021-2050	2051-2080
Tropical night	**0**	(0) **2** (6)	(3) **11** (23)	**0**	(0) **0** (1)	(0) **1** (3)
Number of days which T>30	**5**	(5) **13** (23)	(14) **30** (49)	**0**	(0) **1** (3)	(1) **3** (7)
Number of days which T< -30	**2**	(0) **0** (2)	(0) **0** (0)	**12**	(1) **4** (9)	(0) **1** (3)

	Nova Scotia			Prince Edward Island		
	1976-2005	2021-2050	2051-2080	1976-2005	2021-2050	2051-2080
Tropical night	**0**	(0) **2** (7)	(2) **11** (25)	**1**	(1) **6** (14)	(7) **22** (42)
Number of days which T>30	**1**	(1) **5** (12)	(5) **16** (32)	**1**	(1) **7** (15)	(6) **21** (40)
Number of days which T< -30	**0**	(0) **0** (0)	(0) **0** (0)	**0**	(0) **0** (0)	(0) **0** (0)

Furthermore, timing of the first and last frost of the year is affected by climate change. All Atlantic Provinces except NL have their last frost of spring by the second week of May, while it is projected that the last spring frost will happen 3 weeks earlier (mid-April). NL usually has its last spring frost on the first week of June and it is projected that the last spring frost will happen 3 weeks earlier by 2080s. on the other hand, the first Fall frost that usually occur in the last week of September for NB and NL and the third week of October for NS and PEI, is projected to be delayed for 3 to 4 weeks in Atlantic Canada by 2080s.

2.5.2 Precipitation

Precipitation has been on the rise in Atlantic Canada. For example, winter events of greater than 10 mm precipitation have increased in St. John's (ICLR, 2012). Looking past 2050, overall changes in precipitation will not be large, with Newfoundland projected to see about a 10% increase in the winter by 2050, while other Atlantic provinces are expected to experience precipitation changes in the 0–10% range. There will be a reduction in snow to a total precipitation ratio of about 10%. Summertime precipitation changes will be generally smaller at 0–5%, with the possibility of decreases in New Brunswick and Prince Edward Island (ICLR, 2012).

The higher temperature projection will technically result in higher humidity and consequently more precipitation. However, the variability in precipitation projection is high. NS is the most precipitated province of Atlantic Canada with average total precipitation of 1328 mm per year during 1976-2005 followed by NB with 1106 mm, PEI with 1089 mm and NL with 937 mm, respectively. The average annual total precipitation is projected to increase by 126mm (±190) in NB, 132mm (±111) in NL, 121mm (±214) in NS and 105mm (±175) in PEI by 2080s under RCP8.5, respectively.

Table 2.3 Historical and projected (10th percentile) median (90th percentile) Precipitation (mm) of Atlantic Canada

	New Brunswick			Newfoundland & Labrador		
	1976-2005	2021-2050	2051-2080	1976-2005	2021-2050	2051-2080

precipitation	Annual	**1106**	(1005) **1178** (1350)	(1054) **1232** (1433)	**937**	(916) **1014** (1118)	(961) **1069** (1183)
	Spring	**262**	(202) **281** (365)	(217) **301** (391)	**194**	(169) **212** (259)	(181) **227** (275)
	Summer	**272**	(211) **288** (369)	(202) **293** (392)	**263**	(237) **279** (323)	(244) **290** (338)
	Fall	**294**	(214) **303** (404)	(218) **312** (417)	**255**	(222) **273** (322)	(231) **284** (339)
	Winter	**278**	(220) **306** (390)	(234) **327** (429)	**225**	(198) **250** (306)	(206) **269** (334)

		Nova Scotia			Prince Edward Island		
		1976-2005	2021-2050	2051-2080	1976-2005	2021-2050	2051-2080
precipitation	Annual	**1328**	(1207) **1398** (1605)	(1240) **1449** (1668)	**1089**	(980) **1147** (1330)	(1024) **1194** (1375)
	Spring	**315**	(248) **338** (440)	(250) **353** (459)	**253**	(193) **271** (356)	(203) **286** (375)
	Summer	**266**	(194) **279** (378)	(186) **285** (409)	**239**	(175) **249** (339)	(172) **258** (355)
	Fall	**364**	(263) **372** (482)	(271) **380** (498)	**306**	(219) **312** (418)	(221) **317** (425)
	Winter	**382**	(311) **410** (513)	(326) **431** (551)	**292**	(237) **316** (399)	(250) **333** (425)

Another concern is the projection that the occurrence of freezing rain events in Newfoundland will increase by 50%, with a smaller increase of about 20% projected for the Nova Scotia, New Brunswick and Prince Edward Island areas (ICLR, 2012).

2.5.3 Sea Level Rise

Globally, sea level has risen as demonstrated by very long term tide gauge records, such as the tide gauge installed in the Halifax Harbour. Sea level is projected to continue to rise, where the rate of sea level rise is also expected to increase. Confidence in the projected amount of global sea-level rise is relatively high and may exceed one metre by 2100. However, relative sea level in different parts of Canada is projected to rise or fall, depending on local vertical land motion. Due to land subsidence, parts of Atlantic Canada are projected to experience relative sea-level change higher than the global average during the coming century (Greenan, B.J.W. et al, 2018).

Where relative sea level is projected to rise (most of the Atlantic and Pacific coasts and the Beaufort coast in the Arctic), the frequency and magnitude of extreme high water-level events will increase (high confidence). This will result in increased flooding, which is expected to lead to infrastructure and ecosystem damage as well as coastline erosion, putting communities at risk. Adaptation actions need to be tailored to local projections of relative sea-level change.

Extreme high water-level events are expected to become larger and occur more often in areas where, and in seasons when, there is increased open water along Canada's Arctic and Atlantic coasts, as a result of declining sea ice cover, leading to increased wave action and larger storm surges (high confidence).

Table 2.4 Projected global sea-level rise by 2100 (Atkinson et al., 2016)

Emission scenario	*Likely* global sea-level rise by 2100 (cm), median [90% uncertainty range][1]
Low (RCP2.6)	**44** [28 to 61]
Medium (RCP4.5)	**53** [36 to 71]
High (RCP8.5)	**74** [52 to 98]
High (RCP8.5 – Atlantic Canada)	**87** [75 to 100]

James et al. (2014, 2015), Lemmen et al (2016).	

[1] Relative to 1986–2005.
[2] Scenario is indicative, so percentile values (uncertainty range) are not provided.

Note: The Canadian Extreme Water Level Adaptation Tool (CAN-EWLAT) is a science-based planning tool for climate change adaptation of coastal infrastructure related to future water-level extremes and changes in wave climate.

2.5.4 Storm Activity

It is anticipated that by 2050, intense precipitation will increase such that events now having a 20-year return period will occur about every 10 to 15 years, with the metric for Newfoundland being closer to 10 years. Given the impacts of hurricanes, it is of concern that the IPCC (2007) projects an increase in intense tropical cyclone activity. This is a result of warming of ocean temperatures. The risk of more intense hurricanes and winter storms, leading to more intense precipitation, adds to the risks for more flooding, which is already the most frequent disaster event in Atlantic Canada (ICLR, 2012).

2.6 Climate Change Impacts on Drinking Water Infrastructure Design

Water is coming under increasing pressure in Atlantic Canada, which has direct impacts on the supply, treatment, storage, distribution and operation of drinking water supply systems. In some regions, these climate change impacts could result in lower water levels and poorer quality water, affecting water availability for drinking water supply systems. Infrastructure needs to be robust and resilient to cope with these changing conditions.

In coastal regions, infrastructure will have to withstand more extreme weather and water wear as a result of diminished sea and lake ice. Communities will need to more actively assess their buildings and drinking water supply system layouts, to determine which areas would be vulnerable to coastal flooding and overland flooding, in the case of prolonged heavy rain or high spring flows in a nearby water bodies (AFNESU, 2008). Heavy rains and floods create threats by the sheer volume of extra water that they bring into a community and also by their potential to spread contaminants into water systems.

Older and overextended drinking water infrastructure is likely to be more susceptible to the negative impacts of climate change. As a user of this guideline, one will have to explore opportunities for investments to be rethought and life-cycle costs to be taken into greater consideration. If targeted effectively, new infrastructure investments can significantly improve the long-term resilience of drinking water infrastructure in the face of climate change (J. Boyle, M. Cunningham, J. Dekens, 2013).

This guideline identifies some climate change phenomena which affect the supply, treatment, storage, distribution and operation of drinking water supply systems. The list is meant to serve as an illustration of the variety of climate change parameters, indices and processes which can influence safe and reliable access to drinking water, and is not wholly encompassing or inclusive. Climate phenomena have been broadly adopted from AFN, (2008), and can be summarized as:

- Altered Precipitation Quantity, Form and Timing;
- Changes to Seasonal Water Flow Patterns;
- Warmer Surface Water Temperatures;
- Rising Sea Levels;
- Impacts on Groundwater Reserves;

- Incidence of Drought; and
- Water Quality

2.6.1 Altered Precipitation Quantity, Form, and Timing

In Atlantic Canada, climate science indicates a general trend of heavier or more intensive precipitation from storms, which will invariably increase flood risk, expand flood hazard areas, increase the variability of stream flows, and increase the velocity of water during high flow periods. These changes will have adverse effects on water quality, drinking water sources, and aquatic ecosystem health. It should be noted, that on a local scale some regions will see annual precipitation increases while others will see decreases. Predictions about expected frequency of intense storms and flood events still remain inconclusive. Nonetheless, water resource managers will have to account for, and manage, the significant challenges as storm intensity increases and should therefore consider some or all of the following impacts (EPA, 2014 and AFN, 2008 and Lemmen and Warren, 2004):

- Increases in intense rainfall may result in more nutrients, sediments, pathogens, and toxins being washed into waterbodies and into drinking water sources, requiring additional treatment;
- Emergency plans for drinking water infrastructure need to recognize the possibility of increased risk of high flow and high velocity events due to intense storms and potential low flow periods;
- In areas with less precipitation, reduced stream flow may make meeting water quality goals more challenging;
- Floodplains may expand along major rivers requiring protection or relocation of drinking water infrastructure facilities and coordination with local planning efforts;
- Combined storm and sanitary sewer systems may need to be redesigned because an increase in storm event frequency and intensity can result in more combined sewer overflows causing increased pollutant and pathogen loading to receiving waterbodies, putting new demands on discharge permit and nonpoint pollution programs;
- Melting ice pack, shifting stream flows and altered precipitation patterns will affect ground and surface water levels to varying degrees throughout the year;
- Warmer air temperatures, less ice cover and changes to precipitation form and frequency are expected to cause lakes levels to drop (CIIA, 2005);
- Changes in precipitation patterns and intensity may increase the demand for watershed management that mitigates the impacts of intense storms and build resilience into water management through increased water retention; and
- Flooding may occur with more frequency due to changing freeze and thaw dates and precipitation form.

Groundwater sources may be placed at risk by severe flooding. The presence of surface water in areas normally below the flood line will tend to mobilize pathogens and could lead to the release of chemical contaminants. Flooding of sewage infrastructure (lagoons and lift stations), sewage backflows, or direct overflows associated with sanitary and storm water infrastructure could add significantly to the pathogen load of the floodwater. Inundation of fuel tanks and chemical storage areas could likewise release petroleum hydrocarbons and other species.

Please note the list provided in this guideline is by no means inclusive, and serves to prompt practitioners into identifying potential impacts which may impact their facility or region. Given the variability, practitioners should consider possible changes to precipitation on a community-by-community basis, especially as predictive models do not always agree with each other. It is therefore necessary to consider changes to precipitation on a regional or community level to determine impacts of concern and to develop appropriate adaptation strategies and capacity enhancement measures.

2.6.2 Changes to Seasonal Water Flow Patterns

In some parts Atlantic Canada, droughts, changing patterns of precipitation and snowmelt, and increased water loss due to evaporation as a result of warmer temperatures, will result in changes to the availability of water for drinking. Warmer air temperatures may also result in increased demands on water supplies, and water needs for industry. Water resource managers will have to consider some or all of the following impacts (EPA, 2014 and AFN, 2008):

- Across the Atlantic Canada, it is predicted that many regions will experience earlier spring peak flows, resulting in mid-summer low flow dry periods. These changes to seasonal water flows can also affect water quality.
- Additional investments in water infrastructure may be needed to manage both decreases and increases in seasonal rainfall; and
- Limited water availability and drought in some regions will require drinking water providers to reassess supply facility plans and consider alternative pricing, allocation, water conservation, and water reuse options.

2.6.3 Warmer Surface Water Temperatures

Climate warming is likely to result in warmer surface water temperatures, both as a result of increases in ambient surface air temperature and in levels of evaporation. Water resource managers will have to consider some or all of the following impacts:

- Lower water levels of water storage ponds, which may heat up faster;
- Warmer summer water temperatures could intensify water stratification in deeper water bodies, altering the aquatic environment;
- Warmer water temperatures will support algae and weed growth; and
- Water-borne pathogens may thrive more readily as a result of warmer temperatures and/or higher precipitation levels.

2.6.4 Rising Sea Levels

In Atlantic Canada, depending on location, rising sea levels may shift ocean and estuarine shorelines by inundating lowlands, displacing wetlands, and altering the tidal range in rivers and bays. Storm surges resulting from more extreme weather events will increase the areas subject to periodic inundation. The combination of sea level rise, storm surges, and waterbody movement will affect a range of coastal based water supply and treatment infrastructure and require that a range of management issues be considered, including but not necessarily limited to (EPA, 2014 and AFN, 2008 and Lemmen and Warren, 2004):

- Threats from accelerating coastal erosion patterns and shoreline instability;
- Increased frequency of damage from floods and storm surges;
- Need for watershed-level protection programs to account for changes in natural systems as salinity and pH levels change;
- The range of increases in sea level along Atlantic Canadian Provinces varies between locations, due to localized effects such as land subsidence and glacial re-bound. Localized sea level rise estimates should be obtained;
- Emergency plans for drinking water infrastructure need to account for long-term projections for rising sea levels;
- As sea levels rise and salt water intrudes into freshwater aquifers, affected drinking water systems will need to consider relocating intakes
- Drinking water utilities will need to consider hardening facilities against storm surge, protecting facilities with natural or man-made barriers, and relocation of some treatment facilities and discharge outfalls as a result of sea level rise; and

These overlapping impacts make protecting water resources in coastal areas especially challenging. Watershed-level planning will need to incorporate an integrated approach to coastal management in light of sea level rise including land use planning, building codes, land acquisition and easements, shoreline protection structures (e.g., seawalls and channels), beach nourishment, wetlands management, and underground injection to control salt water intrusion to fresh water supplies (EPA, 2014).

2.6.5 Impact on Groundwater Resources

Changes to the frequency and intensity of drought and precipitation have the potential to affect the quantity and quality of water that can be withdrawn from aquifers. Periods of drought and higher annual mean temperatures will generally increase evapotranspiration and reduce rates of aquifer recharge. Rain falling with greater intensity over shorter time frames could likewise reduce aquifer recharge. This implies an overall decrease in aquifer water balances, and would tend to reduce the volume of water that can be pumped sustainably. Well performance could also decline due to decreases of hydraulic head in supplying aquifers.

Relevant time frames for climate change effects are expected to vary from years to decades (or centuries), due to the time required for groundwater to travel from recharge areas to the well intake. For users drawing water from a deep, regional aquifers, climate effects may not become apparent over the normal operational lifetime of the well (e.g. 20 to 40 years). Substantial changes to hydraulic head in the aquifer would be required before interference with single-home drilled wells could become a concern.

Dug well users would be the most likely to experience adverse effects of climate change. Periods of drought are capable of causing the water table to decline below the reach of dug wells. Depending on the availability of a productive bedrock unit underlying surficial materials, some dug well users are able to replace dug wells with a new, deeper drilled well.

Continued and consistent assessment of municipal well performance and yields would typically provide the earliest and best indications of changes. This would require accurate and detailed records of pumping rates, schedules, and water levels in each well. Efforts to reassess the aquifer yield would need to account for declines in well performance associated with aging screens, pumps, and utility infrastructure. Assessments of aquifer yield may also be updated through aquifer testing, water budget calculations, and/or numerical modelling. For such assessments to be effective, a utility would need to establish existing conditions through collection of baseline data and estimation of the current aquifer yield.

As recharge and travel times are lower for surficial aquifers, any reductions to aquifer recharge or hydraulic head would be experienced first at Municipal wells installed in shallower sand and gravel aquifers. This type of well field has the potential to serve as the first and best indicator of climate change, climate change effects monitoring should thus be focused on these wells.

2.6.6 Incidence of Drought

In some regions Climate Change will make Eastern Canada more vulnerable to drought (Field et al., 2007). With changing temperature patterns, namely a projected rise average annual temperatures, and increasing demand on water resources, incidence of drought may become more frequent in the near to far future. Increased evapotranspiration rates resulting from temperature increases may result in water losses for which drinking water and wetlands managers will need to account. In areas with less precipitation or reduced snowpack, demand for water may shift to underground aquifers and prompt water recycling and reuse, development of new reservoirs, or underground injection of treated water for storage. Increased incidence of wildfire as a result of higher temperatures and drought may increase soil erosion and sedimentation, increase water pollution, increase risk of flooding, and pose a threat to aquatic habitats and water infrastructure.

2.6.7 Water Quality

Throughout Atlantic Canada, warmer air temperatures will result in warmer water. Warmer water holds less dissolved oxygen making instances of low oxygen levels or “hypoxia” more likely; foster harmful algal blooms; and alter the toxicity of some pollutants EPA (2014). Water resource managers will have to consider some or all of the following impacts (EPA, 2014 and Kundzewicz et. al, 2007):

- Higher water turbidity levels, greater movement of pollutants into watercourses and larger quantities of solid matter requiring filtration;
- Warmer surface water temperatures increasing bacteria and fungi concentrations, algal blooms and increased summer phosphorus concentrations;
- Increased drought, extending the cyanobacterial bloom season. Other climate change-associated conditions that may favor presence of cyanobacteria include lower freshwater quantities, increased nutrient levels in water and warmer air temperatures;
- A warmer climate and/or high precipitation levels may enhance the growth of certain water-borne pathogens, including Legionella Pneumophila, Leptospira Interrogans, Vibrio Cholerae, Vibrio Parahaemolyticus, and Toxoplasma Gondii (Health Canada, 2005).
- Increased pollutant concentrations and lower dissolved oxygen levels will result in higher incidences of impaired water quality; and
- Increased growth of algae and microbes will affect drinking water quality.

2.6.8 Design Philosophy to Incorporating Climate Change Impacts

Most infrastructure continues to be designed on the basis of historical climate data and assumptions, generally meaning they do not account for an expected increase in frequency and intensity of climate hazards or new climate hazards (J. Boyle, M. Cunningham, J. Dekens, 2013). In this guideline it is suggested to design infrastructure based on both historical and projected climate data. Using both past and future climate data often results in a more comprehensive and resilient design. Though often representing higher upfront costs, investments in more resilient design, such as one that considers a full range of climate projections, can help avoid larger future costs (in terms of maintenance, repair and replacement), and make a project more resilient to future climate and weather extremes.

Note: In this guideline it is suggested to design infrastructure based on both historical and projected climate data. Using both past and future climate data often results in a more comprehensive and resilient design.

For practitioners using this guideline, it is recommended to consider the following tools and techniques for responding and/or adapting to climate change:

- Consider evolving uncertainty in climate projections to balance costs and potential consequences of failure;
- For critical infrastructure, conduct engineering-economic evaluation of costs and benefits of adaptation measures, with emphasis on highest risks to help planning efforts;
- At a designers discretion, where applicable, and in consultation with climate scientists, increase the magnitude of design parameters or safety factors;
- Perform a formal risk assessment and carry out risk management;
- Review existing practices and use entirely new solutions;
- Develop contingency plans for infrastructure failure;
- Identify infrastructure that is at risk because of a changing climate and retrofit priority assets;
- Consider increased deterioration rates in design and maintenance plans;
- Design based on the most probable climate condition;
- Consider different climate change scenarios or models for design, maintenance or planning;
- Identify locations that may be vulnerable to climate change impacts and avoid them altogether or modify designs accordingly;
- Include flexibility (no regret design) and/or additional safety factor in the design. Acting on the best-case

scenario over the short-term and leaving available space for flexibility in the adaptation or policy to be expanded or build upon at a later time;
- Monitor climate condition and project performance over time. As new information becomes available, and projection models improve, the strategy can be adjusted; and
- Implement design and construction modifications in response to observed changes.

Adaptive capacity is another important concept to consider for users of this manual. The vulnerability of the drinking water sector to climate change is defined by the capacity of the sector to adapt by minimizing adverse impacts and maximizing positive ones (J. Boyle, M. Cunningham, J. Dekens, 2013). This may be difficult to achieve without clear guidance from National building codes and standards (which are anticipated to account for climate change by 2025). Methodologies presented in codes, standards, and best practices will provide greater insight into the management of uncertainty in the application of climate projections for the design of infrastructures as well as programs and policies.

2.6.9 Defining Extreme Events

Different disciplines have different definition for extreme events. Scientist and engineers agree on the definition of extreme events (e.g. heavy precipitation, droughts and etc.) to some extent; extreme events are defined as unusual/unexplainable events with deviation from the observed normal trend regardless of their consequences (Albeverio, Jentsch, & Kantz, 2006). Extreme events definition slightly varies between climate scientists and engineers; Intergovernmental Panel on Climate Change (IPCC) defines the extreme events as any events whose probability is less than 10% or more than 90% of observed probability density function. However, acceptable frequency of failure defines extreme events for engineers. Based on the purposes of structures, engineers design them for events with Mean Recurrence Interval (MRI) or return period of n years (i.e. Annual Exceedance Probability (AEP) of 1/n). It is important for the user to understand the likelihood of extreme events at a facility site and general climate projections for the region to supplement that information. A literature review is suggested for this task.

2.7 Identifying Climate Risks to Drinking Water Infrastructure

Many options exist to address climate change concerns at utilities. When evaluating a response to climate change and assessing potential adaptation strategies, there are several significant issues to be considered such as: deciding which climate information to use, deciding how to incorporate uncertainty, and obtaining a better understanding of system capabilities. A commonly adopted approach to incorporate these concepts into drinking water infrastructure planning, design and operations; is to conduct a comprehensive risk assessment to identify those components or processes which are most at-risk to climate change. Once identified an adaptation plan can be implemented in either the planning, design, or operational phase of an asset. The scope and priority of an adaptation plan depends on the availability of resources to address climate vulnerability of the asset or asset component to a changing climate. Two commonly applied methods to assess climate risk include top-down and bottom-up approaches to climate risk assessment. These methodologies are defined below Gov. AU (2016):

Top-Down Approaches:
Give information on a broad and all-encompassing range of simulated climate change impacts. This approach emphasises understanding the plausible impacts by attempting to represent different sources of uncertainty throughout the asset's chain of processes. This approach often starts with generating in-depth climate projections for the location of interest. Outputs from top-down methods may offer limited value when attempting to improve adaptive capacity or resilience to climate change; providing insights mainly into a likely range of impacts rather than on system sensitivities as well as typically ignoring non-climate influences.

Bottom-Up Approaches:

Bottom-up approaches base their analysis on an understanding of existing pressures and demands on a system; – vulnerabilities to climate change are considered in context with non-climate factors. This approach often starts with generating an inventory of vulnerable asset components or processes, prior to generating specific climate change projections and parameters.

We recommend that users of this guideline adopt a bottom-up approach to climate risk assessment. The bottom-up approach starts with an attempt to identify the nature of climate risks that a system is exposed to under current climate. Often analysis considers other aspects that influence system performance, so that climate risks are not assessed in isolation of other demands on the system. With an understanding of what kind of changes to the climate, or under what circumstances the system becomes more vulnerable to climate changes, users can look to output from climate models to assess if there is high confidence in such conditions occurring and subsequently modify behaviour or conditions to alleviate pressures should such climate change eventuate (Gov. AU, 2016). The most common application of top-down climate risk assessment in Canada is the Engineers Canada Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol.

The PIEVC Protocol:

Systematically reviews historical climate information and projects the nature, severity and probability of future climate changes and events. It also establishes the adaptive capacity of an individual infrastructure as determined by its design, operation and maintenance. It includes an estimate of the severity of climate impacts on the components of the infrastructure (i.e. deterioration, damage or destruction) to enable the identification of higher risk components and the nature of the threat from the climate change impact. This information can be used to make informed engineering judgments on what components require adaptation as well as how to adapt them e.g. design adjustments, changes to operational or maintenance procedures (Engineers Canada, 2020)

To access the PIEVC Protocol visit https://pievc.ca/

To apply the PIEVC Protocol the practitioner using this guideline is recommended to access the publicly available PIEVC Protocol resources. Alternatively, for the purposes of this manual, we illustrate a standard seven (7) step process to identify and mitigate climate risk, which has been compiled based on a variety of commonly adopted bottom-up assessment methodologies such as PIEVC or robust decision-making approaches (Lembert and Groves 2010). Broadly the climate risk assessment framework may be summarized in seven (7) steps, as per Figure 2.2.

Figure 2.2 Climate Risk Assessment Framework Steps

Step 1
- Identify drinking water infrastructure components at the facility of interest.

Step 2
- Select infrastructure component for analysis.

Step 3
- Combine component attribute with climate projections.

Step 4
- Assess climate parameter effects (i.e. vulnerability)

Step 5
- Identify risk which is a function of the occurance probability and impact severity (if it occurs).

Step 6
- Impact scoring.

Step 7
- Implement the risk mitigation or adaptation plan.

When completing a climate risk assessment it is recommended to conduct such an assessment with a team of experts consisting of the facility operators (front-line to back office staff), regulators, engineers, planners, climate scientists, and emergency and first aid specialists, where applicable. A diverse team of participants, known as the climate risk assessment team, with specific subject matter expertise are better equipped to conduct a risk assessment, with more thorough and comprehensive outcomes. An overview for climate risk assessment is outlined below, and can be adapted as required. Additional guidance can also be found in PIEVC literature or similar documentation.

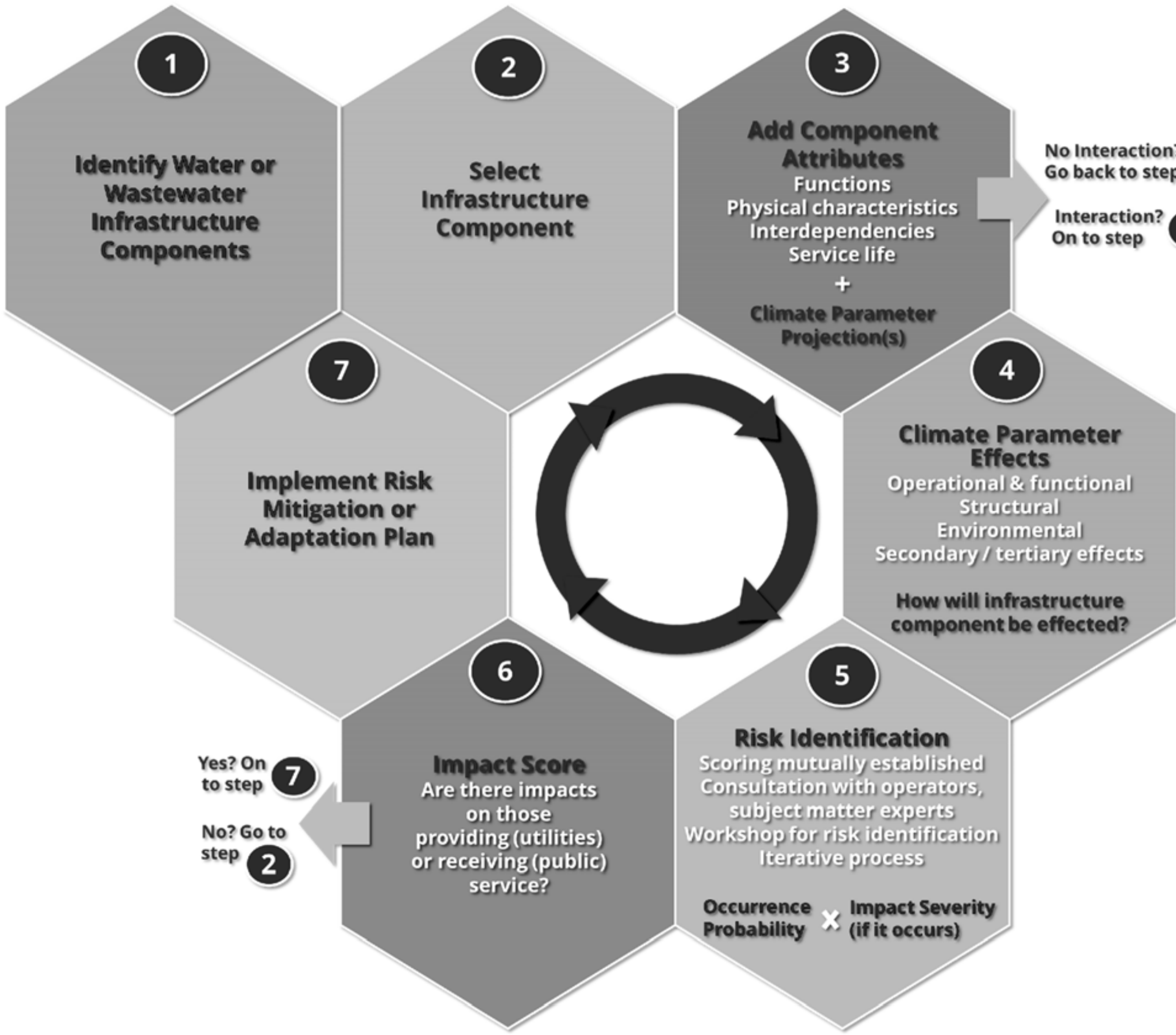
STEP 1: Identify Drinking Water Infrastructure Components at the Facility of Interest

The first step consists of creating a catalogue of all vulnerable or at risk infrastructure components at the facility of interest based on past climate events, and perceived future vulnerabilities related to a changing climate. It is recommended to complete this identification process in a workshop setting with experienced operators, engineers and facility managers. Threshold conditions should be catalogued for critical assets, operational components and utility organization systems that may fail or suffer damage when confronted by climate change impacts. Thresholds can be determined through review of event and performance history, modeling of system performance or inspection of assets. A complete list of components or facility process to assess for climate risk is the typical outcome of such an exercise.

Overflow and capacity targets, as well as level of service targets should be identified at this stage for stormwater drainage and sewerage infrastructure. These are important to ensuring consistent climate change adaptation practices. When determining and setting these objectives, it is important to consider the following (Ali A., Singh A., 2019):

- The relationship between strategic goals, stakeholder expectations, and business level of service targets;
- Current and future levels of service are defined in measurable terms and are being tracked through specified performance measures;
- The risks for not meeting desired levels of service have been considered; and
- Costs for current and future levels of service options are recorded.

Figure 2.3 Bottom-up Climate Risk Assessment Framework



STEP 2: Select Infrastructure Component for Analysis

The next step in the process is to select, not necessarily in sequential order, a partical infrastructure component or processes from the compiled list generated in Step 1, for assessment. If desired, these can be ranked and assessed based on operational thresholds or the severity of consequences as a result of failure.

STEP 3: Combine Component Attribute with Climate Projections

This step combines climate projections supplied by a climate scientist or climate analyst, with the operational process of the selected infrastructure component or processes. Practitioners are cautioned that proper application of climate data can be a complex process which requires interpretation of results and characterization of uncertainty. Typically, engineers, planners, policy makers, and operators are already well equipped to deal with uncertainty by the very nature of their occupation. Weather variability and extreme weather unpredictability is a fact that these groups have learned to accept and respond to appropriately. Using risk assessment as a decision making process in the face of unknowns is no new concept. Making decisions based on projections for long-term climate changes can be approached in the same manner.

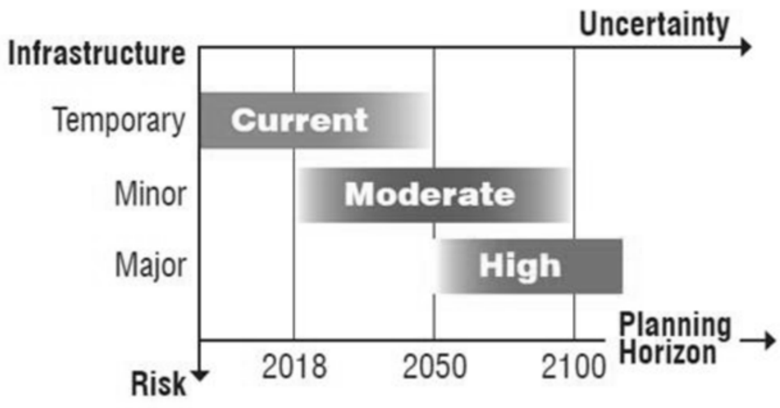
A team with climate projection expertise can filter the sometimes overwhelming volume of available climate information down to a useable short list of information that must be considered in the decision making process. If the current climate is used, there is a high risk that the infrastructure will be undersized and it will not provide the desired level of service in the future climate. The initial cost would be low (e.g. the pipes would be smaller and therefore less expensive). If the high future climate is used, there is a low risk that the infrastructure will not provide the desired level of service. The initial cost would be high: the infrastructure may be overdesigned and the solution may be cost-prohibitive. The moderate future climate would result in a medium risk of failure, and the initial cost would also be medium (Ali A., Singh A., 2019). Ultimately the owner's tolerance for risk will play a central role in how uncertainty is dealt with, along with other non-climatic considerations such as economic, political, and social influences.

Typically, decisions are not made solely on climate projection information alone. If an interaction between the selected infrastructure component or process and changes in climate is found to exist and be of significance, then a risk assessment is necessary and the climate parameter effects should be studied in greater detail (step 4). If the interaction between the selected infrastructure components or processes and the changes in climate are found to be negligible, then the assessor can return to step 2 and select the next component or process. This process is repeated until all components or processes identified by the climate risk assessment team have been considered.

STEP 4: Assess Climate Parameter Effects and Vulnerability
To ensure that climate projection data and plots are interpreted properly, and to allow for informed decision making, it is beneficial for a climate or impact scientist with familiarity in the climate projection field to participate in the both the climate effects and risk assessment process.

The selection of the appropriate climate scenario to use for infrastructure planning and design is summarized in in Figure 2.3. The future climate indices and parameters to use for infrastructure planning and design will vary depending on the type of infrastructure (temporary, minor, or major) and the design life of the infrastructure. Designing for climate change adaptation will result in differing future climate scenarios for different infrastructure, and there is no "one size fits all" solution (Ali A., Singh A., 2019).

Figure 2.4 Selection of future climate scenarios



As part of the process the assessor has to identify climatic vulnerability of the selected asset component or process. Climate vulnerability is the degree to which a system is affected, either adversely or beneficially, by climate stressors. The vulnerability assessment considers the degree to which an infrastructure asset is affected when exposed, for example to increased rainfall due to climate change. Vulnerability can be measured in terms of the consequences associated with failure of an asset. In some instances, the consequences can be very specific and defined for each sub-component of a large infrastructure system. There are several categories of consequences to consider Ali A., Singh A., (2019):

- **Asset Damage**: Damage requiring minor restoration or repair may be considered minor while permanent damage or complete loss of an asset would be considered to be a significantly higher consequence.
- **Financial Loss:** Costs related to third party damages (e.g. basement back ups), environmental clean up / fines and repair / rehab of infrastructure.
- **Loss of Service:** Meeting demand, conveyance and overflow targets.
- **Health and Safety:** A system serving a large number of people would be of major consequence compared to a system serving a smaller number. Casualties or other acute public health consequences would weigh more heavily.
- **Reputation:** Loss of service, health or environmental impacts may affect the reputation of the responsible agency.

Hazard mapping is a valuable tool for understanding vulnerability to climate change. Hazard mapping integrates multiple types of information. Climate change data, hydrologic and hydraulic models, sewerage and stormwater collection capacity data, and operational data provide information regarding hazards (e.g. flooding, combined sewer overflows, etc.). The locations of sensitive areas (e.g. schools, ecologically sensitive areas) are also included in the hazard mapping, which then provides a visual summary of the interactions and interdependencies between infrastructure and facilities. It is recommended to use such tools when conducting a climate vulnerability and impacts assessment.

STEP 5: Identify Risk which is a Function of the Occurrence Probability and Impact Severity (If it occurs)

With a better understanding of the climatic vulnerability of the selected asset component or process, and an appreciation for the effects in event a failure, a risk assessment can be conducted. General risk can be defined as the severity (or consequence) of impacts and probability (or likelihood) of an event occurring. These processes can be numerically defined, as per Figure 1 4 and an impact score generated. It is recommended to complete this scoring exercise in a workshop setting with facility operators (front-line to back office staff), regulators, engineers, planners, climate scientists, and emergency and first aid specialists, where applicable. Multi-disciplinary attendance at round table discussions and expert guidance by climate service providers in the assignment of probability, will help to ensure that both the strengths and limitations in the climate information are properly accounted for in scoring. The scoring system can be adjusted and tailored to a specific site or process on a case-by-case basis, as long as it remains consistent throughout the entire assessment.

The risk analysis will categorize each infrastructure asset according to risk levels. Risk based planning focuses on minimizing the risk associated with the asset through an appropriate intervention strategy, while ensuring that any risks are managed at the minimum cost. Risk management is about finding the "sweet spot" between expected value and risk tolerance levels. For example, one would be taking excessive risk by choosing to upsize little or no pipes within a system to plan for surcharging, while one would be taking insufficient risk if they decided to upsize all pipes within a system (Ali A., Singh A., 2019).

Figure 2.5 Sample Risk Threshold Map

	Consequence				
Likelihood	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Rare (1)	Low	Low	Low	Low	Moderate
Unlikely (2)	Low	Low	Moderate	Moderate	High
Possible (3)	Low	Moderate	Moderate	High	Extreme
Likely (4)	Low	Moderate	High	Extreme	Extreme
Almost certain (5)	Moderate	High	Extreme	Extreme	Extreme

STEP 6: Impact Score
Step 5 will generate a long list of risk scores. Scoring on a numeric scale allows for a quantitative comparison of various climate impacts to determine a priority for the implementation or adaptation. The level of risk of an infrastructure asset will determine its priority for adaptation. For infrastructure that is categorized as an extreme risk, adaptation measures should be implemented immediately (Ali A., Singh A., 2019). As the level of risk decreases, adaptation measures also decrease. Low risk infrastructure should be maintained by the current programs and strategies (i.e. the status quo). Those with low risk or importance can be discarded, while other, higher scores may require a risk mitigation or adaptation plan. This is addressed in Step 7. If the selected asset component or process is discarded due to a low score, the process can return to step 2 and the next asset component or process can be assessed.

STEP 7: Implement the Risk Mitigation or Adaptation Plan
Results from a risk assessment can be used to identify options that reduce system vulnerabilities. Adaptation options can be implemented to reduce potential consequences to operations and infrastructure. In addition to reducing risk, options should also be considered with respect to (1) current utility improvement plans and priorities and (2) current and projected available resources. For example, if assessments indicate high risk to coastal outfalls and pumps from flooding, then options to mitigate flood damage should be considered with respect to overall infrastructure planning and general system updates.

Selecting the right adaptation measures can be determined by the level of risk of the asset, a cost-benefit analysis as well as by examining individual capabilities and resourcing. There are three approaches for climate change adaptation that can be adopted for sewerage and drainage infrastructure planning and design under climate change uncertainties. The three approaches are (Ali A., Singh A., 2019):

- **Do Nothing/Business as Usual:** This approach does not consider climate change, and continues to plan and design infrastructure for the current climate.
- **Middle of the Road:** This approach uses the most likely future climate scenario.
- **Worst-Case:** This approach uses the extreme future climate scenario.

There are applications where all three scenarios are appropriate for infrastructure planning and design. For instance, the "Do nothing" approach is appropriate for temporary infrastructure, infrastructure near the end of its design life, or minor infrastructure repairs requiring immediate attention but a major upgrade is already scheduled in the near future. The "Worst-case" approach is appropriate for infrastructure where the consequences of failure/loss of service are catastrophic (i.e. major infrastructure). The "Middle of the road" approach is appropriate for the remaining categories of infrastructure. This approach balances the risk of failure with the initial cost and is the recommended approach.

The design life of the infrastructure is also an important consideration for infrastructure planning and design. For example, future climate IDF curves increase from the 2050 to the 2100 time horizon. The design life of an infrastructure should be used to select the time horizon for the analysis. When the end of the design life is before 2050, the 2050 time horizon is appropriate. If the design life ends between 2050 and 2100, there are two options for selecting the time horizon (Ali A., Singh A., 2019):

- Use the closer time horizon (2050 or 2100) if the design life ends near one of the time horizons; or,
- Interpolate between the 2050 and 2100 time horizons if the design life ends near the midpoint between the two time horizons.

Following the design and implementation of any adaptation plan, utilities are encouraged to monitor conditions, compare results to projections and reassess both risk and adaptation options as new information becomes available. Monitoring should include remaining aware of new climate information and tools as they become available.

2.8 Adaptation to Climate Change in Drinking Water Infrastructure

The following section provides practitioners and users of this guideline with some general recommendations and advice for adaptation measures for drinking water infrastructure. The examples below are meant to serve as a small sample set of adaptation examples and strategies. The user of this guideline is encouraged to develop project and site specific adaptation strategies identified through a risk assessment process, as described in Section 3.7.

2.8.1 Adaptation Strategies

Adaptation strategies will most likely be a combination of both reactive and proactive responses. In the case of drinking water facilities, a proactive adaptation can incorporate climate change foresight into general required infrastructure planning, design and operations. There are generally three (3) water-related project areas requiring implementation of proactive, 'no regrets'-type approaches (Bruce et al., 2000; Koonce and Hobbs 1994; Regier, 1993; Environment Canada, 1992; Environment Canada, 1996):

- Watershed stewardship: this involves source water protection, and is an essential starting place to ensuring ongoing vitality of water. This approach requires water conservation measures by all users and expanded efforts at water quality protection from agricultural, industrial and human wastes.
- Drinking water facilities: Strength and flexibility should be planned into new structures. These plans should include a greater emphasis on planning and preparedness for droughts and severe floods.
- Water governance plans: Development of informed watershed governance and management strategies, supported by the renewal of national (federal-provincial) monitoring efforts for water quantity and quality and improved procedures for fair allocation of water within basins, provinces, and between jurisdictions, taking in-stream ecosystem needs into account.

Once a range of possible adaptation options has been identified, the operator (or user of this guideline) should prioritize a shortlist of the most appropriate options for implementation. This is similar to the approach outlined in Section 3.7 of this guideline. As part of this process, it is recommended that the user of this guideline develop a cost-benefit analysis as a form of economic evaluation, and a multi-criteria analysis where costing is difficult to quantify.

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

define. A number of criteria are selected that align with climate change objectives. A weighting to demonstrate the relative importance of these factors is selected from an overall score.

After adaptation projects, design modifications or revised operating and maintenance procedures have been shortlisted, it is recommended to develop a business case for climate change adaptation. Once the business case is developed, a spending program can be initiated which addresses all risks associated with stormwater, sanitary and combined sewer systems. To summarize, in order to develop a business case for climate change adaptation projects, one should (Ali A., Singh A., 2019):

- Evaluate Short and Long Term Needs: From a climate change planning perspective, compile all projects within the capital programming timing horizon, organized around the funding allocation categories.
- Analyze Impact of Available Funding: Demonstrate the impact of funding on risk reduction.
- Formulate a Works Program: Combine the optimized treatments and other analysis results into a program of climate change projects

2.8.2 Specific Adaptation Examples

Below a list of examples where adaptation may be required in the drinking water sector in light of a changing climate. These examples are referenced from EPA (2014), AFN (2008) and Lemmen and Warren (2004):

- Water Collection Adaptations
- Increase Reservoir Capacity
- Adaptation to Drought
- Water Intake Relocation
- Assessment of Water Sources and Ecosystem Protection Adaptations
- Higher Loads of Organic Matter
- Water Distribution Adaptations

2.8.2.1 Water Collection Adaptations

Water quantity impacts from climate change may include lower absolute water levels, reduced summer water flows or degraded water quality, particularly during low flow periods. All of these impacts require adaptation in approaches to water collection.

Under flooded conditions exposure of the water supply to pathogens represents the greatest and most immediate threat. As the wells may exhibit GUDI conditions in the absence of flooding, the further mobilization of pathogens into the aquifer or directly to a well head would represent an acute threat to life and health. Measures to improve the resiliency of the groundwater supply to pathogens should be a priority. These measures could include (AFN, 2008 and Lemmen and Warren, 2004):

- Install a UV Light. UV irradiation provides inactivation of protozoa and is relatively inexpensive to add to existing disinfection systems.
- Check and ensure an excellent seal of well cap and replace/renew as needed.
- Confirm casing is in excellent condition. Perforations may develop in older casings, and represent a short-circuit pathway for pathogens.
- Consider extending well vent pipe above the flood line elevation and ensure that the opening is screened; ensure that the vent screen is checked annually and replaced as needed.
- Initiate a GUDI investigation, including seasonal samples for Microscopic Particulate Analysis (MPA).
- Follow up on well head protection planning and inspections to ensure that there is no open storage of manure on agricultural land within the SWPA.
- Consider restrictions on manure storage and spreading within SWPA during periods of highest risk for flooding.
- Construct new wells with an enhanced annular seal and apron at the ground surface.

2.8.2.2 Increase Reservoir Capacity

Increasing storage capacity throughout water systems, including the ability to collect and store rainwater, melt water, and winter stream water will become more important as climate variability increases due to a changing climate. A large volume of precipitation occurring in a short time period will result in quick run-off and less infiltration -- the ability to intercept this run-off will be a key adaptation for maintaining adequate water resources between intense precipitation events. Environment Canada (1996 in Mehdi et al) suggests that large storage dams could be constructed to hold water resulting from early snowmelt. Gan (2000) also suggests snow management as an approach to increasing water storage capacity (Natural Resources Canada, 2004: online). Designs for long-term water storage infrastructure should account for water quality and rising air temperatures that will promote algal and bacterial growth in standing water.

2.8.2.3 Adaptation to Drought

To combat issues associated with projected drought conditions; efforts to manage and adapt to climate effects should focus on monitoring and quantitation of available water, and on development of strategies to increase community awareness while reducing overall use. A climate change adaptation plan to combat drought could, for example, focus on (AFN, 2008 and Lemmen and Warren, 2004):

- Establishment of a database of production well data, including pumping rates, water levels, and water quality;
- Review of area water budgets, including an assessment of the range of potential decreases in available water;
- Identification of thresholds for water stress under shorter term (single summer) and longer term drought to determine the system vulnerability to climate change;
- An outline of strategies for utility operation to anticipate and guard against periods of water stress;
- An outline of strategies for public engagement and water conservation; and
- Compilation of an action plan describing shorter and longer term activities and goals.

2.8.2.4 Water Intake Relocation

Existing water intake locations may become exposed through dropping surface water levels on a more regular basis as a result of drought impacts from a changing climate. When low water levels expose surface water intakes, this can negatively impact water quality. Responses include: lowering surface intakes or installing emergency low-flow intakes at deeper water levels that can take over when water levels reach extreme lows (Mehdi et al., 2006). Water intakes will have to be moved accordingly and research and design investments in desalinization technologies for contaminated waters in coastal communities may be required to combat salinization of freshwater resources (Environment Canada, 1996 in Mehdi et al.).

2.8.2.5 Assessment of Water Sources and Ecosystem Protection Adaptations

For communities involved in overhauling existing drinking water treatment facilities, regional assessments of whether groundwater or surface water is likely to be more negatively impacted by climate change should be included when deciding which water source to use for drinking water. Considerations include the viability of drilling wells to access groundwater, the relative quality groundwater versus surface water and the extent to which surface water sources are expected to warm up and dry up. When possible, communities should seek water from the source that will be under less climate change pressure. In the face of climate change, communities should also focus on protecting and enhancing the health of surface water and groundwater (AFN, 2008).

2.8.2.6 Higher Loads of Organic Matter

Higher concentrations of organic matter in raw water are an expected impact of climate change. This will cause major problems for facilities that are not set up to cope with organic matter and is just one example of the importance of incorporating predictions about climate change impacts to water quality into facility upgrades. Environment Canada (2007) notes that filtering algae is an expensive process that most water filtration systems are not set up to undertake. Algal blooms occur intermittently, and an appropriate inexpensive treatment method that can be applied on an as-needed basis is required (in IPCC, 2007: 188). Ultra and Nanofiltration technologies are increasingly being applied for both large and small systems and provide the safety of an absolute barrier. Currently they are seen to be complex and expensive but increased application and completion will see complexity and cost reduced. This example highlights the need for new technology development in some situations (AFN, 2008).

2.8.2.7 Water Distribution Adaptations

Communities located close to rising open water, such as coastal communities, or in low-lying areas will have to assess their surroundings to determine which areas will be vulnerable to flooding during extreme storm events or as a result of rising seas. In contrast, communities located close to receding lakeshores will have a different set of problems from coastal communities threatened by rising water levels. These communities will have to focus more pointedly on conservation.

2.9 Key Climate Change Indices and Parameters for Consideration

There are many climate parameters and indices that can be considered in climate change adaptation. For the purposes of this guideline, we have compiled a list of parameters for consideration when planning, designing or operating drinking water infrastructure. In the CSA Group standard, CSA S900.1 - Climate Change Adaptation for Wastewater Treatment Plants, the following parameters are considered at a minimum:

Climate Parameters	Secondary Implications Influenced by Climate Parameters
1. Blizzard; 2. Fog; 3. Hurricane/Tropical Storm; 4. Cold Wave; 5. Hail; 6. Ice Storm; 7. Cooling Degree Days; 8. High Temperature; 9. Lightning; 10. Diurnal Temperature Range; 11. High Wind; 12. Low Temperature; 13. Drought; 14. Heat Wave; 15. Snow Accumulation; 16. Freeze/Thaw; 17. Heating Degree Days; 18. Tornado; 19. Freezing Rain; 20. Intense Rain; and 21. Winter Rain.	1. Flooding; 2. Invasive Species; 3. Change In Water Characteristics; 4. Sea Level Rise; 5. Groundwater Elevation Changes; 6. Storm Surges; 7. Permafrost; 8. Watercourse/Waterbody Elevation Changes; 9. Wildfire; and 10. Debris Floods/Flows.

From these parameters the following can be considered as essential information for practitioners:

- Temperature (several sub-parameters);
- Precipitation (several sub-parameters);
- Days with maximum temperature (several thresholds);
- Days with minimum temperature (several thresholds);
- Days with rainfall (several thresholds);
- Days with snowfall (several thresholds);
- Days with precipitation (several thresholds);
- Days with snow depth (several thresholds);
- Wind (several sub-parameters);
- Degree days (several thresholds);
- Bright sunshine (extreme);
- Humidex (several thresholds);
- Wind chill (several thresholds);
- Humidity;
- Pressure;
- Visibility (hours with);
- Cloud amount (hours with); and
- Frost-free (several thresholds).

2.10 Sources of Climate Data

The following section provides practitioners and users of this guideline with some sources of publicly available climate data which can be readily accessed and is known to be quality controlled and regularly updated by Federal and Provincial Governments, as well as national and international academic institutions and research groups. The users of this guideline are reminded that as models continue to resolve a higher number of processes more accurately; new datasets, better post-processing of climate projections, and new data portals will become available.

It is encouraged for practitioners using this guideline to maintain awareness of evolution in climate data and science, and if possible, regularly review newly distributed climate change data. Practitioners are encouraged to regularly engage with climate change scientists or professionals, and to collaborate with such experts when responding to new risks and opportunities during the adaptation planning process, from preliminary stages through to operations.

2.10.1 Climate Risk Atlas of Canada

The Climate Atlas of Canada was created by the Prairie Climate Centre at the University of Winnipeg. It is an innovative climate science and communications tool that allows users to visualize and interact with climate data as well from coast to coast to coast. The atlas uses 24 global climate models. These models have been downscaled to a fine local scale by the Pacific Climate Impacts Consortium (PCIC). Importantly, this 24-model ensemble was created using statistical techniques that preserve daily patterns in the global climate models.

PCIC has provided downscaled projections of daily temperature and precipitation data from 24 climate models using two carbon emission scenarios. The Atlas uses PCIC’s statistically downscaled data (Bias Correction with Constructed Analogues and Quantile mapping, Version 2; BCCAQv2) derived from 24 CMIP5 global climate models (the complete list of models can be found below), for two emissions scenarios (RCP4.5 and RCP8.5). We call the RCP4.5 and RCP8.5 the “Low Carbon” and “High Carbon” scenarios, respectively.

For each model/scenario the PCIC dataset provides daily temperatures (maximum and minimum) and total precipitation at a 10 km x 10 km resolution for all of Canada, for the period 1950-2100. For each model, the simulations for 1950-2005 are the same for both emissions scenarios (RCP4.5 and RCP8.5). The divergent emissions scenarios were used by the models starting in 2006. That is, starting in 2006 the model outputs for the two RCPs begin to differ. Climate projections are provided for two future 30-year periods (2021-2050 and 2051-2080) and a baseline period (1976-2005). Unless otherwise stated, the maps and data presented are the averages of the 24 models.

The Climate Risk Atlas can be accessed at: https://climateatlas.ca/

2.10.2 Canadian Centre for Climate Modelling and Analysis

The Canadian Centre for Climate Modelling and Analysis (CCCma), a section of the Climate Research Division, develops and applies computer models of the climate system to simulate global and Canadian climate, and to predict changes on seasonal to centennial timescales. Analysis of these simulations, together with observations, is used to provide science-based quantitative information to inform climate change adaptation and mitigation in Canada and internationally, and to improve our understanding of the climate system. Notably, CCCma develops the modelling system used to produce seasonal forecasts operationally by Environment and Climate Change Canada, and carries out climate model experiments coordinated by the World Climate Research Programme (WCRP) in support of the Intergovernmental Panel on Climate Change (IPCC).

Data from the Canadian Centre for Climate Modelling and Analysis can be accessed at: https://www.canada.ca/en/environment-climate-change/services/climate-change/science-research-data/modeling-projections-analysis/centre-modelling-analysis.html

2.10.3 The Intergovernmental Panel on Climate Change (IPCC)

The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change. Practitioners can access the IPPC Data Distribution Centre (DDC). The DDC provides climate, socio-economic and environmental data, both from the past and also in scenarios projected into the future. Technical guidelines on the selection and use of different types of data and scenarios in research and assessment are also provided. The DDC is designed primarily for climate change researchers, but materials contained on the site may also be of interest to educators, governmental and non-governmental organisations, and the general public.

The DDC is overseen by the IPCC Task Group on Data Support for Climate Change Assessments (TG-DATA) and jointly managed by the Centre for Environmental Data Analysis (CEDA) in the United Kingdom, the ICSU World Data Center Climate (WDCC) in Germany, and the Center for International Earth Science Information Network (CIESIN) at Columbia University, New York, USA. The data are provided by co-operating modelling and analysis centres.

The DDC provides five (5) main types of data and guidance. These are:

1. Climate estimates from observations:
   - IPCC provides a climate datasets from 1961-1990 with mean monthly data over global land areas for nine variables on a 0.5º latitude/longitude grid, together with decadal anomalies from this mean for the period 1901-1995.
2. Global climate model data:
   - IPCC provides global climate model data at a range of frequencies or as climatologies. Data is held for

climate model projections used as input to the Second, Third, Fourth and Fifth IPCC Assessment Reports The climatologies of climate model projections can be viewed through the DDC visualization service.

3. Socio-economic data and scenarios:
   - Socio-economic data and scenarios are important for characterizing the vulnerability and adaptive capacity of social and economic systems in relation to global and regional climate change. The DDC provides access to baseline and scenario data related to population, economic development, technology and natural resources for use in climate impact assessments. The reference data include country and regional level indicators of socio-economic and resource variables. The scenario data supplied extend to 2100 and are based on the assumptions underlying the set of emissions scenarios developed for the IPCC.
4. Data and scenarios for other environmental changes:
   - Some data and information for other environmental changes is also included in the site. These include data on global mean CO2 concentration, global and regional sea-level rise, regional ground-level ozone concentration, sulphate aerosol concentration and sulphur deposition. Detailed documentation and guidance is also provided for the use of these data.
5. Linked data resources:
   - The DDC also provides links to datasets which have been reviewed and pass a set of linking criteria.

Information regarding the data generated by the Intergovernmental Panel on Climate Change (IPCC) can be accessed at: https://www.ipcc.ch/data/

The Data Distribution Centre portal can be accessed at: http://www.ipcc-data.org/

2.10.4 Canadian Institute for Catastrophic Loss Reduction

The Institute for Catastrophic Loss Reduction (ICLR) is a Canadian based centre for multi-disciplinary disaster prevention research and communication. ICLR was established by Canada's property and casualty (P&C) insurance industry as an independent, not-for-profit research institute affiliated with Western University. Institute staff and research associates are international leaders in wind and seismic engineering, atmospheric science, risk perception, hydrology, economics, geography, health sciences, public policy and a number of other disciplines. The ICLR web-portal is regularly updated with the latest research, reports and data related to infrastructure vulnerability and climate adaptation solutions including drinking water infrastructure.

The ICLR web-portal can be accessed here: https://www.iclr.org/

2.10.5 Canadian Extreme Water Level Adaptation Tool (CAN-EWLAT)

Extreme water levels along Canadian coastlines are a result of a combination of storm surge, tides, and ocean waves. Future projections of climate change in the marine environment indicate that rising sea level and declining sea ice will cause changes in extreme water levels, which will impact Canada's coastlines and the infrastructure in these areas. Understanding these changes is essential for developing adaptation strategies that can minimize the harmful effects that may result.

CAN-EWLAT is a science-based planning tool for climate change adaptation of coastal infrastructure related to future water-level extremes and changes in wave climate. The tool includes two main components:

1. Vertical allowance; and
2. Wave climate.

CAN-EWLAT was developed primarily for DFO Small Craft Harbours (SCH) locations, but it should prove useful for coastal planners dealing with infrastructure along Canada's ocean coastlines.

Canadian Extreme Water Level Adaptation Tool (CAN-EWLAT) can be accessed here:
http://www.bio.gc.ca/science/data-donnees/can-ewlat/index3-en.php

2.11 References

Abeysirigunawardena, D. S., Smith, D. J., & Taylor, B. (2011). Extreme Sea Surge Responses to Climate Variability in Coastal British Columbia, Canada. Annals of the Association of American Geographers, 101(5), 992–1010. https://doi.org/10.1080/00045608.2011.585929

Agilan, V., & Umamahesh, N. V. (2017). What are the best covariates for developing non-stationary rainfall Intensity-Duration-Frequency relationship? Advances in Water Resources, 101, 11–22. https://doi.org/10.1016/J.ADVWATRES.2016.12.016

Agilan, V., Resources, N. U.-A. in W., & 2017, undefined. (n.d.). What are the best covariates for developing non-stationary rainfall intensity-duration-frequency relationship? Elsevier. Retrieved from https://www.sciencedirect.com/science/article/pii/S0309170816308211

Ali A., Singh A., (2019), Asset Management & Climate Change: Planning For a Future Of Uncertainty, WEAO 2019 Technical Conference, Toronto, Ontario

Assembly of First Nations (AFN), 2008, Climate Change and Water: Impacts and Adaptations for First Nations Communities, Funded by Natural Resources Canada: Climate Change Impacts and Adaptation Program (CCIAP), Environmental Stewardship Unit, March 2008

Atkinson, D.E., Forbes, D.L. and James, T.S. (2016): Dynamic coasts in a changing climate; in Canada's Marine Coasts in a Changing Climate, (ed.) D.S. Lemmen, F.J. Warren, T.S. James and C.S.L. Mercer Clarke; Govern-ment of Canada, Ottawa, Ontario, p. 27–68

Attema, J. J., Loriaux, J. M., & Lenderink, G. (2010). Linking increases in hourly precipitation extremes to atmospheric temperature and moisture changes Related content Extreme precipitation response to climate perturbations in an atmospheric mesoscale model. Environmental Research Letters. https://doi.org/10.1088/1748-9326/5/2/025208

Brandes, D., J. G. Hoffman, and J. T. Mangarillo (2005), Base flow recession rates, low flows, and hydrologic features of small watersheds in Pennsylvania, USA, J. Am. Water Resour. Assoc., 41(5), 1177–1186.)

Brown, R. D., & Braaten, R. O. (1998). Spatial and temporal variability of Canadian monthly snow depths, 1946-1995. https://doi.org/10.1080/07055900.1998.9649605

Bush, E., & Lemmen, D. (2019). Canada's changing climate report.

Bush, E.; Lemmen, D. S. (2019). Canada's Changing Climate Report. Government of Canada: Ottawa, ON, Canada, 444. Retrieved from https://www.nrcan.gc.ca/environment/impacts-adaptation/21177

Canadian Institute of International Affairs (CIIA) (2005), "The Transboundary Water Resources of Canada and the United Sates. CIAA: Toronto.

Climate Atlas of Canada (2019), Data Sources and Methods, https://climateatlas.ca/data-sources-and-methods, accessed February 2020

Engineers Canada (2020), PIEVC the Engineering Protocol, https://pievc.ca/protocol, accessed February 2020.

EPA (2014), Climate Change Adaptation Implementation Plan, United States Environmental Protection Agency Office of Water, Report Number: EPA-100-K-14-001A, May 2014

EPA, (2015), Climate Ready Water Utilities Adaptation Strategies Guide for Water Utilities, Adaptation Strategies Guide for Water Utilities, United States Environmental Protection Agency, Office of Water (4608-T) EPA 817-K-15-001.

Field, C.B, et. al. (2007), North America., In Parry, M.L. et al (eds). Cliamte Change 2007: impacts, adaptaion and vulnerability. Contrivution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambride: Cambride University Press, pp. 617-52

Future Snowpack Variability over the Northern Hemisphere in the Second Generation Canadian Earth System Model. Journal of Climate, 30(12), 4633–4656. https://doi.org/10.1175/JCLI-D-16-0612.1

Gan, T.Y. (2000), Reducing vulnerability of water resources of Canadian Prairies to potential droughts and possible climate warming", Water Resources Management, v. 14. No. 2, p. 111-135

Gemin J., Coleman P., Phu K., (2019), Climate Change Adaptation – New CSA Standard For Assessment, WEAO 2019 Technical Conference, Toronto, Ontario

Gov. AU (2016), Approaches to Climate Change Impact Assessment, https://www.climatechangeinaustralia.gov.au/en/ , accessed February 2020

Greenan, B.J.W., James, T.S., Loder, J.W., Pepin, P., Azetsu-Scott, K., Ianson, D., Hamme, R.C., Gilbert, D., Tremblay, J-E., Wang, X.L. and Perrie, W. (2018): Changes in oceans surrounding Canada; Chapter 7 in (eds.)

Bush and Lemmen, Canada's Changing Climate Report; Government of Canada, Ottawa, Ontario, p. 343–423.

Health Canada (2005), "Your Health and a Changing Climate: Information for Health Professionals".

Institute for Catastrophic Loss Reduction (2012). Telling the weather story. Toronto: Insurance Bureau of Canada.

J. Boyle, M. Cunningham, J. Dekens (2013), Climate Change Adaptation and Canadian Infrastructure, A review of the literature, The International Institute for Sustainable Development, November 2013

James, T.S., Henton, J.A., Leonard, L.J., Darlington, A., Forbes, D.L. and Craymer, M. (2014): Relative sea level rise projections for Canada and the adjacent mainland United States; Geological Survey of Canada, Open File 7737, 67 p., <http://publications.gc.ca/collections/collection_2016/ rncan-nrcan/M183-2-7737-eng.pdf>.

Kharin, V. V, Zwiers, F. W., Zhang, · X, Wehner, · M, Zhang, X., & Wehner, M. (2013). Changes in temperature and precipitation extremes in the CMIP5 ensemble. Climatic Change, 119, 345–357. https://doi.org/10.1007/s10584-013-0705-8

Kundzewicz, Z.W., L.J. Mata, N.W. Arnell, P. Döll, P. Kabat, B. Jiménez, K.A. Miller, T. Oki, Z. Sen and I.A. Measured effects of new lake surfaces on regional precipitation. (2010). https://doi.org/10.1623/hysj.52.5.936

Shiklomanov, 2007: Freshwater resources and their management. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 173-210.

Lemmen, D.S., Warren, F.J., James, T.S. and Mercer Clarke, C.S.L. (eds.) (2016): Canada's Marine Coasts in a Changing Climate; Government of Canada, Ottawa, Ontario, 274 p. <https://www.nrcan.gc.ca/sites/www. nrcan.gc.ca/files/earthsciences/pdf/assess/2016/Coastal_Assessment_ FullReport.pdf>.

Li, G., Zhang, X., Cannon, A. J., Murdock, T., Sobie, S., Zwiers, F., … Qian, B. (2018a). Indices of Canada's future climate for general and agricultural adaptation applications. Climatic Change, 148(1–2), 249–263. https://doi.org/10.1007/s10584-018-2199-x

Li, G., Zhang, X., Cannon, A. J., Murdock, T., Sobie, S., Zwiers, F., … Qian, B. (2018b). Indices of Canada's future climate for general and agricultural adaptation applications. Climatic Change, 148(1–2), 249–263. https://doi.org/10.1007/s10584-018-2199-x

Mehdi, B.B. et al. (2007), Impacts of Climate Change on Canadian Water Resources, Brace Centre for Water Resources Management: Ste. Anne de Bellevue, Quebec [online: NRCan: www.c-ciarn.ca/pdf/ciarn_cwra.pdf

Mudryk, L. R., Derksen, C., Howell, S., Laliberté, F., Thackeray, C., Sospedra-Alfonso, R., … Brown, R. (2018). Canadian snow and sea ice: historical trends and projections. The Cryosphere, 12, 1157–1176. https://doi.org/10.5194/tc-12-1157-2018

Sharma, A., Wasko, C., & Lettenmaier, D. P. (2018, November 1). If Precipitation Extremes Are Increasing, Why Aren't Floods? Water Resources Research, Vol. 54, pp. 8545–8551. https://doi.org/10.1029/2018WR023749

Solomon, S., D. Qin, M. Manning, R.B. Alley, T. Berntsen, N.L. Bindoff , Z. Chen, A. Chidthaisong, J.M. Gregory, G.C. Hegerl, M. Heimann, B. Hewitson, B.J. Hoskins, F. Joos, J. Jouzel, V. Kattsov, U. Lohmann, T. Matsuno, M. Molina, N. Nicholls, J. Overpeck, G. Raga, V. Ramaswamy, J. Ren, M. Rusticucci, R. Somerville, T.F. Stocker, P.

Whetton, R.A. Wood and D. Wratt, 2007: Technical Summary. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA. (Hereafter: Solomon et al., 2007.)

Sospedra-Alfonso, R., & Merryfield, W. J. (2017). Influences of Temperature and Precipitation on Historical and THE DYNAMICS OF NOVA SCOTIA'S CLIMATE. (n.d.). In Natural History of Nova Scotia. Retrieved from https://ojs.library.dal.ca/NSM/issue/view/349

Vincent, L. A., Zhang, X., Mekis, É., Wan, H., & Bush, E. J. (2018). Changes in Canada's Climate: Trends in Indices Based on Daily Temperature and Precipitation Data. Atmosphere-Ocean, 56(5), 332–349. https://doi.org/10.1080/07055900.2018.1514579

Chapter 3 Source Water Development 64

3.1 General 64

3.2 Surface Water 64

3.2.1 Quantity Assessment 64

3.2.2 Watershed Delineation and Protection 65

3.2.2.1 Watershed Delineation 65

3.2.2.2 Watershed Protection 65

3.2.3 Water Treatability 65

3.2.3.1 Laboratory Scale Testing Program 65

3.2.3.2 Pilot Scale Testing Program 65

3.2.4 Required Intake Facility 67

3.2.5 Impoundments and Reservoirs 67

3.3 Groundwater Supply 67

3.3.1 Location 68

3.3.2 Exploration Program 69

3.3.3 Well and Aquifer Hydraulic Testing 70

3.3.4 Groundwater Quality 72

3.3.5 Disinfection and Treatment 72

3.3.6 Well Construction 73

3.3.6.1 Casing 74

3.3.6.2 Stabilization Liners and Screens 75

3.3.6.3 Grouting 75

3.3.6.4 Well Screens 75

3.3.6.5 Well Development 75

3.3.6.6 Disinfection 76

3.3.6.7 Abandonment or De-commissioning? 76

3.3.7 Pump Hydraulics 76

3.3.8 Wellhead Requirements 77

3.3.8.1 Discharge Piping 77

3.3.8.2 Pitless Well Head Completion 77

3.3.9 Monitoring 78

3.3.9.1 Observation Wells 78

3.3.9.2 Well Head Protection Plan 78

3.3.9.3 Commissioning 78

3.4 Source Water Protection ... 79
3.4.1 Capture Zone Delineation ... 80
3.4.2 Risk Analysis ... 80
3.4.3 Monitoring Plan ... 80
3.4.4 Emergency-Contingency Plan ... 81

Chapter 3 Source Water Development

3.1 General

In selecting the source of water to be developed, the design engineer should prove to the satisfaction of the utility and the regulator that an adequate supply of water is available. In addition, it should be demonstrated that the water source to be developed is the most feasible source and meets, or the proposed level of treatment meets, the appropriate water quality guidelines or standards.

A *surface water supply source* includes all tributary streams and drainage basins, natural lakes and artificial reservoirs or impoundments above the point of water supply intake.

A *groundwater supply* includes all water obtained from dug, drilled, bored or driven wells.

Groundwater under the direct influence of surface water (GUDI) is water beneath the surface of the ground with:

- Significant occurrence of insects or other macro-organisms, algae or large diameter pathogens such as Giardia lamblia, or
- Significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity or pH that closely correlate to climatological or surface water conditions.

Criteria used for determination of GUDI differs between jurisdiction, and the appropriate regulatory agency should be consulted.

3.2 Surface Water

3.2.1 Quantity Assessment

A surface water quantity assessment should include a review of the available yield of the water supply.

Yield assessments can be estimated using different methods. 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.

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 when considering climate change impacts, and a drought return period should be determined;
- A minimum drought return period of one in fifty years (i.e., 1/50-yr) should be used for calculating safe yield;
- A statistical analysis should be performed to determine the 1/20-yr return periods within a 95% confidence interval;
- A minimum drought duration of 60 days should be used;
- Where precipitation data is used to calculate yield, the runoff characteristics should adequately reflect the average conditions of the watershed;
- 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 extreme drought of 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 (increased due to climate change impacts) , and seepage;
- The yield should be adequate to provide ample water for other legal users of the source;

- Future precipitation projections should include consideration of climate change when calculating the safe yield.

3.2.2 Watershed Delineation and Protection

3.2.2.1 Watershed Delineation

All surface water supplies should have their watersheds geographically delineated. Features that should be indicated include the following:

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

3.2.2.2 Watershed Protection

The owner of the surface water supply should have adequate watershed protection in place. This may include, but not limited to, the following measures:

- Source Area Advisory Committee;
- Source Area Protection Plans; and
- Contingency Plans.

The respective provinces should be contacted for specific watershed protection regulations and requirements.

3.2.3 Water Treatability

All drinking water should meet drinking water standards and/or the *Guidelines for Canadian Drinking Water Quality* for the parameters identified by respective provincial regulators.

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.

3.2.3.1 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.

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 tests program can be used to estimate appropriate design parameters of the process equipment, to assist in the concept design of the water treatment facility, and in the determination of a budget cost for the facility.

3.2.3.2 Pilot Scale Testing 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 results should be used to confirm that the process is capable of treating 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 the course of a pilot study:

1. Average, maximum and peak design flow rates;
2. Influent and pilot plant effluent quality including colour, turbidity, temperature, pH, iron, manganese, natural organic matter, chlorine demand, trihalomethane formation potential, microbiological characteristics, and 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; and
   - Costs.
4. Flocculation requirements:
   - Mixing intensity; and
   - 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); and
   - 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, flow rate and backwash water quality;
   - Reject characteristics including flow rates and quality (if applicable); and
   - Scraping frequency and filter ripening periods (i.e., slow sand filtration).
7. Disinfection systems:
   - Chlorine demand;
   - Contact times;
   - Residuals;
   - Disinfection by-product formation potential;

- Intensity (UV systems only); and
- Inactivation.

8. Aeration systems:
   - Air loading and/or flow rates;
   - Mixing requirements;
   - Pressure requirements; and
   - Removal efficiencies.

9. Residuals handling and treatment:
   - Characterization of residual streams including sources, flows, solids content as well as chemical, physical and microbiological quality;
   - Treatment requirements including equalization, chemical addition, effluent quality and clarification requirements; and
   - Recycling feasibility.

3.2.4 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;
- An intake structure with a screen that meets Department of Fisheries and Ocean (DFO) intake velocity requirements.
- An intake that is set at optimum depth to draw water of highest quality
- An intake that is not be impacted by drought conditions;
- Consideration of redundancy;
- A method by which to clean the screen and/or the intake; and
- Located sufficient distance from shore to avoid shore wash influence.

3.2.5 Impoundments and Reservoirs

Impoundments and reservoirs should meet the following general requirements:

- Should be of sufficient volume to sustain, if possible the 1/50-yr 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 authority having jurisdiction;
- The hydraulic structure should be designed in accordance with the latest version of *the Canadian Dam Safety Association: Dam Safety Guidelines*, or the authority having jurisdiction; and
- The site should be made as secure as is reasonably possible through the use of fencing, signage and patrolling/policing, if necessary.

3.3 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 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 two hours at least once every seven days.

3.3.1 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 impacts;
- 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;
- Land uses in source water zones;
- Distance from existing production wells; and
- 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 set-backs from potential contaminant sources. Required separation distances are based on the time of travel to the well, and the persistence of the contaminant source. Further guidance on source water protection is provided in Section 3.4.

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);
- Wastewater treatment facilities; and
- Industrial activities (manufacturing or processing facilities).

Required setbacks are legislated as a part of water well regulations in each province (e.g. sewer pipelines, on-site sewage 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 Groundwater Under the Direct Influence of Surface Water (GUDI).

The location of production wells may also consider the long-term sustainable yield of the host aquifer. A watershed scale water-balance approach or groundwater modeling approach should be applied that considers climate, 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.

3.3.2 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 sources and water supply requirements.

Test drilling should be supervised by a qualified hydrogeologist to ensure that all available geologic and hydrogeologic 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; and
- 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.

3.3.3 Well and 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 one-hour steps);
- Constant-rate testing for at least 24 hours, or as specified by the local authority (completed production wells generally require a 72-hour test); and
- Recovery monitoring until well recovers to 95% of the static water level, or as specified by the local 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); and
- Calculated pumping rate between readings.

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

Hydraulic testing documentation should include:

- Well owner and location details for all wells involved (Site Map);
- Pumping test operator or sub-consultant details;
- Well identification and construction details (depth, diameter, casing stick up);
- Pumping test set-up details (pump size, pump elevation, riser pipe size, flow rate control, static water levels);
- Type of test (step, constant rate, recovery);
- Number of observation wells;
- 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; and
- Log of field observations including metering data to show flow rate adjustments.

Water quality samples should be collected during the constant-rate test at the following intervals:

- Within the first hour;
- Mid-point; and
- 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.

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[2]	Major ions, trace metals, chemical-physical parameters[1] TSS[2]	Major ions, trace metals, chemical-physical parameters[1] TSS[2] EPA 624[3] Total coliform/ E.coli[4] The following tests may be included if warranted, based on the well field setting: EPA 625[5] Pesticides (OCOP)[6] Gross Alpha, Beta & Gamma[7, 8]

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 MAC and IMAC parameters may be required by some jurisdictions.
1. TSS – total suspended solids.
2. EPA 624 – A series of 35 volatile organic compounds, including BTEX parameters (Benzene, Toluene, Ethyl Benzene and Xylenes: 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-volatile organic compounds.
5. 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 are analysed.
7. Total Uranium and Lead-210 may be required instead.

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);
- Estimated sustainable pumping rate for the production well(s);
- 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; and
- 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 agency and proponent.

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

3.3.4 Groundwater Quality

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

- Are compared to the Health Canada Guidelines for Canadian Drinking Water Quality (GCDWQ);
- 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; and
- Provide evidence of contaminant sources that were not identifiable as part of the well siting study.

The regulator should be consulted for advice on use of other criteria for which no GCDWQ values exist.
If the GCDWQ 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, uranium);
  - Drawdown effects (e.g. hardness, dissolved solids, 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, landfill); and
- Non-point source contaminant sources (e.g. agriculture, road salting).

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

All groundwater quality testing associated with a municipal groundwater supply should be performed by a CALA member (Canadian Association for Laboratory Accreditation).

3.3.5 Disinfection and Treatment

All raw municipal water 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, cryptosporidium). If the source water turbidity is elevated, chemically assisted microfiltration may be needed. Barring system-specific exceptions, groundwater should be disinfected section 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, 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.

3.3.6 Well Construction

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

Wells addressed by this manual 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 land local conditions. Such sources commonly draw groundwater under the direct influence of surface water, and may require treatment in compliance with surface water standards.

All well construction work should be properly supervised by qualified personnel. A log of each well should be developed, showing the borehole lithology and stratigraphy, and well construction details (e.g. casing, open borehole or screen, slot-size) . A copy of each well log should be provided to the regulatory agency and to the proponent.

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

Figure 3.1 provides an example of open-borehole well construction, and Figure 3.2 provides an example of screened well construction. Both figures are from AWWA A100-97).

Figure 3.1 Example of Open-Borehole Well Construction

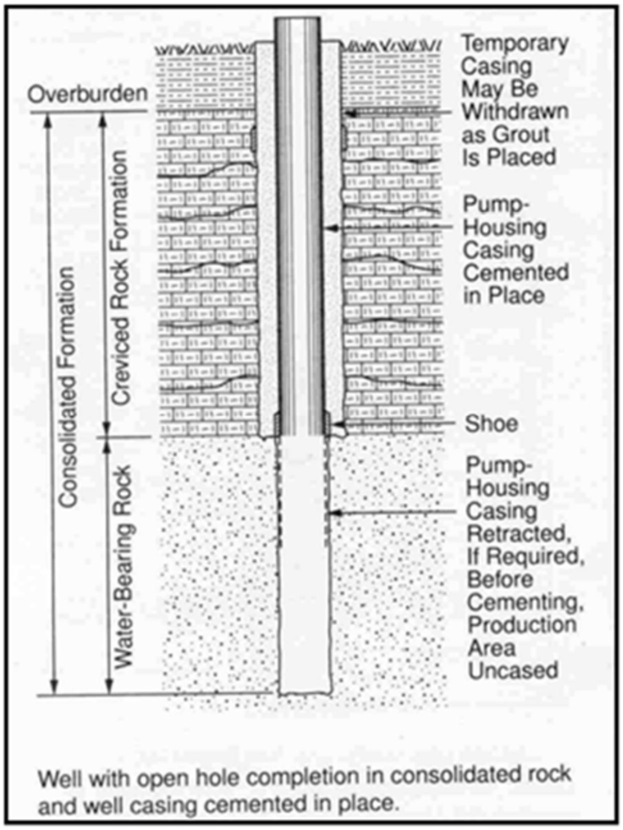
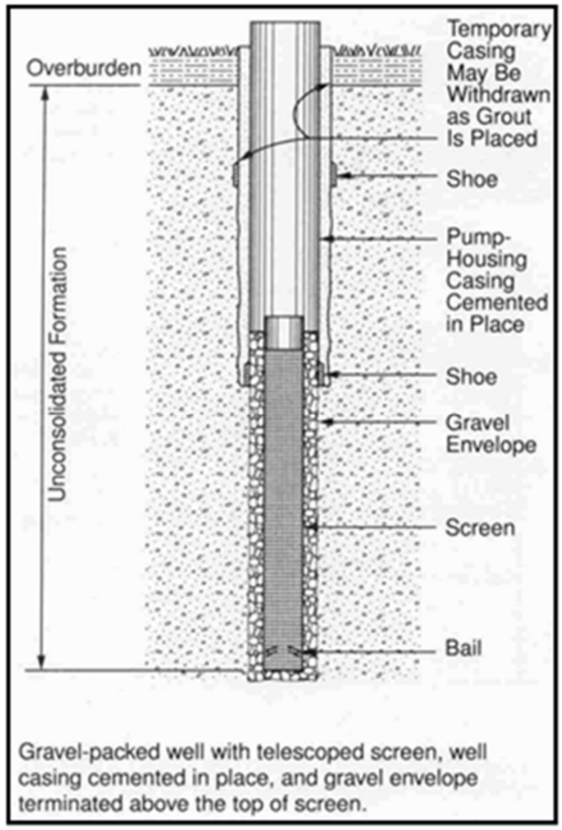


Figure 3.2 Example of Screened Well Construction



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 regulator.

3.3.6.1 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 be as per AWWA or ASTM specifications, or regulatory agency 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 regulator. 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 flow rates, pumping equipment specifications, well head completion appurtenances, and screen-liner requirements. Typical well completion diameters for municipal wells should be 203 mm, 254 mm and 305 mm. The minimum casing diameter should be 203 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, outer grouted casings).

3.3.6.2 Stabilization Liners and 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 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; and
- 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.

3.3.6.3 Grouting

Placement of an annular seal is not a requirement in all jurisdictions of Atlantic Canada. Grouting is, however, 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 regulator. 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 tremmie 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.

3.3.6.4 Well Screens

All screened wells must be properly designed, based upon AWWA or other specifications, as approved by the regulatory agency. 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.

3.3.6.5 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.

3.3.6.6 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 agency 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.

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

3.3.6.7 Abandonment or De-commissioning?

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 abandoned as per the requirements of the regulator.

All pumps, wire, and piping will be first 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 abandonment.

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. Abandonment 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 abandonment should be supervised by qualified personnel.

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

Proposed abandonment procedures should be approved by the regulator. The procedure used should then be documented and submitted to the regulatory agency and to the proponent.

3.3.7 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 and vertical lift requirements;
- Friction/head losses;
- Service pressure; and
- Long-term power requirements.

Municipal 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.

3.3.8 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, telemetry);
- Design of associated distribution control and/or treatment facilities;
- 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; and
- Well instrumentation requirements (e.g., water level tube, down-hole pressure/water level transducers for SCADA monitoring and telemetry).

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, water tight 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 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.

3.3.8.1 Discharge Piping

Discharge or riser piping should meet AWWA or ASTM specifications for water supply pipe.
Discharge piping should be designed to minimize friction losses, and be equipped with the following:

- Check valve;
- Shutoff valve;
- Pressure gauge;
- Total or accumulating flow meter; and
- 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 discoloration into the distribution lines.

Discharge piping should be protected against entrance of contaminants. The production well top of casing elevation will be above the 100 year flood level and any climate change impact.

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.

3.3.8.2 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 100 year flood level. Pitless units should make provision for an access tube within which water levels can be independently measured.

3.3.9 Monitoring

Although detailed well head and aquifer protection planning is not included in this design manual, it is recommended that a municipal well field completion include a provision for routine surveillance of water levels and water quality in both the pumping well and the host aquifer. The regulatory agency should be contacted for their requirements.

3.3.9.1 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 100 year flood stage and any climate change impact. 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.

3.3.9.2 Well Head Protection Plan

A Well Head Protection Plan (WHPP) should be prepared to provide long term management and protection of the groundwater supply. This plan generally comprises of mapping of capture zones, an assessment of risk posed by land uses in the area, monitoring, education, and reporting. Each province provides specific guidance for well head protection planning.

3.3.9.3 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 one to three 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; and
- 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, flow rate and water quality data should be reviewed by a qualified hydrogeologist, and recommendations made for adjustments or further monitoring as warranted.

3.4 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. Procedures vary for surface water and groundwater sources. Source water protection forms the first step of the Multi-barrier Approach:

- Protect the Source (Source Water Protection Plan);
- Provide a certified operator;
- Provide Treatment and/or Disinfection;
- Monitor raw and treated water quality;
- Reporting and Regulations; and
- Provide operator continuing education.

Typical components of a source water protection plan 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; and
- Stakeholder outreach and education.

Source water protection plans are typically administered by a Source Water Protection Committee, composed of utility operators, municipal staff, government regulators, planners, community stakeholders, land owners, and technical specialists. The committee conducts regular meetings to discuss monitoring data and activity within the source water protection area.

Typical components of a Source Water Protection Plan (SWPP) include:

- 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;
- A Risk Analysis and property-specific risk tables;
- A Monitoring Plan; and
- An Emergency/Contingency Plan.

3.4.1 Capture Zone Delineation

Capture zones are typically delineated based on aquifer vulnerability and Time of Travel (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 2 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.

Capture zones for larger municipal supplies are often delineated using 3D numerical models. For smaller public supplies, and in less complex settings, a 2D-anlytic 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.

3.4.2 Risk Analysis

The level of risk to drinking water varies according the Contaminant of Concern (COC), and increases in areas closer to the well, where travel times are shorter. Some contaminants move at the speed of the groundwater, and others move more slowly 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. Land uses associated with COCs that pose a lower health risk, and those which are less likely to reach the well, are generally manageable in the outer zones of a SWPA. Risk tables may be developed in order to assist the Source Water Protection Committee in assessing risk and preparing and administering a Source Water Protection Plan.

3.4.3 Monitoring Plan

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

- Daily volume pumped from individual wells;
- Daily maximum and minimum water levels;
- Water quality sampling from production wells;
- Water quality sampling from observation wells; and
- Well field / SWPA inspection.

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 Contingency/Emergency Plan would be invoked. In most cases (as for organochlorines and volatile organic compounds (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 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 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 sewage disposal systems;
- Condition of fuel oil storage tanks; and
- Unauthorized fires/burning.

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

3.4.4 Emergency-Contingency Plan

An Emergency-Contingency Plan 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 Public Works representative, often a supervising municipal engineer.

Elements of an Emergency-Contingency Plan may include:

- Notification.
- Assessment.
- Communications.
- Response (e.g. containment).
- Post Emergency Activities (e.g. remediation, confirmatory monitoring).
- Documentation.
- Public Relations.

In the event that an emergency involves a chemical spill, the local Fire Department’s HAZMAT team will generally act as the first responder.

Chapter 4 Design of Water Treatment Facilities 85

4.1 Design Basis 85

4.1.1 Design Flows 85

4.1.2 Target Contaminants and Process Selection 85

4.2 Site Selection 85

4.2.1 General 85

4.2.2 Proximity to Existing Infrastructure 86

4.2.3 Climate Change Infrastructure Resilience 86

4.2.4 Separation Distances and Future Site Expansion 86

4.2.5 Hydraulic Grade Lines 86

4.2.6 Topography and Geotechnical Investigations 87

4.2.7 Land Ownership 87

4.2.8 Site-Related Life-cycle Costs 87

4.3 Layouts 88

4.3.1 Site Layout 88

4.3.2 Building/Plant Layout 88

4.3.3 Provisions for Future Expansion 88

4.4 Piping & Instrumentation Diagrams and Plant Control 89

4.5 Stand-by Power 89

4.6 Chemical Feed Facilities 89

4.6.1 General 89

4.6.1.1 Plans and Specifications 89

4.6.1.2 Chemical Application 89

4.6.2 Chemical Feed System Design 90

4.6.2.1 Equipment Design 90

4.6.2.2 Number of Chemical Feed Systems 90

4.6.2.3 Control of Chemical Feed Systems 90

4.6.2.4 Dry Chemical Feeders 90

4.6.2.5 Positive Displacement Metering Pumps 91

4.6.2.6 Siphon Control 91

4.6.2.7 Cross-Connection Control 91

4.6.2.8 Make-up Water Supply 91

4.6.2.9 Chemical Storage Requirements 91

4.6.2.10 Batch Tanks 92

4.6.2.11 Day Tanks 92
4.6.2.12 Solution Transport 93
4.6.2.13 Handling 93
4.6.3 Chemicals 93
4.6.3.1 General 93
4.6.3.2 Chlorine Gas 94
4.6.3.3 Acids and Caustics 94
4.6.3.4 Sodium Chlorite for Chlorine Dioxide Generation 95
4.7 Plant Facilities 95
4.7.1 Maintenance and Storage Facilities 95
4.7.2 Offices and Control Area 95
4.7.3 Washroom Facilities 95
4.7.4 Lunchrooms 95
4.7.5 Facility Water Supply 95
4.8 Laboratory Facilities 95
4.8.1 General 95
4.8.2 Testing Equipment 96
4.8.3 Physical Facilities 96
4.9 Monitoring 96
4.9.1 Sample Taps and Locations 96
4.9.2 On-line Monitoring Equipment 97
4.10 Operations and Safety 97
4.10.1 Operation and Maintenance Manuals 97
4.10.2 Safety and Hazardous Materials 97
4.11 Facility Construction 98
4.11.1 Basic Materials of Construction 98
4.11.1.2 Prefabricated Tankage 98
4.11.1.3 Superstructure 98
4.11.1.4 Access, Ladders, Catwalks and Stairways 98
4.11.2 Valves and Piping Materials 98
4.12 Labeling and Colour Coding 99
4.12.1 Commissioning and Testing 99
4.12.2 Security 100
4.13 Remote Operation of Facilities 100

4.14 Other Considerations 100

Chapter 4 Design of Water Treatment Facilities

4.1 Design Basis

4.1.1 Design Flows

Water treatment facilities should be designed such that major process equipment and facilities 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 projections. Maximum Day demand is the maximum amount of water supplied to the system on any given day within a calendar year.

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 facilities 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 and Process Selection

Typically, the target contaminants will be identified and the process selection will be conducted in a *Pre-Design Report*. The process selection should take into consideration the ability to meet all water quality requirements in the *Guidelines for Canadian Drinking Water Quality (GCDWQ)*, or water quality requirements as adopted by the regulator.

The designer should confirm the *Pre-Design Report* findings prior to design of a new water treatment facility. 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 1.2.2 for a further description of Pre-Design Report recommendations.

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, the test for redundancy should consider the process with the largest single component out of service.

4.2 Site Selection

4.2.1 General

New water treatment facilities should be located such that the selected site maximizes the use of existing infrastructure. In some cases, a new water treatment facility 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 water treatment facility 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; and
- 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 water treatment facility. The facility 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 plant 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 water treatment facility as close as possible to existing transmission mains will result in lower transmission main extension costs;
- Proximity to sanitary sewer services: in some instances, existing sanitary sewer services will be close enough to permit discharge of plant wastes to the sewer, 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; and
- Proximity to public access routes: locating a water treatment facility in close proximity to 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 water treatment facility. This may entail ensuring the facility is constructed above flood lines and also that the access to the facility does not require transport through flood areas, to minimize impact of extreme weather on facility operations. Water treatment facilities are typically extremely energy-intensive, making significant indirect contributions to greenhouse gas emissions when connected to conventional power grids. When practical, measures should be taken to minimize non-essential energy via energy-efficient building design (heating, insulation, lighting, construction materials, etc.). However, the most significant reduction of total power consumption at a typical water treatment facility is likely to be achieved by process and equipment selection and optimization. An example of this is consideration of overall pumping efficiency as a primary component in a pump selection process. A holistic approach to the impacts of the facility on climate change should be taken, considering the inputs required for operation and maintenance (power, chemicals, consumable materials, etc.) over the life of the facility.

4.2.4 Separation Distances and Future Site Expansion

When possible, water treatment facilities 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 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).

4.2.5 Hydraulic Grade Lines

The design of new water treatment facilities 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 and Geotechnical Investigations

Water treatment facilities should be located 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 facilities should be located in locations that exhibit relatively good drainage patterns and dry soil conditions. Such locations prevent the possibility of untreated groundwater and/or surface water intrusion into underground conveyance structures. All water facilities should be located above the 100-year return period flood levels with an additional safety factor provided in consideration of the effects of climate change.

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; and
- 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 water treatment facility. 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; and
- 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 Net-Present-Worth (NPW) analysis. A NPW analysis takes into account 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 NPW 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 climate change resilience;
- Provisions for expansion of plant waste treatment and disposal facilities;
- Access roads, driveways and walkways;
- Site grading and site drainage;
- Chemical delivery and storage; and
- Security-related issues (e.g., fence lines).

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; and
- Dehumidification (if required).

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

- Equipment accessibility for operation, servicing, and removal;
- Flexibility of operation;
- Convenience and ease of maintenance;
- Back-up power requirements;
- Separation of chemical storage and feeding;
- Manual overrides for automated controls;
- Location of electrical equipment in cool, dry places;
- Redundancy and servicing requirements;
- Spare parts room;
- Provision for removal of equipment;
- Drainage of process areas and process piping/conduits;
- Safety provisions including alarms, railings, etc.; and
- Potential for cross-connections.

Some chemical feed and/or process areas may have specific requirements. Refer to Chapter 4 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 HVAC and electrical systems; and
- Provision of wall castings for future piping penetrations.

4.4 Piping & Instrumentation Diagrams and Plant Control

Piping and Instrumentation (P&ID) diagrams should be developed for all water treatment facilities and should be provided in the detailed design drawings. Copies should be made available at the facility for use by operations and managerial staff. P&ID diagrams should include all major and minor processes along with all ancillary process equipment.

All plants should be designed with a user-friendly human-machine interface (HMI) system to facilitate plant operation and on-line 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. Consideration should also 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.

All electrical controls should be located above grade, in areas not subject to flooding or impacts of climate change.

4.5 Stand-by Power

Dedicated stand-by power should be provided such that water may continue to be treated and supplied to meet the average daily demand during power outages. Alternatives to permanent stand-by power may be considered with proper justification by the authority having jurisdiction (e.g. provision of infrastructure for connection of portable generator).

4.6 Chemical Feed Facilities

4.6.1 General

4.6.1.1 Plans and 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 NSF approval for use in potable water treatment;
- Operating and control procedures including proposed application rates; and
- Descriptions of testing equipment and procedures.

4.6.1.2 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; and
- Ensure maximum efficiency of treatment.

4.6.2 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.

4.6.2.1 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; and
- Chemical feeders and pumps should operate at no less than 20% of feed range unless two (2) 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.

4.6.2.2 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 Chapter 4);
- Where redundancy is provided, the stand-by unit(s) should be of sufficient capacity to replace the duty unit(s); and
- 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.

4.6.2.3 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 flow rates;
- 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; and
- Weigh scales are recommended for fluoride solution feed systems.

4.6.2.4 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; and
- Provide a dust enclosure and/or collection system.

4.6.2.5 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 flow rates against the maximum pressure at the point of injection;
- Be outfitted with calibration columns and pressure relief valves; and
- A minimum of one (1) duty and one (1) 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.

4.6.2.6 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; and
- Providing a suitable air gap.

4.6.2.7 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;
- Liquid chemical cannot be siphoned through solution feeders into the process water as per section 4.6.2.5.; and
- No direct connection exists between any component of the treatment process tankage and the sewer. Provide an air gap between a receiving sewer/waste drain and process tank drain/overflow piping .

4.6.2.8 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;
- 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 4.7.5; and
- Be protected from backflow and cross-connections as specified in sections 4.6.2.5 and 4.6.2.6, respectively.

4.6.2.9 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/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; and
- Material Safety Data Sheets (MSDS) 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; and
- Bulk liquid storage to provide a minimum 150 % of tanker truck shipping capacity.

4.6.2.10 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 (1) solution tank should be provided (two (2) is recommended for redundancy purposes);
- Solution/batch tanks should be covered, including access ports;
- Subsurface solution tanks should not be used; if absolutely necessary, they should:
  - Be free from sources of possible contamination; and
  - Ensure positive drainage for ground waters, 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; and
- Tankage is to be labeled as per Section 4.12.

4.6.2.11 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 4.6.2.9;
- A minimum of one (1) 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 this 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; and
- Tankage should be labeled as per Section 4.12.

4.6.2.12 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; and
- Clearly colour coded as per section 4.12.

4.6.2.13 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 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; and
- Provision should be made for measuring quantities of chemicals used to prepare feed solutions.

4.6.3 Chemicals

4.6.3.1 General

Chemical shipping containers should be fully labeled, including:

- Chemical name;
- Purity;
- Concentration;
- Supplier name and address; and
- Date of delivery.

Chemicals and water contact materials should meet *NSF/ANSI/CAN 60: 2018 Drinking Water Treatment Chemicals – Health Effects* and *NSF/ANSI/CAN 61: 2018 Drinking Water System Components – Health Effects* where these materials are available for the application. Concrete and some other materials commonly used in drinking water facilities are acceptable without NSF certification—however, chemical admixtures and concrete coatings used for tanks in contact with water should be.

Provisions should be considered for assay of chemicals delivered.

4.6.3.2 Chlorine Gas

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

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; and
- Provided with doors equipped with panic hardware, assuring ready means of exit and opening outwards only to the building exterior.

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
- Stored in areas not in direct sunlight or exposed to excessive heat.

Where chlorine gas is used, the room should be constructed to provide the following:

- 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 floorand 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;
- Inspection window;
- 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; and
- A balance located in front of the inspection window should be provided.

4.6.3.3 Acids and 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.

4.6.3.4 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 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 so as 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; and
- Check valves should be provided to prevent backflow of chlorine into the sodium chlorite piping.

4.7 Plant Facilities

4.7.1 Maintenance and Storage Facilities

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

4.7.2 Offices and Control Area

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 and a telephone. Additional offices may be required for plant staff. Security cameras and CCTV monitors, if provided, should also be located in this area.

4.7.3 Washroom Facilities

A minimum of one (1) male and one (1) female washroom facility should be provided. Shower facilities 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 common washroom. Designers should consult local building and/or plumbing codes for the minimum facilities required.

4.7.4 Lunchrooms

A lunchroom should be provided and should be separate from all control and laboratory areas.

4.7.5 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 contact time has been achieved.

4.8 Laboratory Facilities

4.8.1 General

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

Some jurisdictions may require quarterly confirmation of analytical results from an accredited laboratory, for appropriate QA/QC for continuous on-line instrumentation.

4.8.2 Testing Equipment

As a minimum, the following laboratory equipment should be specified:

- All water facilities should provide the means necessary for obtaining water quality samples from select locations in both the water treatment plant and the distribution system;
- Water treatment facilities should have the following bench-top equipment:
  - Nephelometric turbidity meter;
  - pH meter;
  - Free and total chlorine residual analyzers;
  - Spectrophotometer;
  - Titration equipment if required for water quality testing specific to the facility;
  - Glassware appropriate for preparing reagents and analysis (e.g., pipettes, beakers, volumetric flasks, graduated cylinders, Erlenmeyer flasks);.
  - Deionized water;
  - Thermometer;
  - Fume hood if required for specific reagents or water quality testing specific to the facility; and
  - Analytical balance to 0.1 mg accuracy.
- Surface water treatment facilities 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 GCDWQ MAC/AOs;
- Fluoridated water supplies should have equipment capable of measuring fluoride to a lower detection limit below that of the treatment standard;
- Systems which utilize poly- and/or orthophosphates should have equipment capable of measuring phosphates from 0.1 to 20 mg/L;

4.8.3 Physical Facilities

All water treatment facilities should have sufficient bench space, cabinetry/storage, ventilation, lighting and sinks.

An eye wash 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.

Air conditioning is recommended for all personnel areas.

4.9 Monitoring

4.9.1 Sample Taps and 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.

4.9.2 On-line Monitoring Equipment

Water treatment plants should provide continuous on-line monitoring for the following parameters:

- All water treatment plants should monitor the following:
  - 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;
  - ADisinfection residual in treated water leaving the facility; and
  - Raw water, treated water, and waste water flow.
- In addition to the above, surface water treatment plants should also monitor the following:
  - Clarified (pre-filter), individual post-filter effluent turbidities and backwash turbidity;
  - Flocculation tank pH;
  - Raw and treated water colour.
- 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 on-line monitoring instrumentation should be considered and is encouraged where conditions warrant. Advanced monitoring for parameters such as online TOC, UV254, streaming current, DBPfp, etc. may be desirable for more in-depth water quality monitoring and process control.

4.10 Operations and Safety

4.10.1 Operation and Maintenance Manuals

An Operation and Maintenance 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.

4.10.2 Safety and Hazardous Materials

All water treatment plants should be adequately equipped to meet requirements of the current Occupational Health and Safety Act. All water treatment plant staff should be adequately trained in emergency first aid, confined spaces (if applicable), and Workplace Hazardous Materials Information System (WHMIS). All Material Safety Data Sheets (MSDS) should be made available at the locations in which the potentially hazardous material is used. A safety program is recommended for implementation at all water treatment plants.

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 4.6.3.2.
- Respiratory protective equipment meeting the Occupational Health and Safety Act, General Safety Regulation – Selection of Respiratory Equipment, 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; and

- 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:
  - Minimum one (1) pair of rubber gloves;
  - One (1) dust respirator certified for toxic dusts;
  - Protective clothing;
  - Goggles or face mask; and
  - 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;
- Standard Operating Practices (SOPs) should be developed and contingency plans should be documented.

4.11 Facility Construction

4.11.1 Basic Materials of Construction

4.11.1.1 Concrete Tankage

Concrete tankage should be cast-in-place, steel reinforced concrete tankage, conforming to current CSA and ASTM standards.

4.11.1.2 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.

4.11.1.3 Superstructure

In general, all water treatment plants 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 taking into account projected climate change impacts. 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. Where components of the facility are to be located outside a building, the designer must consider the effects of extreme weather such as heavy and accumulative snowfall/snowdrifts, high winds, extended cold temperatures, 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).

4.11.1.4 Access, Ladders, Catwalks and Stairways

Access hatches, stairways, catwalks and ladders 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 side 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.

4.11.2 Valves and 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 polyvinyl chloride (PVC), polyethylene (PE), 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.

4.12 Labeling and Colour Coding

To facilitate identification of process piping in water facilities, 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 following colour scheme:

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 & Coagulant Aids	Orange with Green Band
Potassium Permanganate	Violet
Soda Ash	Light Green with Orange Band
Sulfuric Acid	Yellow with Red Band
Sulfur Dioxide	Light Green with Yellow Band
Waste Piping	
Backwash Waste	Light Brown
Sludge	Dark Brown
Sewer (Sanitary)	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 sufficient contrast to easily differentiate the two, a 150 mm band of contrasting colour should be on one of the pipes at 750 mm intervals.

4.12.1 Commissioning and Testing

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

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.

4.12.2 Security

All water treatment facilities 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 should be provided at minimum.

4.13 Remote Operation of Facilities

Remote operation of the water treatment facility using a Supervisory Control and Data Acquisition (SCADA) systems should be considered. The SCADA system should:

- Be capable of monitoring and recording on-line 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; and
- Only be provided in-conjunction with an available off-site operator with an adequate response time.

4.14 Other Considerations

Consideration should be given to the design requirements and recommendations of all other provincial and national 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 this document, may impact the overall design of the facility.

Chapter 5 Design of Water Treatment Processes ... 106
5.1.1 Pre-sedimentation ... 106
5.1.2 Screening ... 106
5.2 Coagulation/Flocculation Process ... 106
5.2.1 General Description ... 106
5.2.2 Rapid Mixing ... 107
5.2.2.1 Chemical Injection ... 107
5.2.2.2 In-line Static Mixers ... 107
5.2.2.3 In-line Mechanical Mixers ... 107
5.2.2.4 Paddle-Type Rapid Mixer ... 107
5.2.3 Flocculation ... 108
5.2.3.1 Flocculation Basins ... 108
5.2.3.2 Flocculators ... 108
5.3 Clarification ... 108
5.3.1 Sedimentation ... 109
5.3.1.1 General ... 109
5.3.1.2 Conventional Sedimentation ... 109
5.3.1.3 Plate and Tube Sedimentation ... 110
5.3.1.4 Solids Contact Clarifiers ... 110
5.3.1.5 Upflow Sludge Blanket Clarifiers ... 110
5.3.1.6 Ballasted Flocculation ... 111
5.3.2 Dissolved Air Flotation ... 111
5.3.2.1 General ... 111
5.3.2.2 Design Criteria ... 112
5.3.3 Adsorption Clarification ... 112
5.4 Filtration ... 112
5.4.1 Rapid Rate Gravity Filtration ... 113
5.4.1.1 Pre-treatment ... 113
5.4.1.2 Rate of Filtration ... 113
5.4.1.3 Number of Units and Redundancy ... 113
5.4.1.4 Headloss and Control ... 113
5.4.1.5 Filter Flow Control ... 114
5.4.1.6 Structural and Hydraulic Details ... 114
5.4.1.7 Filter Media ... 115

5.4.1.8 Filter Underdrains 116
5.4.1.9 Surface Wash or Subsurface Wash 117
5.4.1.10 Filter to Waste 117
5.4.1.11 On-line Turbidity Monitoring 117
5.4.1.12 Filter Appurtenances 117
5.4.1.13 Backwashing 117
5.4.1.14 Air Scour 118
5.4.2 Rapid Rate Pressure Filtration 118
5.4.2.1 Rate of Filtration 118
5.4.2.2 Additional Requirements 118
5.4.3 Direct Filtration 119
5.4.3.1 Piloting and Approval Requirements 119
5.4.3.2 Pretreatment 119
5.4.3.3 General Design 120
5.4.3.4 Rate of Filtration 120
5.4.4 Slow Sand Filtration 120
5.4.4.1 Application 120
5.4.4.2 Number and Redundancy 120
5.4.4.3 General Design 120
5.4.4.4 Rate of Filtration 120
5.4.4.5 Underdrains 120
5.4.4.6 Filter Media 121
5.4.4.7 Water Depth and Headloss 121
5.4.4.8 Appurtenances 121
5.4.4.9 Scraping and Ripening 121
5.4.5 Biological Filtration 121
5.4.5.1 General Design 121
5.4.5.2 Piloting Requirements 122
5.4.6 Membrane Filtration 122
5.4.6.1 Applicable Processes 122
5.4.6.2 Number and Redundancy 123
5.4.6.3 Piloting Requirements 123
5.4.6.4 Membrane Materials 123
5.4.6.5 Membrane Configurations 124

5.4.6.6 Design Criteria ... 124
5.4.6.7 Integrity Testing ... 124
5.5 Disinfection ... 124
5.5.1 Chlorination ... 124
5.5.1.1 Inactivation Requirements ... 125
5.5.1.2 Residual Chlorine ... 126
5.5.1.3 Chlorination Equipment ... 126
5.5.1.4 General Guidelines ... 127
5.5.2 Alternate Disinfectants ... 128
5.5.2.1 Types of Alternate Disinfectants ... 128
5.5.2.2 Process Descriptions ... 128
5.5.2.3 Contact Time ... 129
5.5.2.4 Disinfectant Residual ... 130
5.5.2.5 Piloting Requirements ... 130
5.6 Softening ... 130
5.6.1 Lime or Lime-Soda Processes ... 130
5.6.2 Cation Exchange Processes ... 130
5.7 Aeration ... 131
5.7.1 Natural Draft Aeration ... 131
5.7.2 Forced or Induced Draft Aeration ... 132
5.7.3 Spray Aeration ... 132
5.7.4 Pressure Aeration ... 132
5.7.5 Packed Tower Aeration ... 132
5.7.5.1 Piloting Requirements ... 132
5.7.5.2 Process Design ... 133
5.7.5.3 Materials of Construction ... 133
5.7.5.4 Water Flow System ... 133
5.7.5.5 Air Flow System ... 133
5.7.5.6 Other ... 134
5.7.6 Other Methods of Aeration ... 134
5.7.7 Protection of Aerators ... 134
5.7.8 By-Pass ... 134
5.7.9 Monitoring ... 134
5.8 Iron and Manganese Control ... 134

5.8.1 Removal by Oxidation, Detention and Filtration....135
5.8.2 Removal by Lime-Soda Softening....135
5.8.3 Removal by Manganese Coated Media Filtration....135
5.8.3.1 Oxidant Addition....135
5.8.3.2 Media....135
5.8.3.3 Design....135
5.8.3.4 Sample Taps....136
5.8.4 Proprietary Media....136
5.8.5 Removal by Ion Exchange....136
5.8.6 Sequestration....136
5.8.6.1 Polyphosphates Sequestration....136
5.8.6.2 Sodium Silicates Sequestration....137
5.8.7 Testing 137
5.9 Fluoridation....137
5.9.1 Naturally Occuring Fluoride....137
5.9.2 Artificial Fluoridation....137
5.9.2.1 Fluoride Compound Storage....137
5.9.2.2 Chemical Feed Equipment and Methods....137
5.9.2.3 Secondary Controls....138
5.9.2.4 Protective Equipment....138
5.9.2.5 Dust Control....138
5.9.2.6 Testing Equipment....139
5.10 Stabilization and Corrosion Control....139
5.10.1 Carbon Dioxide Addition....139
5.10.2 Acid Addition....140
5.10.3 Corrosion Inhibitors....140
5.10.4 Split Treatment....140
5.10.5 Alkali Addition....140
5.10.6 Carbon Dioxide Reduction by Aeration....140
5.10.7 Water Unstable Due to Biochemical Activity....141
5.10.8 Testing 141
5.11 Taste and Odour Control....141
5.11.1 Chlorination....141
5.11.2 Chlorine Dioxide....141

5.11.3 Powdered Activated Carbon 141
5.11.4 Granular Activated Carbon 142
5.11.5 Aeration 142
5.11.6 Potassium Permanganate 142
5.11.7 Ozone 142
5.11.8 Piloting Requirements 142
5.12 Cyanobacteria 142
5.13 Waste Handling 142
5.13.1 General 142
5.13.2 Sanitary Waste 142
5.13.3 Water Treatment Plant Residuals 142
5.13.3.1 Brine Waste 143
5.13.3.2 Lime Softening Sludge 143
5.13.3.3 Coagulation Sludges 143
5.13.3.4 Spent Filter Backwash Water 143
5.13.4 Quantity 143
5.13.5 Direct Discharge to Sewer 143
5.13.6 Waste Treatment 144
5.13.6.1 Waste Equalization and Mixing 144
5.13.6.2 Lagoon Treatment 144
5.13.6.3 Thickening and Sedimentation 144
5.13.6.4 Dissolved Air Flotation 145
5.13.6.5 Membranes 145
5.13.6.6 Polymer Addition 145
5.13.6.7 Iron and Manganese Wastes 145
5.13.7 Spent Filter Backwash Water Recycling 146
5.13.8 Dewatering 146
5.13.8.1 Air/Gravity Drying Processes 146
5.13.8.2 Mechanical Dewatering Processes 147
5.13.8.3 Comparison of Dewatering Processes 147
5.13.9 Sludge Disposal 148
5.14 Emerging Technologies 148

Chapter 5 Design of Water Treatment Processes

5.1 Presedimentation and Screening

5.1.1 Pre-sedimentation

Raw water containing high levels of turbidity may require pre-sedimentation, either with or without the addition of coagulants. Pre-sedimentation basins should:

- Have hopper bottoms or be equipped with mechanical moving sludge removal apparatus;
- Have a means of dewatering the settled sediments;
- Be designed such that the incoming water is dispersed evenly across the tank width to prevent short-circuiting;
- Have provisions for a by-pass around the pre-sedimentation unit; and
- Be designed with a minimum of three (3) hours detention time (actual detention time is to be determined through sedimentation tests).

5.1.2 Screening

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

Fine screens used at an end-of-pipe intake, where water is being extracted from fish-bearing waters, must conform to the Department of Fisheries and Oceans (DFO) document *Freshwater Intake End-of-Pipe Fish Screen Guidelines.* The 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 water treatment facility 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 and 9 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 agencies 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 degrees 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 natural organic matter with the goal of reducing or eliminating DBP formation. Enhanced coagulation is now ubiquitous in conventional water treatment, as turbidity removal alone is no longer the primary focus of surface water treatment facilities. Coagulation processes at surface water treatment facilities in Atlantic Canada, with relatively low raw water turbidites, which target enhanced coagulation generally produce “sweep flocculation” conditions. This term refers to the process in which sufficiently high concentrations of coagulant are added to precipitate metal hydroxides, which then enmesh particles into larger agglomerates during flocculation and adsorb dissolved organic matter onto its surfaces.

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.

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 addition should be derived from jar and/or pilot testing and 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 – 1500 s^{-1};
- Retention time (*t*) = 0.5 – 1.0 seconds; and
- *Gt* = 500 – 1500.

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) = 3000 – 5000 s-1;
- Retention time (*t*) = 0.5 – 1.0 seconds; and
- *Gt* = 2000 – 3000.

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 – 1000 s-1;
- Retention time (t) = 10 – 60 seconds; and
- *Gt* = 6000 – 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 two-stage flocculation to permit a tapered velocity gradient. Three-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 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 water treatment plants; and
- 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 – 80 s^{-1} depending on number of flocculation stages);
- Be designed to provide a total Gt of 20,000 – 110,000;
- Have a maximum peripheral speed of 1.0 m/s;
- Have variable speed motors consisting of a minimum of three (3) 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;
- Be designed to provide a mixing intensity (*G*) of 5 – 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); and

- Have a maximum liquid velocity of 1.0 m/s.

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. Sedimentation basins typically follow the flocculation process. 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; and
- Ballasted flocculation and sedimentation.

5.3.1.1 General

The following should apply to all sedimentation basins:

- A minimum of two (2) 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; and
    - 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; and
    - Sludge disposal should be by an approved method as stipulated by the 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 two (2) and four (4) hours after coagulation/flocculation processes;
- Retention time should be minimum two (2) hours for lime softening processes;
- Surface overflow rates should not exceed 1.2 m/hr;
- Flow through the basin should be laminar and velocities through the sedimentation basin should not exceed

0.15 m/min;
- Water depth should be 3.0 – 5.0 m, with minimum 0.3 m freeboard;
- Minimum length: width ratio = 4:1 (5:1 is recommended);
- Inlet/outlet weir loadings rates may be as high as 360 m3/day/m; and
- Should meet the requirements of Section 5.3.1.1.

5.3.1.3 Plate and 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/hr (*Alberta suggests 5.0 – 6.3, GLUMRB at 4.8*.);
- Application rates for plates (or tubes) should not exceed 1.2 m/hr, based on 80% of the horizontal projected area;
- Water depth should be 3.6 – 5.0 m, with 0.6 – 1.0 m freeboard;
- Inlet and outlet considerations – Maintain velocities suitable 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 Section 5.3.1.1; and
- Proprietary designs that do not meet these requirements should be subject to pilot testing requirements as per Section 3.2.3.2.

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 3.2.3.2;
- Solids contact clarifiers should be designed for the maximum flow rate and should be adjustable to changing flow rates 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/hr;
- Tubes may be used to increase loading rates and should meet the requirements of Section 5.4.1.3;
- Retention time should be two (2) to four (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 flow rate; and
- 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 3.2.3.2;
- Upflow sludge blanket clarifiers should be designed for the maximum flow rate and should be adjustable to changing flow rates and water quality;
- Flocculation time should be minimum 30 minutes and in a separate tank or in a baffled chamber;
- Surface overflow rates should not exceed 2.4 m/hr;

- Tubes and/or plates may be used to increase loading rates to 4.9 m/hr, however, pilot testing should be conducted as per Section 5.4.1.3;
- Retention time should be one (1) to two (2) hours;
- Should have a means of measuring solids concentration and collecting sludge in the central flocculation zone; and
- Sludge waste concentration should not exceed 3% for clarifiers and 5% for softening units;
- Should meet the requirements of Section 4.3.1.1.

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 allow 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 3.2.3.2;
- Clarifiers should be designed for the maximum flow rate and should be adjustable to changing flow rates and water quality;
- Tubes may be used to increase loading rates and should meet the requirements of Section 5.3.1.3;
- Should have a means of recycling and cleaning ballast for reintroduction to the flocculation process; and
- 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. DAF clarifiers follow flocculation and 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 dissolved air flotation 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.

5.3.2.1 General

The following should apply to all DAF systems:

- A minimum of two (2) 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 Authority having jurisdiction; and
- 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 do are operated in the range of 10 to 30 m/h, and in some applications at 40 m/h 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 µm and 100 µm;
- Recycle ratio should be approximately 10%;
- Saturation pressure should be 400 kPa to 600 Kpa;
- Air concentration in the process tank after injection should be between 8 mg/L 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; and
- Should meet the requirements of Section 5.3.1.1.

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 3.2.3.2;
- The units should be designed for the maximum flow rate 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/hr;
- The filtration zones should be backwashed using air scour; and
- The requirements of Section 5.3.1.1 should be met.

5.4 Filtration

Barring system specific exceptions, filtration shall be provided for all supplies treating a surface water or a groundwater under the direct influence (GUDI) of surface water. Acceptable filtration processes include, upon the discretion of the reviewing Authority, the following:

- Rapid rate gravity filtration;
- Rapid rate pressure filtration;
- Diatomaceous earth filtration;
- Slow sand filtration;
- Direct Filtration;
- Deep bed, rapid rate gravity filtration;

- Biological filtration;
- Membrane filtration; and
- 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.

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/hr. 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 reviewing authority. In any case, the filtration rate should be justified by the designing engineer to the satisfaction of the reviewing 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 3.2.3.2. 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 and Redundancy

A minimum of two (2) filtration units should be provided. The filters should be designed to enable the facility to operate with one filter out of service provided that provincial health related water quality requirements are met while one filter is out of service.

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.

Piping systems should be designed to accommodate flows greater than the design capacity of the filters so as to accommodate future expansion.

5.4.1.4 Headloss and 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 provided that it is adequately demonstrated that adverse impacts on water quality, and operation and maintenance of the filter will not result.

5.4.1.5 Filter Flow Control

Controlling flow to rapid 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 maintain a minimum level in the filter above the top of the media bed at all times, and the water level above the filter will increase over the filter run and with increasing flows, as headloss in the filter increases. Flow rates through the filter will decrease very slowly over the course of the filter runs in this configuration, as the accumulating volume of water above the filter is subtracted from the filtered water volume and

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 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 and 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; and
- 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;
- 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 metres of filter area; and
- 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 version of AWWA/ANSI Standard B-100 and NSF/ANSI/CAN 61 standards;
5. 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	0.5
Uniformity Coefficient	< 1.7	< 1.65

6. 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

7. Torpedo Sand:

	Range	Typical
Depth (mm)	75	75
Effective Size (mm)	0.8 – 2.0	1.2
Uniformity Coefficient	< 1.7	1.5

8. Granular activated carbon (GAC) as a single media may be considered for filtration only after the piloting

requirements of Section 3.2.3.2 have been satisfied, and provided the design meets the following requirements:

The media should meet the following specifications (AWWA/ASCE):

Iodide Number: > 500 mg/g carbon
Density: 0.25 g/cc
Moisture Content: < 8% by wt.
Ash Content: < 4% by wt.
Effective Size: 1.2 – 1.6 mm
Uniformity Coefficient: < 1.9
Empty Bed Contact Time: 5 – 25 minutes
Depth: 0.3 – 1.2 m
Effective Size: 0.50 to 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); and
- Provisions should be made for replacement, or regeneration, of media.

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 3.2.3.2.

5.4.1.8 Filter Underdrains

Filter underdrains may either be gravel or proprietary designs (such as porous plate), unless otherwise approved. Manifold type underdrain systems should meet the following requirements, unless otherwise approved:

- 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 coarsest gravel should be 62 mm in size when the gravel rests directly on the strainer system, and must extend above the top of the perforated laterals. Gravel underdrain media should consist of a minimum of four (4) layers, unless otherwise approved, meeting the following requirements:

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

- 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 (*AWWA/ASCE recommends 0.0015 to 0.005, GLUMRB selected for consistency*);
- Provide the total cross-sectional area of the laterals at approximately 200% of the total area of the final openings (*AWWA/ASCE recommends 200 to 400%, GLUMRB selected for consistency*);
- Provide the cross-sectional area of the manifold at approximately 150% to 200% of the total area of the

laterals (*AWWA/ASCE recommends 150 to 300%, GLUMRB selected for consistency*); and
- 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 backsiphonage, if connected to the treated water system;
- Rate of flow to be 4.9 m/hr for fixed nozzles and 1.2 m/hr for revolving arms; and
- 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 5.5.1.9 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.

5.4.1.11 On-line Turbidity Monitoring

On-line continuous read turbidity meters should be provided for all filters, including filters used specifically for iron and manganese removal. The readout should be data-logged continuously and be connected to the SCADA system.

5.4.1.12 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; and
- A pressure hose and storage rack at the operating floor for washing filter walls.

5.4.1.13 Backwashing

Storage Requirements

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

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/hr for systems not using air scour (*Alberta; GLUMRB suggests 37-50 m/hr*);
  - Between 12 and 18 m/hr for systems using air scour;
  - 24 m/hr 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; and

- A minimum 10 minutes of backwash water for systems that use air scour (*Alberta; GLUMRB suggests minimum 15 minutes under all circumstances; Alberta selected as air scour helps to reduce backwash time*).

- Air scour duration should be as specified in Section 5.5.1.11;
- Backwash water should be filtered water, provided from the clearwell, backwash tanks, or the service watermain;
- Backwash pumps should include a minimum of one (1) duty and one (1) 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 flow rate do not occur; and
- Backwash systems should be operator initiated, and automatic systems should be operator adjustable.

5.4.1.14 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/hr;
- Air scour duration should be 3 to 5 minutes (Alberta);
- 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 5.5.1.10;
- 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; and
- 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 9). 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/hr is provided. Use of higher filtration rates will be subject to demonstration of successful application and/or pilot testing requirements as specified in Section 3.2.3.2.

5.4.2.2 Additional Requirements

Pressure filtration systems should meet the following requirements:

- 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 1500 mm;
- Backwash water troughs/collectors should be minimum 450 mm above media surface;
- An adequate underdrain system capable of uniformly distributing a backwash water flow rate suitable for the filter media installed in the pressure filter;
- Backwash water flow indicators should be provided;
- 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; and
- 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:

- Color < 20 color units
- Turbidity < 5 NTU
- Algae < 2000 asu/ml
- Iron < 0.3 mg/L
- Manganese < 0.05 mg/L

5.4.3.1 Piloting and 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, 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 contaminants of concern;
- Temperature;
- Total solids; and
- General inorganic chemical characteristics.

After approval of the engineering report, a pilot study demonstration should be conducted and should meet the requirements of Section 3.2.3.2 and be to the satisfaction of the reviewing 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; and
- 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 reviewing authority for approval where required by the regulator.

5.4.3.2 Pretreatment

The coagulation and flocculation processes should be designed as per the design criteria outlined in the pilot studies and as per Section 5.3. 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 4.5.1**, 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 5.5.1.2.

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 3.2.3.2 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 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 one (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 and 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); and
- Protection from freezing.

5.4.4.4 Rate of Filtration

Filtration rates should range from 0.04 to 0.40 m/hr. Filtration rates above this range will have to be adequately demonstrated through piloting studies as per Section 3.2.3.2.

5.4.4.5 Underdrains

The supporting gravel should be as per the requirements of Section (5.4.1, Rapid Rate Gravity Filtration.

Each filter unit should be equipped with a main drain and an adequate number evenly spaced (max. 1000 mm) laterals to collect the filtered water, with a maximum water velocity of 0.23 m/sec.

5.4.4.6 Filter Media

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

- Minimum initial sand depth of 750 mm to 1300 mm;
- Effective size between 0.15 mm 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; and
- 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 and Headloss

Design water depth should be between 1800 mm and 2100 mm and the effluent piping design should ensure that the water level is maintained above the level of the filter sand (AWWA/ASCE; GLMURB recommends 0.9 – 1.8 m; AWWA/ASCE 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 and 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. However this can be overcome with regular and frequent backwashing cycles as described in section 5.5.1.10).

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. GAC 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 5.5.1, unless otherwise noted. Pressure filtration should not be used for biological filtration, except where biological filtration is targeting specific contaminants (e.g. iron, manganese).

5.4.5.2 Piloting Requirements

Biological filtration systems should not be constructed without undertaking pilot studies as per the requirements of Section 3.2.3.2.

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. However, some basic design criteria will be specified that should pertain 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 regulator:

- Microfiltration (MF);
- Ultrafiltration (UF);
- Nanofiltration (NF); and
- Reverse Osmosis (RO).

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 - 0.1 µm pore size
Nanofiltration	0.001 – 0.01 µm pore size
Reverse Osmosis	0.0001 µm um pore size

µm = micrometre = (1 x 10-6 metres = 1 x 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. MWCO 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 nanofiltration and reverse osmosis 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), biological substances. In addition, most membranes will not tolerate high/low pH water or free chlorine.

5.4.6.2 Number and Redundancy

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

- A minimum of two (2) trains are provided;
- A minimum of one (1) redundant feed/suction pump is provided; and
- 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., >2000 L/min), 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

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 3.2.3.2.

5.4.6.4 Membrane Materials

The first step in designing a membrane treatment system is the selection of the membrane material. 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 5.1.

Table 5.1 Properties of Various Membrane Materials

Material	pH Range	Tolerance to Chlorine (mg/L)	Maximum Temperature (°C)
Cellulose Acetate	3 to 6	~1	530
Polyamide	2 to 12	<0.1	80
Polysulfone	1 to 13	~100	875
Polyvinylidene fluoride (PVDF)	2 to 10	>100	75
Aluminum Oxide (ceramic)	0 to 14	>100	>100

The two (2) most important organic polymeric materials include cellulose acetate and polyamide, with other membranes being made from polypropylene, polyethylene, aromatic polyamides, polysulfone and other polymers (Mallevialle et al., 1996). 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 (AWWA 1998). Inorganic membranes resist compaction, high temperature, and extreme pH values and can operate under a broad range of temperatures. The major drawback of inorganic membranes is their high density and cost.

Membranes can consist of hydrophilic or hydrophobic materials (AWWA, 1992), which can have an effect on fouling. 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 disinfection by-products (DBP) precursor.

5.4.6.5 Membrane Configurations

Membrane systems consist of membrane elements or modules that are generally manufactured in two (2) different configurations, hollow fiber and spiral. Microfiltration and ultrafiltration 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 5.2

Table 5.2 Typical Membrane System Design Criteria

Design Parameter	Microfiltration	Ultrafiltration	Nanofiltration	Reverse Osmosis
Flux rate ($L/m^2/hr$)	34-170	34-170	14-34	10-34
TMP[1] (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	0.1-0.2μm	0.01-0.1μm	95-98% rej. Of $Mg50_4$	98-99.7% rej. Of Nacl

[1] Transmembrane Pressure

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, DOC and/or conductivity should also be routinely performed and should be on-line 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 shall 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. However, other disinfectants such as chloramines, ozone, chlorine dioxide, ultraviolet light (UV) or mixed oxidants may also be considered.

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 disinfection by-products (DBPs). Careful consideration should be given to potential DBP increases when selecting disinfectants and processes that require pre-chlorination.

5.5.1.1 Inactivation Requirements

The method of determining adequate disinfection for chlorination should be the C_t (i.e., C_t = free chlorine concentration in mg/L X disinfectant contact time 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 C_t 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 contact time of the chlorine in water with relation to pH, ammonia, taste, temperature, microbiological quality and disinfection by-product (DBP) formation potential (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 4.3. Tracer studies may be required to determine a more accurate baffling factor in some circumstances:

Table 5.3 Baffling Factors for CT 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 contact time, 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 C_t calculations:

- Use maximum flow rate;
- Determine the volume of each process unit in the disinfection system using the minimum water level expected at the maximum hourly flow;
- Calculate the theoretical retention time;
- Determine the baffling factor based on unit process baffling conditions or by tracer studies; and
- Calculate T_{10} by multiplying theoretical retention time by baffling factor.

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

5.5.1.2 Residual Chlorine

Chlorination systems should be designed to provide a minimum free chlorine residual of 0.2 mg/L throughout the distribution system, or a minimum level as designated by the regulatory authority. Minimum combined chlorine residual, if applicable, should be 1.0 to 2.0 mg/L. Local authorities may define a specific range of minimum acceptable chlorine residuals concentrations.

5.5.1.3 Chlorination Equipment

Type

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

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 (see Section 5.6.1.2 Residual Chlorine). The equipment should be designed such that it will provide an accurate chlorine feed over the entire dosing range.

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.

Automatic Switchover

Automatic switchover of chlorine cylinders should be provided to prevent inadequately disinfected water from entering the distribution system.

Automatic Proportioning

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

Eductor

Each eductor should be selected for the point of application with consideration given to the quantity of chlorine to be added, the maximum injector flow rate, 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.

Injector/Diffuser

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.

Residual Monitoring Equipment

Continuous on-line 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* should be provided and should be capable of measuring disinfectant residuals to 0.02 mg/L. It is recommended that the DPD 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.

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.

Chlorinator Piping
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 (PE) or other materials approved by the Chlorine Institute should be used for chlorine solution pipe and fittings (nylon materials is 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 4.6.2.11 and 4.6.3.2).

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

5.5.1.4 General Guidelines
In addition to the requirements of Section 4.6.3.2, the following should be provided for all disinfection systems that use chlorination:
- Weigh scales constructed from corrosion resistant material and located remote from sources of moisture;
- Chlorine leak detection equipment as per Chapter 4; and
- 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 so as 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; and
- Chlorine institute emergency kit A and B should be provided.

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 this manual. 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 reviewing Authority:

- Chloramination;
- Ozonation;
- Chlorine Dioxide Addition;
- Ultraviolet Disinfection; and
- Mixed Oxidant Disinfection.

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

5.5.2.2 Process Descriptions

Chloramination

Chloramines are a weak disinfectant for *Giardia lamblia* and virus reduction and require long contact times for adequate disinfection. However, it does have a long-lasting residual and forms lower concentration of THMs and HAAs in comparison to free chlorine. Therefore, chloramines may be best suited as a stable distribution system disinfectant.

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.

Ozonation

Ozone (O_3) is a very effective disinfectant for both *Giardia lamblia* and viruses, and is also used for taste and odour control. 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 chlorine or chloramines. Ozone systems should include provisions for leak detection and alarms as well as an ozone off-gas destruction system.

Chlorine Dioxide

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 disinfection by-products, which have health-based maximum acceptable concentrations of 1.0 mg/L in the *Guidelines for Canadian Drinking Water Quality*. As recommended in this document, chlorine dioxide dosing should be kept to a maximum of 1.2 mg/L to limit the formation of these by-products.

Ultraviolet Disinfection

Ultraviolet (UV) disinfection is the process by 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. UV systems may provide relatively high inactivations of *Giardia*, *Cryptosporidium* and viruses, while not forming

DBPs. UV systems do not however provide a residual and as such, a secondary disinfectant such as chlorine should be provided. UV Dose requirements for pathogen inactivation are provided in Table 5.4.

Table 5.4 UV Dose Requirements for Pathogen Inactivation (adapted from Health Canada GCDWQ; Guideline Technical Documents)

Microorganism	1-log	2-log	3-log	4-log
Giardia	2.1	5.2	11	22
Cryptosporidium	2.5	5.8	12	22
Adenoviruses	10-76	26-137	39-199	51-261
Other Viruses	4-10	8.2-26	12.3-44	16.4-61

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 (2) units (1 duty and 1 stand-by) or a minimum of 50% redundancy (2 duty and 1 stand-by);
- Be based on maximum instantaneous flow rates 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 4.4 should be used to meet the, unless a lower RED has been demonstrated through on-site validation testing as per the USEPA UVDGM (November, 2006);
- 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 UV transmittance;
- 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; and
- Reactor isolation and lamp breakage response plans.

Onsite Hypochlorite Generation (OSG) and 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.

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 disinfectant by-products should be disclosed.

5.5.2.3 Contact Time

Alternate disinfectants should meet either the Ct requirements of Section 5.6.1.1, or, an approved equivalent disinfection ability such as the required microbiological removal requirements as per regulatory requirements (e.g., UV disinfection).

5.5.2.4 Disinfectant Residual
Regardless of the primary disinfectant used, free chlorine residuals should be provided consistent with Section 5.6.1.3. Should the primary disinfectant not be capable of providing the required chlorine residuals, then a secondary chlorination system should also be provided, consistent with the requirements of Section 5.6.1.

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 3.2.3.2.

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 process should meet the following criteria:
- Design of coagulation and clarification facilities should be as outlined in Section 5.3;
- 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; and
- 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 1000 mm;
- The rate of softening should not exceed 17 m/hr;
- Backwash rates range from 14-20 m/hr 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 5.5.1.6;
- 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 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 (2) 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; and
- 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; and
- 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; and
- Packed tower aeration.

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/hr;
- 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 degrees; and
- Protection from insects by 24 mesh screen.

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 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/hr;
- 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; and
- 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 flow rate, space and amount of head available;
- Nozzle diameters in the range of 25 to 38 mm;
- An enclosed basin to contain the spray; and
- 24 mesh screen 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 3.2.3.2. 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; and
- Provide screened and filtered air, free of dust, fumes, and dirt.

5.7.5 Packed Tower Aeration

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

5.7.5.1 Piloting Requirements

PTA 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 3.2.3.2. Values for Henry’s constant should be discussed with the reviewing authority prior to developing plans and specifications.

In addition to those requirements in Section 3.2.3.2, pilot testing should evaluate a variety of loading rates and air: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 reviewing 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 10:1;
- The volumetric air to water ratio at peak flow should be between 25:1 and 80:1;
- The design should consider potential fouling due to calcium carbonate and iron precipitation from bacterial regrowth (a pre-treatment system may be required); and
- 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 three (3) metres in order 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 sanitary sewer;
- A blow-off line 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; and
- 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 (it is also recommended that a 4 mesh screen 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); and
- 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 maintenance and operations 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 3 for blower and disinfectant feeding equipment;
- Security measures should be provided as per Chapter 3;
- 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; and
- 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 5.6

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 and 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 and Filtration

Oxidation may be by aeration, as indicated in Section 5.8, or by chemical oxidation with chlorine, potassium permanganate, ozone, or chlorine dioxide. A minimum detention time of 30 minutes should be provided following aeration, unless indicated otherwise through pilot testing (see Section 3.2.3.2). 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 potassium permanganate, chlorine and chlorine dioxide is “rapid” and the design of detention basins should provide minimum five (5) minutes of contact time.

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 5.4.1. Filters should meet the requirements of Section 5.5.

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 5.7.

5.8.3 Removal by Manganese Coated Media Filtration

Removal of iron and manganese by contact adsorption using pre-coated filter media is the preferred 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 potassium permanganate, 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 disinfection by-products). Multiple oxidizing agents may be used to reduce the required primary oxidant dosage. Pilot studies as per the requirements of Section 3.2.3.2 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 contact time prior to the oxidized water reaching the filters (this may require a small contact tank in some cases to ensure adequate contact time). 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 revision of *AWWA/ANSI Standard B102 Manganese Greensand for Filters.*

5.8.3.3 Design

Iron and manganese removal systems should be designed as outlined in Table 5.5:

Table 5.1 Iron and Manganese Removal System Design Criteria

	Iron Removal	Manganese Removal
Bed type	Dual media	Single
Anthracite	375 – 450 mm	None
Manganese greensand	450 – 600 mm	> 750 mm

PH	6.2 – 8.5	7.0 – 8.5
Filtration rate	4.0 – 12 m/hr	4.0 – 12m/hr
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 design 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 20-40 m/hr 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 5.5.1.9. 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 the individual filter effluents; and
- At points between the anthracite media and the manganese coated media.

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 this manual. These proprietary media may be satisfactory in many circumstances. If, in the opinion of the regulator, 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.

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 maximum allowable concentration of manganese. The total phosphate applied should not exceed 10 mg/L as PO_4. Phosphate addition should not adversely affect chlorine residuals or 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 mg/L of iron, and the maximum allowable concentration 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 3.2.3.2. 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 SiO2. 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 4.8.2. . The equipment should have the capacity to measure iron and manganese to minimum concentrations of 0.1 mg/L and 0.05 mg/L, respectively. Where polyphosphate sequestration is practiced, phosphate testing equipment should be provided.

5.9 Fluoridation
5.9.1 Naturally Occuring Fluoride
Where fluoride is naturally occurring and above the GCDWQ or regulatory requirements, fluoride should be removed by an acceptable means to less than the required limit. Such methods might include ion exchange, reverse osmosis or proprietary technologies (refer to appropriate sections in the manual for fluoride removal process design guidelines).

5.9.2 Artificial Fluoridation
Where artificial fluoridation is provided, a dosage of 0.8 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 fluorosilic acid may be used for fluoridation and should meet the applicable AWWA and NSF standards. Any other compounds used for fluoridation will 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 fluorosilic 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 and Methods
In addition to the requirements in Chapter 3, 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 fluorosilic 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 $CaCO3$);
- 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; and
- 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 as outlined in Chapter 3 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.

5.10 Stabilization and Corrosion Control
Corrosion is the deterioration of a material, in most cases a metal that results from a reaction with its environment. In drinking water, this is a major concern in the distribution system due to leaching contaminants from pipe material. Corrosion in the distribution system can be caused by a number of different factors, such as type of piping material, age of the piping and fittings, the stagnation time of the water and the water quality in the system. Water that is unstable/corrosive due to natural and/or subsequent treatment processes should be stabilized to minimize corrosion in the distribution system and premise plumbing. Corrosion control strategies should be based on the primary goal of minimizing the resulting concentrations of lead and copper at the consumer’s tap.

Water quality has an impact on corrosion rates in drinking water. The main water quality parameters affecting corrosion are pH and alkalinity. A pH that is too low (acidic) can cause increased corrosion rates, and a pH that is too high (alkaline) can also cause increased corrosion, while alkalinity is used to control buffering capacity of the water system. According to Health Canada, the optimal pH range for lead and copper corrosion is 7.5-9.5, and the optimal alkalinity range for lead and copper control is 30 – 75mg/L as calcium carbonate. Treated water should be adjusted to within these pH and alkalinity ranges in order to limit lead corrosion in the distribution system.

There are a number of strategies to help control lead corrosion. The first would be to remove the source of lead from the piping material and replace it with a corrosion resistant, non-leaded pipe material. In most cases this is not always feasible, so other methods to control lead release are commonly used. These methods include changes in treated water quality and/or the addition of corrosion inhibiting chemicals.

Other factors that affect corrosion rates are water temperature and flow rate. A high water temperature can increase corrosion rates. A high water flow rate can increase lead concentrations in the distribution system due to materials sloughing off from the pipe wall. Stagnation time can also affect corrosion rates, having a longer contact time to react with the pipe before flushing out of the tap.

The following strategies for stabilization and corrosion control should be considered based on the site specific characteristics of the water system and the requirements of the regulator.

5.10.1 Carbon Dioxide Addition
Re-carbonation basins should provide:
- A total minimum detention time of 20 minutes;
- Two (2) compartments, with a depth that will provide a diffuser submergence greater than 2.3 m but not greater that the submergence recommended by the manufacturer, 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; and
- Provisions should be made for draining the re-carbonation basin and for removing sludge.

5.10.2 Acid Addition

Feed equipment should conform to Chapter 4. Operator safety precautions should be followed as outlined in Chapter 4. Piping materials should be of a type suitable for the chemical being fed.

5.10.3 Corrosion Inhibitors

Corrosion inhibiting chemicals are often used to minimize corrosion in the distribution system. Corrosion inhibiting chemicals include phosphate- and silicate-based compounds.

Phosphate-based compounds include orthophosphate and blended phosphates. Orthophosphate-based compounds form a protective coating on pipe walls to reduce the amount of lead released to the water. Orthophosphate and zinc-orthophosphate are the phosphate-based compounds that are most successful at reducing lead release in the distribution system. Polyphosphates do not form a protective barrier on pipe interiors, and should not be considered a corrosion inhibiting chemical, although they may be marketed as such.

Silicate-based corrosion inhibitors are a mixture of soda ash and silicon dioxide. There is limited data on how sodium silicate chemicals work, as it is 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.

The feeding of phosphates may be used for sequestering calcium in lime-softened water, corrosion control, and in conjunction with alkali feed following ion exchange softening. Phosphate addition should meet the following requirements:

- Feed equipment should conform to Chapter 3;
- 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); and
- Adequate chlorine residuals should be maintained in the distribution system.

Note that when using phosphates for corrosion control, the Langelier Saturation Index is no longer applicable for determination of corrosion protection potential.

5.10.4 Split Treatment

Under some circumstances, a softening water treatment plant can be designed using “split treatment” in which raw water is blended with softened water to partially stabilize the water prior to secondary clarification and filtration. Treatment plants that utilize “split treatment” should also contain facilities for further stabilization by other means.

5.10.5 Alkali Addition

Water with low alkalinity should be stabilized. Perhaps the most common method of water stabilization is alkali addition. Alkali addition involves the addition of a base to raise the pH of the water within the range stipulated by the Regulatory requirements or to a non-corrosive state. The most common chemicals used for this purpose include lime, sodium hydroxide and soda ash (others may be possible and will be subject to approval by the reviewing Authority).

Chemical feed facilities or alkali addition should conform to Chapter 4.

5.10.6 Carbon Dioxide Reduction by Aeration

The carbon dioxide content may be reduced by aeration. Aeration systems should meet the requirements of Section 5.8.

5.10.7 Water Unstable Due to Biochemical Activity

Water in the distribution system that is unstable due to biodegradation of organic matter in water (e.g., dead-end watermains), the biochemical action within the tubercles, and the reduction of sulfates to sulfides, should be prevented by maintenance of free and/or combined chlorine residual throughout the distribution system. Reducing the biological dissolved organic carbon (BDOC) and natural organic matter (NOM) prior to entering the distribution system may be considered to prevent the development of biologically unstable water.

5.10.8 Testing

Corrosion cannot be measured using one single parameter or method. The most common method for measuring corrosion is lead concentrations at the consumer's tap. Monitoring lead levels at the consumer's tap can help identify sources of lead and help in finding an effective strategy to control corrosion and reduce contaminant levels at the tap.

Laboratory testing equipment should be provided for determining the effectiveness of stabilization treatments where specific water quality parameter targets have been established (e.g. pH, alkalinity, etc.). A coupon corrosion testing station should be considered for in-situ measurement of corrosion in distribution systems to establish the current rate of corrosion and evaluate changes over time with the implementation or adjustment of corrosion control treatment strategies (e.g. addition of corrosion inhibitors).

5.11 Taste and Odour Control

Provision should be made for control of taste and odour at surface water treatment plants. Chemicals should be added sufficiently ahead of other treatment processes to assure adequate contact time. Where severe taste and odour problems are encountered, in-plant and/or pilot studies may be required. Consideration should be given to the flexibility of the equipment for various control processes.

5.11.1 Chlorination

Chlorination for taste and odour control should have adequate contact time. DBP levels likely to result from use of chlorine to treat tastes and odours should be considered.

5.11.2 Chlorine Dioxide

Taste and odour control by chlorine dioxide should require proper storage and handling of sodium chlorite, as per Section 5.6.2.

5.11.3 Powdered Activated Carbon

Taste and odour control using powdered activated carbon (PAC) should meet the following requirements:

- PAC should be added as early as possible in the treatment process to provide maximum contact time;
- Flexibility to add PAC at several points is recommended;
- PAC should not be applied near the point of chlorine addition or other oxidant;
- PAC 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;
- Provision should be made for adequate dust control;
- Provision should made for a rate of PAC feed up to 40 mg/L; and
- PAC should be considered potentially combustible material and should be stored in a separate fire retardant building or room, equipped with explosion proof outlets, lights and motors.

5.11.4 Granular Activated Carbon

Granular activated carbon filters should meet the requirements of Section 5.5. Media for granular activated carbon filters and absorbers should meet the requirements of Section 5.5.1.5.

5.11.5 Aeration

See Section 4.8 for the requirements for aeration systems.

5.11.6 Potassium Permanganate

Potassium permanganate addition for taste and odour control should not result in discolouration of the treated water.

5.11.7 Ozone

Ozone, when used for taste and odour control, should be designed such that adequate contact time is achieved. Ozone is generally more desirable for treating water with high threshold odours.

5.11.8 Piloting Requirements

Any other method of taste and odour control should be subject to pilot testing and should meet the requirements of Section 3.2.3.2.

5.12 Cyanobacteria

Still in process.

5.13 Waste Handling

5.13.1 General

Provisions should be made for proper handling and disposal of water treatment plant 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 Authority having jurisdiction. Water quality requirements imposed by the regulatory agency 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 Authority having jurisdiction, the latter should govern.

5.13.2 Sanitary Waste

Sanitary wastes from water treatment plants include waste from washroom facilities, kitchen facilities, lunch rooms and laboratory wastes. The sanitary waste from water treatment plants, 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 sewage disposal system designed and constructed to meet the requirements of the province in which it is to be constructed.

5.13.3 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.

5.13.3.1 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 agency will dictate the allowable rate of discharge.

5.13.3.2 Lime Softening Sludge
Sludge from water treatment plants 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.

5.13.3.3 Coagulation Sludges
Typically, aluminum and/or iron coagulants are used in conventional surface water treatment plants. 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.

5.13.3.4 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.

5.13.4 Quantity
An accurate means of measuring residuals/waste streams and their respective quantities should be provided.

5.13.5 Direct Discharge to Sewer
Where ultimate disposal is to be to a sanitary sewer, consideration should be given to the capacity of the sanitary sewer system and sewage treatment plant and, as a result, may require holding tanks to prevent overloading of sanitary sewer facilities. Consideration should also be given to future capacity scenarios considering climate change parameters. Discharge to sewage 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 sewerage 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.

5.13.6 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 satisfactory operating data to confirm the suitability of a particular process does not exist for a given residuals stream, pilot testing should be performed and should meet the requirements of Section 3.2.3.2.

5.13.6.1 Waste Equalization and 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.

5.13.6.2 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 two (2) years of sludge storage. A minimum of (2) 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 for climate change variability, and location free from flooding and future flooding levels;
- When necessary, dikes, 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; and
- Parallel operation ability.

Note that lagoons may not be sufficient for removal of aluminum levels to meet the discharge regulatory requirements for some water treatment plants using aluminum-based coagulants and discharging to fresh water 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.

5.13.6.3 Thickening and Sedimentation

Thickening should refer 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/hr.

Sedimentation, with respect to waste treatment, should refer 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/hr.

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 4.4.1.

Coagulant addition, if necessary, should meet the requirements of Sections 4.2.

5.13.6.4 Dissolved Air Flotation

Dissolved air flotation may be applicable for treatment of water treatment plant 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/hr. DAF system design should also meet the requirements of Section 4.4.2. Coagulant addition, if necessary, should meet the requirements of Sections 4.2.

5.13.6.5 Membranes

Membranes may be suitable for the treatment of water treatment plant residuals. Careful consideration should be given to allowable flux rates and such would have to be confirmed through pilot testing as per Section 2.2.3.2.

5.13.6.6 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 4.13.5.1 to ensure consistent chemical feed can be maintained. Polymer system design should meet the requirements of Chapter 3.

5.13.6.7 Iron and 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 4.13.4.

Sand Filters

Sand filters should have the following features:

- A total filter area adequate to dewater the applied solids;
- Two (2) filters should be provided, unless the filter is of size small enough that it may be cleaned and returned to service in one 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, 75-100 mm of torpedo sand, and minimum 225 mm of supporting gravel;
- Filter sand should have an effective size of 0.3 to 0.5 mm and a uniformity coefficient not to exceed 3.5;
- 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; and
- Any deviations to the above should be subject to pilot testing requirements as per Section 2.2.3.2.

Lagoons
Lagoons should have the following features:

- 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 4:1 and a minimum width:depth ratio of 3:1;
- Outlets and inlet located to minimize short-circuiting;
- A weir outlet device with a weir length equal to or greater than the liquid depth; and
- Velocity to be dissipated at the inlet.

5.13.7 Spent Filter Backwash Water Recycling

Spent filter backwash (SFBW) water recycling is practiced in many facilities throughout the United States and CanadaWaste recycling has been shown to be an effective method of water recovery and is considered a climate change resiliency feature. Furthermore, the Filter Backwash Recycle Rule (USEPA, 2001) indicates that SFBW recycling may be acceptable provided hydraulic surges due to recycling are kept below 10% of the plant influent flow rate and provided the recycle is introduced at a location in the process train so as to ensure all recycle flows are subjected to all treatment processes at the respective plants.

SFBW treatment and recycle may be considered as part of the design for surface water and groundwater treatment facilities. Where used, the system design should conform to the EPA Filter Backwash Recycle Rule. 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.

5.13.8 Dewatering

Methods of dewatering include the following:

- Air/gravity drying processes:
  - Sand drying beds;
  - Freeze-thaw beds;
  - Solar drying beds; and
  - Vacuum assisted drying beds
- Mechanical dewatering processes:
  - Belt filter presses;
  - Centrifuges; and
  - Pressure filters.

A complete discussion on each of these dewatering processes is beyond the scope of this manual. Some general guidelines, however, are provided.

5.13.8.1 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 20-75 cm for coagulant sludges and 30-120 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 (2) drying beds, each sized to accommodate one (1) year of sludge storage.

olar 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.

5.13.8.2 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% - 60% and coagulant sludges to 15% - 20%. The applied pressure is typically in the 600 to 1,500 kPa range. Roller bearings should be designed to have an L-10 service life of approximately 300,000 hrs. 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.

Similar to air dewatering systems, decanting and drainage systems should be provided and required solids concentration, drainage discharge location and regulatory requirements should be considered.

5.13.8.3 Comparison of Dewatering Processes

The relative performance of the dewatering processes described above are provided in Table 5.6:

Table 5.6 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

5.13.9 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 regulator 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; and
- Mechanical dewatering or calcination of lime sludges may be considered, provided pilot studies (see Section 2.2.3.2) are conducted.

Landfill disposal may be considered provided the landfill is capable of accepting the waste.

Drying beds for lime sludge are not recommended.

5.14 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 this manual. All emerging technologies should, however, be subject to the pilot testing requirements of Section 2.2.3.2. An engineering report is recommended to be submitted to the regulator 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.

Chapter 6 Pumping Facilities 151
6.1 Facility Types 151
6.1.1 Raw Water Pumping Facility 151
6.1.2 Booster Pumping Facility..151
6.1.3 Fire Pumping Facility 151
6.2 Facility Construction 152
6.2.1 General 152
6.2.2 Location 152
6.2.2.1 Site Protection 152
6.2.3 Pumping Stations..152
6.2.4 Suction Well..152
6.2.5 Screening / Fish Attraction 153
6.2.6 Equipment Servicing...153
6.2.7 Stairways and Ladders..153
6.2.8 Heating 153
6.2.9 Ventilation 153
6.2.10 Dehumidification 154
6.2.11 Lighting 154
6.2.12 Sanitary and Other Conveniences 154
6.3 Pumps 154
6.3.1 Selection 154
6.3.1.1 Water Quality 154
6.3.1.2 System Head Curves 155
6.3.1.3 Modes of Operation 155
6.3.1.4 Pump Flow / Head Margins 155
6.3.1.5 Type of Pump Control.. 155
6.3.1.6 Future System Changes 156
6.3.2 Suction Lift Pumps..156
6.3.3 Priming 156
6.4 Booster Pumps 156
6.4.1 Metering...156
6.4.2 Individual Home Booster Pumps...156
6.5 Automatic and Remote Controlled Stations 157
6.6 Appurtenances 157

6.6.1 Isolation Valves....157
6.6.2 Check Valves....157
6.6.3 Suction and Discharge Piping....157
6.6.4 Gauges and Meters....157
6.6.5 Water Seals....158
6.6.6 Transient Pressure (Water Hammer) Control....158
6.7 Electrical....158
6.7.1 Power Supply....158
6.7.2 Pump Motor....158
6.7.3 Stand-by Power....158
6.7.4 Controls....159
6.8 Safety Precautions....159
6.9 Station Monitoring....159

Chapter 6 Pumping Facilities

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 water treatment plant. 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; and
- 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, and
- 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. No pumping station should be subject to flooding.

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 impact 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 one metre above the 100-year flood elevation, or one metre above the highest recorded flood elevation, with consideration of the impacts of climate change events;
- Structures and electrical and mechanical equipment should be protected from physical damage from flooding events;
- The pumping station should be located in areas where it will remain fully operational and fully accessible during flooding events, through the provision of back-up generators or alternative power supply;
- The pumping station should be protected to prevent vandalism and entrance by animals or unauthorized persons; and
- 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 located 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, and should also meet the specific requirements of the 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 metres 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 Owner; and
- Have outward opening doors.

6.2.4 Suction Well

Suction wells should:

- Be watertight;
- Have floors sloped to permit removal of water and entrained solids;
- Be covered or otherwise protected against contamination; and
- 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 shall 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 Federal Department of Fisheries and Oceans 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 shall be in accordance with requirements of the provincial department of Fish and Wildlife or the Federal Department of Fisheries and Oceans.

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 (2) fixed screens in series will suffice, while for larger plants the use of at least two (2) 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 departments of Fish and Wildlife or the federal Department of Fisheries and Oceans. 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; and
- A convenient tool board, or other facilities as needed, for proper maintenance of the equipment.

The creation of confined spaces that must be entered for maintenance should be avoided] move to the left margin.

6.2.7 Stairways and Ladders

Stairways or ladders should:
- Be provided between all floors, and in pits or compartments which must be entered; and
- 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 shall be designed in accordance with the Canadian Building Code.

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

Adequate ventilation shall be provided for all pump stations. Provide ventilation systems in accordance with the Canadian Electrical Code, and existing local and provincial codes. Ventilation equipment must meet the requirements of the 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 provided to prevent excessive temperatures as a result of heat generated by motors and other electro-mechanical equipment.

6.2.10 Dehumidification

Dehumidification should be provided 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 Canadian Electrical Code and to relevant provincial codes.

6.2.12 Sanitary and Other Conveniences

All pumping stations that are manned for extended periods should be provided with potable water, lavatory and toilet facilities. Acceptable options for the disposal of wastewater include, but are not limited to, a municipal system, on-site sewage disposal systems, or a holding tank.

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 within ± 10 % of the Best Efficiency Point (BEP) of the pump. Operating within this range the hydraulic efficiency and the operational reliability of the pump are not substantially degraded. Within this region, the design service life of the pump will not be affected by the internal hydraulic loads or flow-induced vibration; and
- 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; and
- 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 flow rate 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 flow rate requirements;
- Pump operation in series or parallel; and
- 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; and
- System hydraulics will change due to corrosion, scaling etc.

Pumps should be selected to work within a maximum margin of 20% of best efficiency point. 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.

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. 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. Closed-loop controller shall 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 shutoff 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 shall 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 devise 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, shall 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 it's 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; ~~and~~
- Be within allowable limits, preferably less than 5 meters. 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 required NPSHr (Net Positive Suction Head) to the 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 sanitary quality than that of the water being pumped. Means should be provided to prevent either backpressure or backsiphonage backflow. When an air-operated ejector is used, the screened intake should draw clean air from a point at least 3 metres above the ground or other source of possible contamination, unless the air is filtered by an apparatus approved by the reviewing 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 cutoff 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 cutoff pressure which will prevent excessive cycling; and
- 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.

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 utility.

6.5 Automatic and 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 applicable provincial and local electrical codes and the Canadian Electrical Code.

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 1/2 times the area of the suction pipe and they should be screened.

6.6.3 Suction and Discharge Piping

In general, suction and discharge piping should be as follows:

- Designed and arranged to provided 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 Owner;
- Have corrosion resistant fitted bolts;
- Include couplings where required to provide sufficient flexibility to allow removal of equipment and valves; and
- Pipe material capable of functioning in the pumping application, and should be approved by the Owner.

The pipe work pressure class shall 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 Gauges and Meters

Each pump:

- Should have a standard pressure gauge on its discharge line;
- Should have a compound gauge on its suction line; and
- Should have 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; and
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; and
- 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.

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. 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 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; and
- 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 meter around all pumps and motors. All panels and controls should have NEMA 3 enclosures.

All floor mounted electrical equipment should be mounted on 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 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 manned 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; and
- Station pressure.

Alarm Points
- Pump alarms, including:
  - Discharge pressure too low;
  - Discharge pressure too high; and
  - Motor temperature alarm.
- Station alarm points, including:

- Building temperature alarm;
- Building fire alarm;
- Building station flood;
- Power failure alarm;
- Illegal entry alarm; and
- Surge valve alarm.

Chapter 7 Treated Water Storage Facilities 163
7.1 General 163
7.2 Definitions 163
7.3 Materials of Construction 165
7.3.1 Standards and Materials Selection 165
7.3.2 Steel Construction 165
7.3.3 Concrete Construction 166
7.3.4 Composite Elevated Tank Construction 166
7.4 Storage Requirements 166
7.4.1 Water Storage Facility Design Capacity 166
7.4.2 Peak Balancing Storage Requirements 168
7.4.1 Fire Flow Storage Requirements 168
7.4.1 Emergency Storage 168
7.4.2 Dead Storage 169
7.4.3 Plant Storage 169
7.4.3.1 Clearwell Storage 169
7.4.4 Water Storage Facility Design Operating Levels 169
7.5 Water Quality 169
7.5.1 Detention Time 169
7.5.2 Reservoir Mixing 170
7.5.3 Chlorine Maintenance 170
7.5.4 Blending of Water Sources 170
7.6 Location of Distribution Storage 170
7.6.1 Elevated Storage 170
7.6.2 Above Ground and In-Ground Storage Reservoirs 171
7.7 Facility Requirements 171
7.7.1 Inlet/Outlet and Baffle Wall 171
7.7.2 Level Control 171
7.7.3 Overflow 171
7.7.4 Drainage of Storage Structures 172
7.7.5 Roof Drainage 172
7.7.6 Roof and Sidewall 172
7.7.7 Vents 172
7.7.8 Frost Protection 173

7.7.9 Internal Catwalk 173
7.7.10 Silt Stop 173
7.7.11 Grading 173
7.7.12 Corrosion Prevention/Reduction 173
7.7.13 Disinfection 173
7.7.1 Water Quality Monitoring 173
7.7.2 Adjacent Compartments 174
7.7.3 Basins and Wet-wells 174
7.7.4 Standby Power 174
7.8 Water Treatment Plant Storage 174
7.8.1 Backwash Tanks 174
7.8.2 Clearwell 174
7.8.3 Adjacent Compartments 174
7.8.4 Wet-Wells 174
7.9 Hydropneumatic Tanks 174
7.9.1 Location 175
7.9.2 Sizing 175
7.9.3 Piping 175
7.9.4 Appurtenances 175
7.10 Security/Safety 175
7.10.1 Access 175
7.10.2 Safety 175
7.10.3 Protection 176

Chapter 7 Treated Water Storage Facilities

7.1 General

Water storage is essential for meeting all of 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 this manual 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 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.

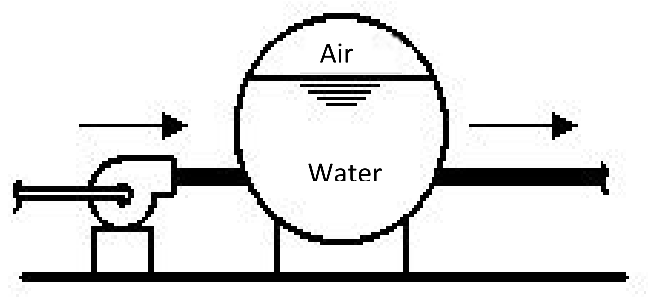
Elevated Tank

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 7-3a.

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



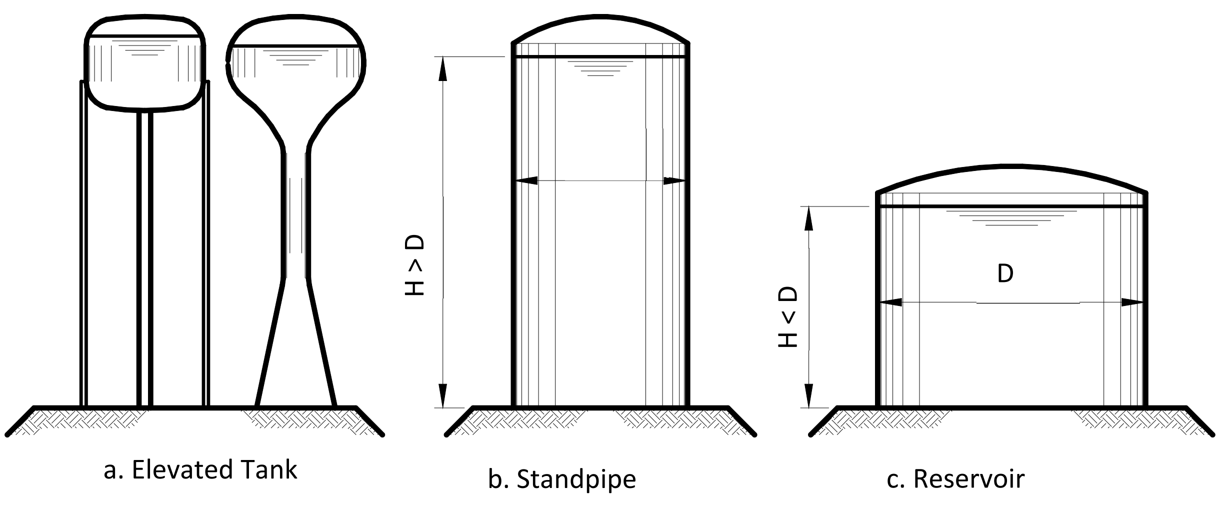
<u>Reservoir</u>

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 7.2c.

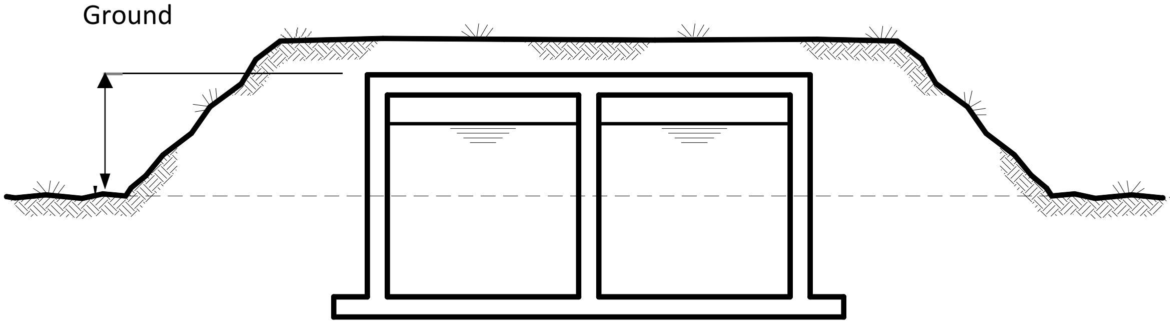
Figure 7.2 Above Ground Storage



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



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 7.2b.

7.3 Materials of Construction

7.3.1 Standards and 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 regulator. In the absence of such standards, materials meeting applicable Product Standards and acceptable to the regulator may be selected. Special attention should be given to selecting pipe materials that will protect against internal and external pipe corrosion. All products should comply with NSF/ANSI/CSA Standards. Any material that comes in contact with drinking water must be certified to *NSF/ANSI/CAN 61: 2018 Drinking Water System Components – Health Effects*.

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 and should also consider the effects of climate change.

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 current AWWA Standard (D100) concerning tanks, standpipes, reservoirs, and elevated tanks. Welded structures are field coated and generally follow AWWA D102 Standard for Coating Steel Water-Storage Tanks. Pre-finished Bolted Steel structures should follow the current AWWA Standard D103. Welded or Bolted Steel reservoir may be constructed with a self-supporting geodesic aluminum dome roof which should follow AWWA D108. Welded and bolted steel reservoirs should be protected from corrosion with an adequately designed corrosion protection system in accordance with applicable AWWA Standards (D104 and D106).

7.3.3 Concrete Construction

Concrete structures should follow the current AWWA standards (D110) 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 considered. The application of ANSI/NSF Standard 61 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 consists of a welded steel tank founded on a single concrete pedestal support structure. This type of construction should follow the AWWA Standard D107.

7.4 Storage Requirements

Water storage has a number of benefits:

System Operation (Convenience)
In some situations, storage is provided to allow a treatment plant to be operated for only one (1) or two (2) shifts, thereby reducing personnel costs. In this situation, storage provides the water required for the periods of time when the plant shuts down.

Requirements
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 utility 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 shutdowns. 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 is capable of satisfying only the maximum day demand may be calculated using the following equation:

S = A+B+C

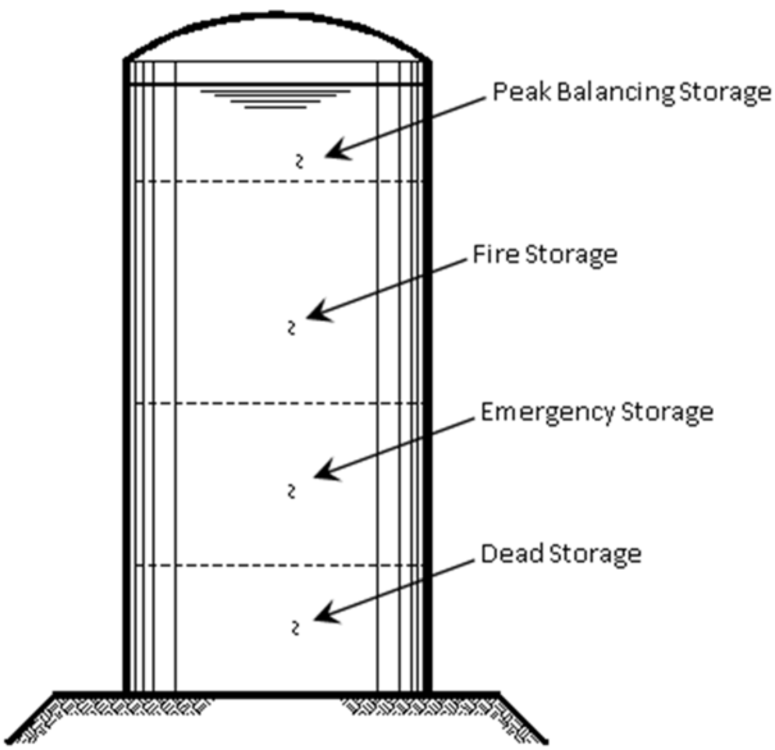
Where:
S = Total storage requirement, m^3

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 6.4.4)

Notes
The above equation is for the calculation of the storage requirement for a system where the water treatment plant is capable of satisfying only the maximum day demand. For situations where the water treatment plant can supply more, the above storage requirements can be reduced accordingly.
The maximum day demand referred to in the foregoing equation should be calculated using the factors in Table 7.1, 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 on the basis of an evaluation of the flow characteristics within the system.
Should the proponent 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.
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 water treatment facility, i.e. backwash and domestic use.

Source: Design Guidelines for Drinking-Water Systems,
Ontario Ministry of the Environment, 2019
(https://www.ontario.ca/document/design-guidelines-drinking-water-systems-0)

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.

7.4.1 Fire Flow Storage Requirements

Fire Flow Storage, where provided, is typically established by the utility. The utility 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 provide, consult the utility design guidelines or refer to the latest edition of Fire Underwriters Survey (FUS) document Water Supply for Public Fire Protection. The designer should contact the Local FUS office to obtain a copy of a water supply survey for the respective utility, should one be available.

The level of Fire Flow Storage may be reduced, accordingly, if the water treatment plant can supply more than the maximum day demand. The designer may also wish to consult the Ontario Ministry of Environment Design Guidelines for Drinking Water Systems, Chapter 8, for an alternative method of establishing fire flow criteria for small municipalities.

7.4.1 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, watermain failures, electrical power outages, natural disasters, or effects of climate change. 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.

In considering emergency storage, it is acceptable to evaluate significantly reduced supplies during emergencies. The designer should consult with the utility regarding local emergency storage requirements. If requirements are not clear, identify factors which may influence the need for emergency storage as noted above.

In the absence of clear information, 15% of projected average daily design flow can be used, or 25% of (Peak Balancing + Fire Flow)

7.4.2 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.

7.4.3 Plant Storage

The designer should recognize the need to calculate, in addition to distribution storage requirements, the requirement for the operation of the water treatment facility (i.e. backwash and domestic use).

7.4.3.1 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 (2) compartments along with adequate measures for circulation should be provided. Clearwells that can be depleted should not be used to achieve the required chlorine contact times. A separate contact tank should be provided to meet the disinfection requirements as per chapter 5.

7.4.4 Water Storage Facility Design Operating Levels

The top water level, 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 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 pressures 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 disinfectant by-products, 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 publication “Maintaining Water Quality in Finished Water Storage Facilities” by the AWWA Research Foundation should be referenced.

7.5.1 Detention Time

The allowable detention 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 maximum 72 hour turnover 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.

7.5.2 Reservoir Mixing

Mixing should be considered in the design of the Water Storage facility in an effort to ensure a more consistent water quality throughout. 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 take into account 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 contact time requirements for primary disinfection should be achieved in accordance with the requirements outlined in (Chapter 5, Section 5.6 – Disinfection). 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 system are often located at water storage tanks and may provide disinfectant addition at the inlet or outlet of the storage tank as required.

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, as the chemical quality of blended water may affect the integrity of the distribution system.

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-ground water storage and pumps may be required.

7.6.2 Above Ground and 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 above maximum flood level based on a 100 year flood, including climate change considerations.
- 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. Sewers, drains, standing water, and similar sources of possible contamination must be kept at least 15 m from the reservoir; and
- 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 and Baffle Wall

A detailed design of the inlet, and outlet and, if required – baffle walls, mixing, etc., is required to ensure maximum turnover of water in a storage tank. A publication such as “Maintaining Water Quality in Finished Water Storage Facilities” by the AWWA Research Foundation should be referenced.

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; and
- Changes in water level in a storage tank during daily domestic water demands should be limited to a maximum 9 m to stabilize pressure fluctuations within the distribution system.

7.7.3 Overflow

All above ground water storage structures should be provided with an overflow which is brought down to an elevation between 300mm and 600mm above the ground surface, and discharges over a drainage inlet structure or a splash plate. An overflow should not be connected directly to a sewer 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 sewer or 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 and 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; and
- 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, four-mesh non-corrodible screen may be used; and
- They should, on ground-level structures, terminate in an inverted U construction with the opening 600mm to 900mm above the roof or sod and covered with twenty-four mesh non-corrodible screen installed within the pipe at a location least susceptible to vandalism.

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 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 AWWA Standard D102 and be certified to ANSI/NSF standard 61, and be acceptable to the regulator. 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 volatile organic compounds 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; and
- Cathodic protection should be designed and installed by qualified technical personnel and a maintenance contract should be provided. Refer to AWWA D104 and D106 for corrosion protection standards for steel reservoirs.

7.7.13 Disinfection

- Finished water storage structures should be disinfected in accordance with current AWWA Standard C652. Two (2) 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 should be in accordance with the requirements of the regulator;
- A disinfection procedure (AWWA Standard C652 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.

7.7.1 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.

7.7.2 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.

7.7.3 Basins and Wet-wells

Receiving basins and pump wet-wells for finished water should be designed as finished water storage structures.

7.7.4 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.

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 contact time for chlorine (see Section5.6) special attention must be given to size and baffling;
- If used to provide chlorine contact time, 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 downgrade receiving areas of overflow water. Adequate surface detention should be provided to prevent soil erosion and to provide safe dissipation of chlorine; and
- 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 hydropneumatic (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 sizing requirements as outlined in section 7.4.

Pressure tank storage is not to be considered for fire protection purposes.

Pressure tanks should meet ASME Code 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, with consideration to climate change, and be completely housed.

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/min pump should have a 7,500 L pressure tank; and
- 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 600mm 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 (2) 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 100mm 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; and
- 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 eight inches in diameter should have protective bars over the riser openings inside the tank; and

- Railings or handholds should be provided on elevated tanks where persons must transfer from the access tube to the water compartment.

7.10.3 Protection

All finished water storage structures should have suitable watertight roofs which exclude birds, animals, insects, and excessive dust.

Fencing, locks and access manholes, and other necessary precautions should be provided to prevent trespassing, vandalism, and sabotage as per AWWA standards. A climate change resilience assessment should be completed to protect against climate change parameters.

Chapter 8 Transmission and Distribution Systems 179

8.1 Definitions 179

8.2 Materials 181

8.2.1 Standards, Materials Selection 181

8.2.2 Used Materials 181

8.2.3 Joints 181

8.2.4 Corrosion Prevention/Reduction 181

8.3 Design Criteria – Transmission and Distribution Systems 182

8.3.1 Transmission and Distribution Pipelines 182

8.3.1.1 Transmission Mains 182

8.3.1.2 Primary Distribution Mains 182

8.3.2 Water Demands 182

8.3.3 Pressure 183

8.3.4 Diameter 184

8.3.5 Velocity 184

8.3.6 Dead Ends/Looping Requirements 184

8.3.7 Fire Protection 184

8.3.8 Fire Pumps 185

8.3.9 Drain/Flushing Devices 185

8.3.10 Air Relief and Vacuum Valves 185

8.3.11 District Metered Areas 185

8.3.12 Crossing Obstacles 186

8.3.12.1 Road Crossings 186

8.3.12.2 Sewers 186

8.3.12.3 Surface Water Crossings 186

8.3.12.4 Horizontal Drillings 186

8.3.13 Bedding 187

8.3.14 Cover 187

8.3.15 Thrust Restraint 187

8.3.16 Pressure and Leakage Testing 187

8.3.17 Disinfection 187

8.3.18 Commissioning 187

8.4 Hydrants 187

8.4.1 Location and Spacing 187

8.4.2 Valves and Nozzles 188
8.4.3 Hydrant Leads 188
8.4.4 Drainage 188
8.5 Valve and Metering Chambers 188
8.5.1 Chamber Construction 188
8.5.2 Air Relief and Vacuum Valves Chambers 188
8.5.3 Flow Measurement and Meter Chamber 188
8.5.4 Pressure Reducing Valve Chambers 188
8.5.5 Chamber Drainage 189
8.6 Separation Distances to Sanitary and Stormsewers 189
8.6.1 Parallel Installation 189
8.6.2 Crossings 189
8.6.3 Forcemains 189
8.6.4 Manholes 190
8.6.5 Other Sources of Contamination 190
8.6.6 Exceptions 190
8.7 Cross Connection Control 190
8.7.1 Cross Connection Control Program 190
8.8 Water Services and Plumbing 190
8.8.1 Plumbing 190
8.8.2 Consumer Connections (Laterals and Curb-Stops) 190
8.8.3 Booster Pumps 191
8.8.4 Service Meters 191

Chapter 8 Transmission and 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 requirements of a distribution system is to supply each customer with 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. (Water Transmission and Distribution Systems, AWWA, 1996).

Transmission mains typically do not have service connections.

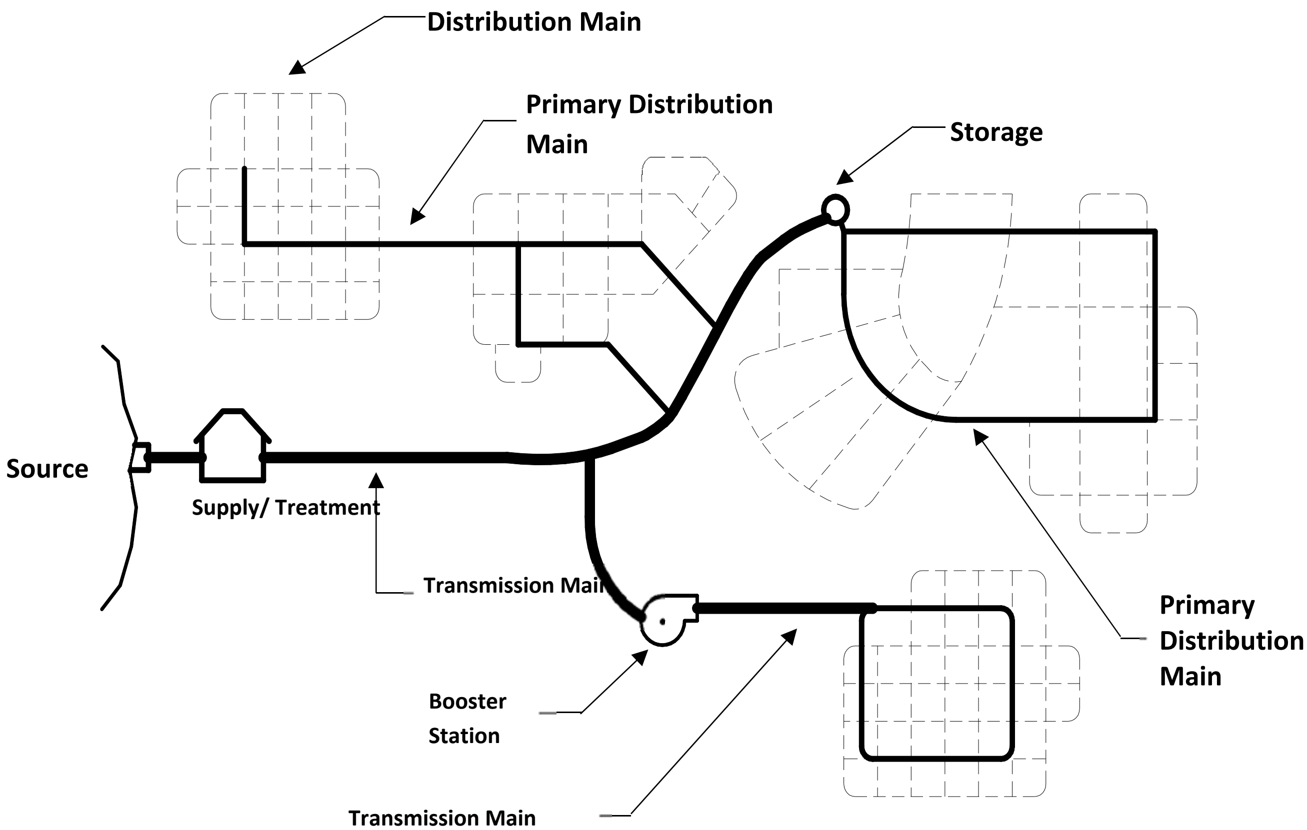
Primary Distribution Main

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. (Water Transmission and Distribution Systems, AWWA, 1996)

Figure 8.1 Transmission and Distribution Systems



Service Line (Lateral)

A service line is the pipe (and all appurtenances) that runs between the utility's water main and the customer's place of use, including fire lines. (Water Transmission and Distribution Systems, AWWA, 1996)

Service Connection

A service connection is the portion of the service line from the utility's water main to the curb stop at or adjacent to the street line or the customer's property line. (Water Transmission and Distribution Systems, AWWA, 1996)

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 demand.
- **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 demand.
- **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 demand.
- **Instantaneous Peak Demand** is a short duration high water flow rate that can occur in a water supply system.

8.2 Materials

There are a variety of materials in use within water transmission and distribution systems. Typical water pipe material used throughout the Atlantic Provinces include:

- Ductile Iron (DI);
- Polyvinyl Chloride (PVC);
- High Density Polyethylene (HDPE); and
- Concrete Pressure Pipe.

8.2.1 Standards, Materials Selection

Pipe, fittings, valves, and fire hydrants should conform to the latest standards issued by the CSA, AWWA, NSF, or NFPA, and be acceptable to the regulator.

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; and
- 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 regulator. 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 to selecting pipe materials which will protect against both internal and external pipe corrosion. All products should comply with CSA/ANSI Standards.

If soils are found to be aggressive, and the choice of materials is limited and subject to corrosion, action should be taken to protect the water main and fittings by encasement (wraps, coatings, etc) and/or provision of cathodic protection. For small copper pipes, sacrificial anodes are recommended.

The design and installation of watermain encasements and cathodic protection should be as per the manufacturers' recommendations.

8.3 Design Criteria – Transmission and Distribution Systems

8.3.1 Transmission and 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; and
- Addressing climate change risk and vulnerability.

8.3.1.2 Primary Distribution Mains

Primary distribution mains typically receives 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; and
- 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; and
- Pressure Surge Relief (requirements can be addressed by storage in the distribution system or other acceptable means).

8.3.2 Water Demands

The average day demand, maximum day demand, peak hour demand, minimum hour demand and instantaneous peak demand are defined in section 8.1.

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 the following table can be used as a guide.

The peaking factors indicated contained in Table 8.1 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 to 1,000	0.4	2.75	4.13
1,001 to 2,000	0.45	2.50	3.75
2,001 to 3,000	0.45	2.25	3.38
3,001 to 10,000	0.50	2.00	3.00
10,001 to 25,000	0.60	1.90	2.85
25,001 to 50,000	0.65	1.80	2.70
50,001 to 75,000	0.65	1.75	2.62
75,001 to 150,000	0.70	1.65	2.48
Greater than 150,000	0.80	1.50	2.25

Source: Design Guidelines for Drinking Water System's, Ontario 2019

Guideline average day water demand values can be referenced in the following documents:
- Modelling, Analysis and Design of Water Distribution Systems, Lee Cesario, 1995, AWWA;
- Design and Construction of Small Water Systems, 1999, AWWA;
- Nova Scotia Department of Environment and Labour, On-Site Sewage Disposal Systems, Technical Guidelines, Appendix F, April 2013;
- MAYS, Larry W, Water Distribution Systems Handbook, 2000;
- Province of Ontario, Design Guidelines for Drinking Water Systems, 2019; and
- Johns Hopkins University and Office of Technical Standards.

8.3.3 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, within a minimum of 75 psi.

The system should be designed to maintain normal operating pressures 350 – 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.. (Design Guidelines for Drinking Water Systems, Ontario MOE 2019).

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.

8.3.4 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; and
- 100 mm for service mains not providing fire protection.

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 (5 ft/s). The maximum fire flow velocity should be 3.0 m/s (10 ft/s).

Flushing devices should be sized to provide a flow that provides a minimum cleansing velocity of 0.8m/s (≈2.6 ft/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 connected to any sewer.

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 Fire Underwriters Survey Water Supply for Public Fire Protection (also see AWWA Manual M31 Distribution for Fire Protection, 1998. ISBN 0-89867-935-4).

8.3.8 Fire Pumps

National Fire Protection Association (NFPA 20) 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; and
- 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, Treated Water Storage Facilities).

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 AWWA C651 and due care with respect to: de-chlorinating; exit velocity of water during flushing (potential erosion/scour); minimum separation distance from nearest water-course; storage etc.

Flushing device should not be directly connected to any sewer.

8.3.10 Air Relief and 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 AWWA Manual M51 Air-Valves: Air-Release, Air/Vacuum and Combination)

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 (8 feet) 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.

8.3.11 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 utility 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 will result in watermain crossing obstacles. Considerations include, but are not limited to, the following.

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 is approved;
- Drainage is adequate; and
- Ditches crossing water mains should provide minimum cover of 1.5 m or insulate the watermain for frost protection.

8.3.12.2 Sewers

See section 8.6.

8.3.12.3 Surface Water Crossings

Surface water crossings, whether over or under water, require special considerations. The regulator 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 peak flood and vulnerability to climate change should be determined.

A minimum ground cover of 600mm should be provided over the pipe. When crossing water-courses which are greater than 4.5 metres 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; the valves should be easily accessible, not subject to flooding and should be within a properly constructed chamber; and
- 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 approved by the regulator 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.

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 sewer, consideration should be given to using restrained joints.

8.3.16 Pressure and Leakage Testing

All types of installed pipe should be pressure tested and leakage tested in accordance with the latest edition of AWWA Standard C600, 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 AWWA Standard C651. The specifications should include detailed procedures for the adequate flushing, disinfection, and microbiological testing of all water mains. In an emergency or unusual situation, the disinfection procedure should be discussed with the regulator.

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 Hydrants

All fire hydrants and flush hydrants should be of 'self draining' Dry-Barrel type. In areas having high water tables, appropriate measures should be taken to ensure drainage of the hydrant barrel (pumping or other suitable means).

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 Chapter 10, Small Systems.

8.4.1 Location and Spacing

Hydrants should be provided at each street intersection and at intermediate points between intersections as recommended by the FUS Water Supply for Public Fire Protection. In the absence of clear guidance hydrant spacing may range from 100 m to 175 m depending on the area being served and in accordance with FUS requirements.

8.4.2 Valves and Nozzles

Fire hydrants should have a bottom valve size of at least 125 mm (5 inch), one 113 mm (4.5 inch) pumper outlet and two 63 mm (2.5 inch) outlets.

Outlet and nozzle sizes should be standardized throughout the water distribution system.

Specific requirements should be coordinated with the local fire authority.

8.4.3 Hydrant Leads

The hydrant lead should be minimum of 150 mm (6 inch) in diameter. Shut-off valves should be installed in all hydrant leads.

8.4.4 Drainage

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.

Hydrants may also require to be pumped dry when hydrant drains are plugged during freezing weather. Hydrant drains consisting of a gravel pocket or dry well should be provided unless the natural soils will provide adequate drainage.

Hydrant drains should not be connected to or located within 3 m (10 ft) of sanitary sewers or storm drains.

8.5 Valve and Metering Chambers

8.5.1 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; and
- Include gravity or pump drainage.

8.5.2 Air Relief and 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.

8.5.3 Flow Measurement and Meter Chamber

Chambers containing flow monitoring/measurement devices should be located at off-road locations where feasible.

8.5.4 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; and
- Upstream and downstream pressure gauges.

8.5.5 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. Drains should be equipped with a backflow prevention device and screening to prevent the entry of insects, birds, and rodents.

In areas where high ground water levels are evident, above water table chambers should be considered.

8.6 Separation Distances to Sanitary and Stormsewers

The following factors should be considered in providing adequate separation:

- Materials and type of joints for water and sewer pipes;
- Soil conditions;
- Service and branch connections into the water main and sewer line;
- Compensating variations in the horizontal and vertical separations;
- Space for repair and alterations of water and sewer pipes; and
- Off-setting of pipes around manholes.

The requirements of the Atlantic Canada Wastewater Guidelines should be referenced.

8.6.1 Parallel Installation

Water mains should be laid at least 3 m horizontally from any existing or proposed sewer/pipe/manhole. The distance should be measured edge to edge. In cases where it is not practical to maintain a 3 m separation, the regulator 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; and
- 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 regulator.
- (GLUMRB, 1997, NSDOE, 1992) remove?

8.6.2 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 (see NSDOE Specifications, 1992, GLUMRB, 1997).remove? Special structural support for the water and/or sewer pipes may be required.

8.6.3 Forcemains

There should be at least 3 m horizontal separation between watermains and sanitary sewer forcemains. When crossing, the watermain should be above the forcemain with a vertical separation of a minimum 450 mm at the crossing.

The regulator should be contacted in instances where existing infrastructure does not allow for the watermain to be placed above the forcemain at the required separation.

8.6.4 Manholes

A watermain should not pass through or come in contact with any part of the sewer manhole.

8.6.5 Other Sources of Contamination

Design engineers should exercise caution when locating water mains at or near certain sites such as sewage treatment plants or industrial complexes. On site waste 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 reviewing authority.

8.6.6 Exceptions

The regulator 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 1000 kPa (≈150 psi) pressure rated pipe or equivalent and should be pressure tested to ensure water tightness.

8.7 Cross Connection Control

8.7.1 Cross Connection Control Program

Backflow prevention devices should be installed on consumer service connections where there is a risk of contamination of the potable water supply system resulting from back flow or back pressure.

ACWWA considers the adoption and enforcement of a Cross Connection By-law as a Best Practice to protect public health. When a project includes the design of service connections, the utility should be contacted to determine if a Cross Connection Control program exists so that the appropriate backflow prevention device can be selected.

8.8 Water Services and Plumbing

8.8.1 Plumbing

Water services and plumbing should conform to relevant local and/or provincial plumbing codes, or to the applicable National Plumbing Code. Solders and flux should be lead free.

8.8.2 Consumer Connections (Laterals and Curb-Stops)

All consumer connections (laterals) should conform with the following:

- Minimum cover 1.6 m;
- Maximum cover 2.0 m;
- 300 mm minimum 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 m from outdoor fuel tank;
- Minimum separation from sewage disposal field of 6 m;
- Single family residence connections should be minimum 20 mm copper or 25 mm high density polyethylene (HDPE) pipe. Large sizes may be required depending on length of lateral and grade elevations;
- Only lead free solder and flux should be used;
- Maximum velocity of flow should not exceed 4.5m/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 valve should be fitted before the metering device; and
- Pressure reducing valves to be fitted as required before metering device (HRWC, 2003, GLUMRB, 1997)

8.8.3 Booster Pumps

Individual booster pumps should not be used for any individual service from the public water supply mains unless approved by the utility.

8.8.4 Service Meters

Each service consumer connection should be individually metered with an approved metering device.

8.8.5 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; and
- Access to a loading station should be strictly controlled to minimize water safety and security concerns.

8.8.6 Water Quality Monitoring Stations

Dedicated water monitoring stations are 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 regulator and the utility.

Chapter 9 Operation and Maintenance 193

9.1 General 193

9.2 Surface Water Source Facilities 193

9.2.1 Water Quality Documentation 193

9.2.2 Operational Requirements 193

9.2.3 Maintenance Requirements 193

9.2.4 Documentation 194

9.3 Groundwater Source Facilities 194

9.3.1 Water Quality Documentation 194

9.3.2 Operational Requirements 194

9.3.3 Maintenance Requirements 194

9.3.4 Documentation 194

9.4 Pumping Facilities 195

9.4.1 Operational Requirements 195

9.4.2 Maintenance Requirements 195

9.5 Water Treatment Facilities 195

9.5.1 Water Quality Compliance Requirements 195

9.5.2 Water Quality Operational Requirements 196

9.5.3 Maintenance Requirements 196

9.5.4 System Documentation 197

9.6 Treated Water Storage Facilities 197

9.6.1 Operation and Maintenance Requirements 197

9.6.2 Cold Weather Operation 197

9.7 Transmission and Distribution Systems 197

9.7.1 Operation and Maintenance Requirements 197

9.8 Small Water Supply Systems 198

9.9 Safety 198

9.10 Overall Documentation 199

9.11 Operator Training Scheduling 199

9.12 SCADA Monitoring 199

9.13 Security 199

Chapter 9 Operation and Maintenance

9.1 General

Operation and maintenance (O&M) 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 Utility should retain a current copy of the O&M manual at head office, and at individual facilities, for immediate access by the water utility personnel.

The O&M manuals should contain pertinent information on the normal day to day operation and maintenance of the facility, program schedules, descriptions of routine tasks and means to assess the system for implications of climate change throughout asset life.

Operations manuals should include up to date standard operating procedures and contingency plans.

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 regulator. 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; and
- Notifications 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 8.4); and
- 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 back-up supply (if any);
- Cleaning frequencies;
- Impoundment and reservoir specifications;
- Screen specifications;
- Pump specifications (see section 9.4); and
- Standard operating procedures and contingencies.

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 regulator. 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; and
- 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/development;
- Monitoring well purging/cleaning/development;
- Submersible pump maintenance; and
- Disinfection.

For manufactured components (e.g., valves, 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;
- 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, flow rate and pump monitoring information; and
- Standard operating procedures and contingencies.

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; and
- Power supply schematic;
- Overall standard operating procedures; and
- 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; and
- Out of service/lock out procedure.

9.5 Water Treatment Facilities

9.5.1 Water Quality Compliance Requirements

Water quality compliance monitoring, recording, and reporting should be in accordance with the requirements of the Approval 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 water treatment plants 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 turbidities;
- 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; and
- Diagnosis of problems.

9.5.3 Maintenance Requirements

Maintenance requirements of an O&M manual for water treatment plants 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; and
- 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;
- HVAC systems;
- Back-up 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;
- Sanitary waste systems;
- Storm sewer systems; and
- 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;
- Effects of climate change on existing infrastructure and treatment process;
- 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;
- Maintenance schedules; and
- Back-up of all electronic information.

9.6 Treated Water Storage Facilities

9.6.1 Operation and 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); and
  - Disinfection.
- Return to service;
- Monitoring devices (gauges and meters); and
- 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 operation, maintenance and emergency procedures be addressed by the O&M manual.

9.7 Transmission and Distribution Systems

9.7.1 Operation and Maintenance Requirements

Operation 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 (gauges and meters);
- Record Keeping;
- Preventative Maintenance;
- System mapping; and
- 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, for the most part governed by manufacturers specification 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; and
- 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;
- 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; and
- 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 utility 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 utility/responsible engineer;
- Name and phone number of facility supervisor;
- Description and schematic of facility and monitoring devices;
- Regular power supply information;
- Back-up power supply information;
- Instructions for system shut-down; and
- Location of as-built drawings.

9.11 Operator Training Scheduling

A program for operator training should be developed and included in the operation and maintenance manual. The program should include reference to required periodic refresher courses.

The operator in direct charge of the utility should be responsible for ensuring the schedule is implemented and followed.

9.12 SCADA Monitoring

Where appropriate, the operation and maintenance 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) on a regular basis to confirm the SCADA system is operating properly.

9.13 Security

The operation and maintenance 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.; and
- Protection of equipment from theft and vandalism.

Chapter 10 Small Water Supply Systems 202

10.1 General 202

10.2 Outline of a Small Water Supply System 202

10.3 Approval Requirements 203

10.4 Water Use Requirements 203

10.4.1 Average Use 203

10.4.2 Maximum Day Demand 203

10.4.3 Peak Hour Demand 203

10.4.4 Outdoor Use 204

10.4.5 Fire Protection 204

10.5 Source of Supply 204

10.5.1 Surface Water 204

10.5.1.1 Impounding Reservoirs 204

10.5.1.2 Intakes 204

10.5.2 Groundwater 205

10.5.2.1 Number of Wells 205

10.6 Water Treatment 205

10.6.1 Treatment of Surface Water 206

10.6.1.1 Disinfection of Surface Water 206

10.6.2 Treatment of Groundwater 206

10.6.2.1 Disinfection of Groundwater 206

10.6.3 Methods of Disinfection 207

10.7 Auxiliary Power 207

10.8 Water Storage 207

10.8.1 Storage Capacity 207

10.8.2 Water Storage Materials 207

10.8.3 Treated Water Pump 208

10.8.4 Acceptable Pressure 208

10.9 Pressure Tanks 208

10.10 Water Distribution System 208

10.10.1 Material 208

10.10.2 Distribution System Piping Diameter 208

10.10.3 Pressure Rating 208

10.10.4 Velocities 208

10.10.5 Service Connections 208
10.10.6 Water Meters 208
10.10.7 Hydrants 208
10.10.8 Individual Home Booster Pumps 209
10.11 Monitoring Requirements 209
10.12 Facility Classification and Operator Certification 209
10.13 Easements, Statutory Rights of Way, and Restrictive Covenants 209

Chapter 10 Small Water Supply Systems

10.1 General

The requirement of this manual 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 utility 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; and
- Small residential communities.

The definition of a small water supply system may vary between regulatory agencies, however they typically can be defined by the number of service connections as follows:

- Very Small Water System – 5 to 14 service connections; and
- 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 may be performed by part time staff, or contractors;
- Technologies used often need to be relatively simple; and

The regulatory agency should be contacted to determine site specific requirements for a small water system.

10.3 Approval Requirements

The approval requirement of small water systems is similar to the approval requirement of a municipal system, and therefore the process outlined in Chapter 1 should be followed.

Proponents planning a small water supply system should consult with the regulator to discuss the scope of the project and to determine the regulatory requirements.

10.4 Water Use Requirements

It is essential that the water treatment facilities 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.

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 220-450 Lcpd.

Small system communities that have commercial users have to 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. The characteristics of a small rural water system, however, require special consideration. 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 occurs over an eight-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 average daily flow divided by 24 hours, and multiplying it by the appropriate peak rate factor obtained in Table 10.1.

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	4.5
167	500	0.4	2.9	4.3

Source: Based on Table 3.3, Design Guidelines for Drinking-Water Systems, Ontario, 2008 (MOE).

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/min for one 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.

10.5.1 Surface Water

Subject to the source and the requirements of the regulator, a hydrology study by a professional hydrologist may be required to confirm 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 is considered to be a low stream flow with a return period of twenty-five years.

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.

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 the Department of Fisheries and Oceans 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 and 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 regulator.

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.

A well protection plan may be required by the regulator.

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 on-line and alternating in use.

If the individual wells are not capable of providing the maximum day demand, at least one 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 groundwater under the direct influence of surface water (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 proponent, in this regard, may present innovative options to the regulator for consideration. In addition, management plans, standard operating procedures and contingencies should be in place to deal with the reduced capacity and water quality maintenance requirements.

The regulator may consider system specific exceptions, and may require the provision of emergency water storage and/or emergency shutdown 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 GCDWQ.

The 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; and
- 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 shall be disinfected (as discussed in Section 10.6.3).

10.6.2 Treatment of Groundwater

The water quality investigation should include all health and aesthetic parameters in the GCDWQ.

Proprietary treatment units will typically be used.

10.6.2.1 Disinfection of Groundwater

Barring system specific exceptions, groundwater shall be disinfected (as discussed in Section 10.6.3).

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 hypo-chlorination 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 contact time and free chlorine residuals have to be considered when planning and locating the disinfection facilities.

Ultraviolet (UV) disinfection may be used when a measurable residual is not required in the water distribution system (groundwater system). When UV disinfection is used, chlorination may be required periodically to disinfect the distribution system.

Novel or alternative disinfections may be considered for use for small water supply systems, however may require additional review by regulators 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.

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.

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 one 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 kPa 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 regulator 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. 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 network is 900 kPa (175 psi).

10.10.4 Velocities

Velocities in the water distribution system should be a maximum of 1.5 m/s (5 ft/s).

10.10.5 Service Connections

Service connections should be a minimum 19 mm (¾ inch) diameter.

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 (2.6vft/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 utility, should be outlined by the regulator in the Approval/Permit to Operate.

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

In instances where monitoring is the responsibility of a regulator, reporting will be the responsibility of the regulator and/or laboratory.

10.12 Facility Classification and Operator Certification

It is recommended that operators of small water supply systems be thoroughly trained in all aspects of the operation and maintenance 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 regulator should be consulted regarding specific requirements.

10.13 Easements, Statutory Rights of Way, and 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 metres.

Appendix A

References

ATLANTIC CANADA
WATER & WASTEWATER ASSOCIATION

Consultant

CBCL

Peer Review

exp.