Guidance for Deriving Site-Specific Water Quality Objectives for Alberta Rivers

Government of Alberta

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Site-Specific Water Quality Objectives

for Alberta Rivers

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EXECUTIVE SUMMARY

Under the Land-use Framework, regional plans are being developed which will establish environmental outcomes and take a cumulative effects approach to the management of combined impacts of existing and new development. Water quality objectives may also be established that will reflect the desired regional outcomes and contribute to their achievement. Once water quality objectives are established they have action or management commitments.

Three management directions for water quality are possible:

- *Use Protection*, which identifies ambient limits beyond which water quality should not deteriorate, but which allows for some further contaminant loading (i.e., some degradation of water quality) within that constraint;
- *Maintain water quality*, which implies no further degradation of water quality and no increase in overall contaminant loading; and
- *Improve water quality*, which implies reduction of overall contaminant loads so that improvement occurs.

This guidance document focuses on the latter two and

- Clarifies terminology and principles;
- Provides practical, science-based guidance for drafting site-specific water quality objectives; and
- Discusses the application of water quality objectives in environmental management.

It outlines foundational concepts about water quality management, and defines guidelines, objectives, triggers, targets, and ambient limits. It describes the principle of protecting all uses of water and that use-protection guidelines are consequently the desired minimum level of protection.

The typical steps involved in drafting objectives include identifying the variables of concern (substances or conditions); assessing the situation for each variable with respect to existing guidelines; confirming the management direction; and deriving a draft objective (four methods are outlined). A decision tree is provided to assist the steps. Although not addressed in this guidance document, draft water quality objectives may then be considered in a socio-economic context before establishment in regional plans, management frameworks, or other processes.

Water quality objectives may be used when monitoring identifies undesirable conditions relative to pre-defined triggers, and when planning watershed and contaminant management so as to achieve the objectives. Their application needs to consider: where they apply (i.e., specific location or reach); when they apply (e.g., to specific seasons and/or flow conditions); what actions or management commitments are associated with them; what monitoring will be done to evaluate performance; and how often the variables of concern and their objectives will be reviewed.

This document is for professionals tasked with drafting site-specific water quality objectives. This field of environmental science and management continues to evolve and methods and guidance may be revised in the future.

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ACKNOWLEDGEMENTS

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1.0 INTRODUCTION

The fundamental goal under the Water for Life Strategy (WfL) (GOA 2003; 2008a) is to ensure the sustainable management of the province's water resources so that Albertans are assured of:

- Safe and secure drinking water;
- Healthy aquatic ecosystems ; and
- Reliable quality water supplies for a sustainable economy.

Existing policies, legislation and agreements provide guidance for water management in the province. This includes support for the protection of water uses and encouragement for non-degradation, pollution prevention, and continuous improvement (e.g. PPWB 1991; AEP 1996; AENV 1999a).

The Land-use Framework (LUF) has been established by the Government of Alberta to manage growth and integrate economic, environmental, and social considerations in planning and decision-making (GOA 2008b). As part of the LUF, regional plans are being developed which will establish regional outcomes and take a cumulative effects management approach to manage the combined impacts of existing and new developments.

Regional or other planning processes may also establish surface water quality objectives for variables that are of concern in the achievement of the broader outcomes of WfL and the plans. Water quality objectives (WQO) are the specific desired outcomes in any management of water quality. These objectives will be developed within the context of provincial policy but will be place-based and may vary with the region, watershed, and circumstance. The provincial direction is that WQO will be established and contaminant loads managed in such a way that the objectives are achieved. Once established both regulatory and non-regulatory tools may be used to ensure objectives are met. There will be action and/or management commitments associated with WQO, such as the cumulative management of contaminant loads. As of 2011 WQO already exist in a number of locations in Alberta (Section 3).

Three general management approaches or directions for water quality are possible:

- *Use Protection*, in which the use-specific water quality guidelines are generally the point beyond which water quality should not deteriorate (the ambient limit), but which allows for some further substance loading (i.e., some degradation of water quality) within that constraint (CCME 2003a);
- *Maintain water quality*, which implies no further degradation of water quality and no increase in overall contaminant loading; and
- *Improve water quality*, which implies reduction of overall contaminant loads so that improvement occurs.

The management approach may be applied uniformly to all water quality variables, or it may differ from one variable (contaminant) of concern to another. The approaches are relevant to aquatic ecosystem health (AEH), but generally deal with individual water quality variables and contaminants, versus AEH itself. Aquatic ecosystem health is a more general concept, involving many water quality variables and additional ecosystem components such as sediments, biota, and physical habitat.

This guidance document focuses on the approaches of maintaining or improving water quality. Guidance for the use protection approach can be found in the Alberta surface water quality guidelines (SWQG) (AENV 1999b), the *Industrial Release Limits Policy* (AENV 2000), and the *Water Quality Based Effluent Limits Procedures Manual* (AEP 1995).

The objective of this document is to:

- Clarify terminology and principles associated with water quality objectives and management;
- Provide practical, science-based guidance for drafting site-specific water quality objectives (SSWQO); and
- Discuss the application of SSWQO in management plans.

Since water management plans are concentrating on large river basins, the focus of this document is on approaches for large rivers. This guidance document is intended to promote technical consistency for professionals tasked with the derivation of SSWQO in Alberta. Because of the details and complexity of natural ecosystems, place-based situations, and water quality data, it is impractical to spell out all details of a derivation procedure. Scientific expertise in the subject will still need to be applied. Further, this field of environmental science and management continues to evolve and revised methods and guidance may be set out in the future.

Once SSWQO are drafted, they would usually enter a regional or other planning process to be considered in a socio-economic context and potentially modified, before final establishment (see GOA 2011). There would likely be much iteration between drafting objectives, determining management directions, establishing objectives, and developing management plans/frameworks. The relationship of the water quality aspects to a larger planning process and the cumulative effects management system (CEMS), is depicted in Figure 1.

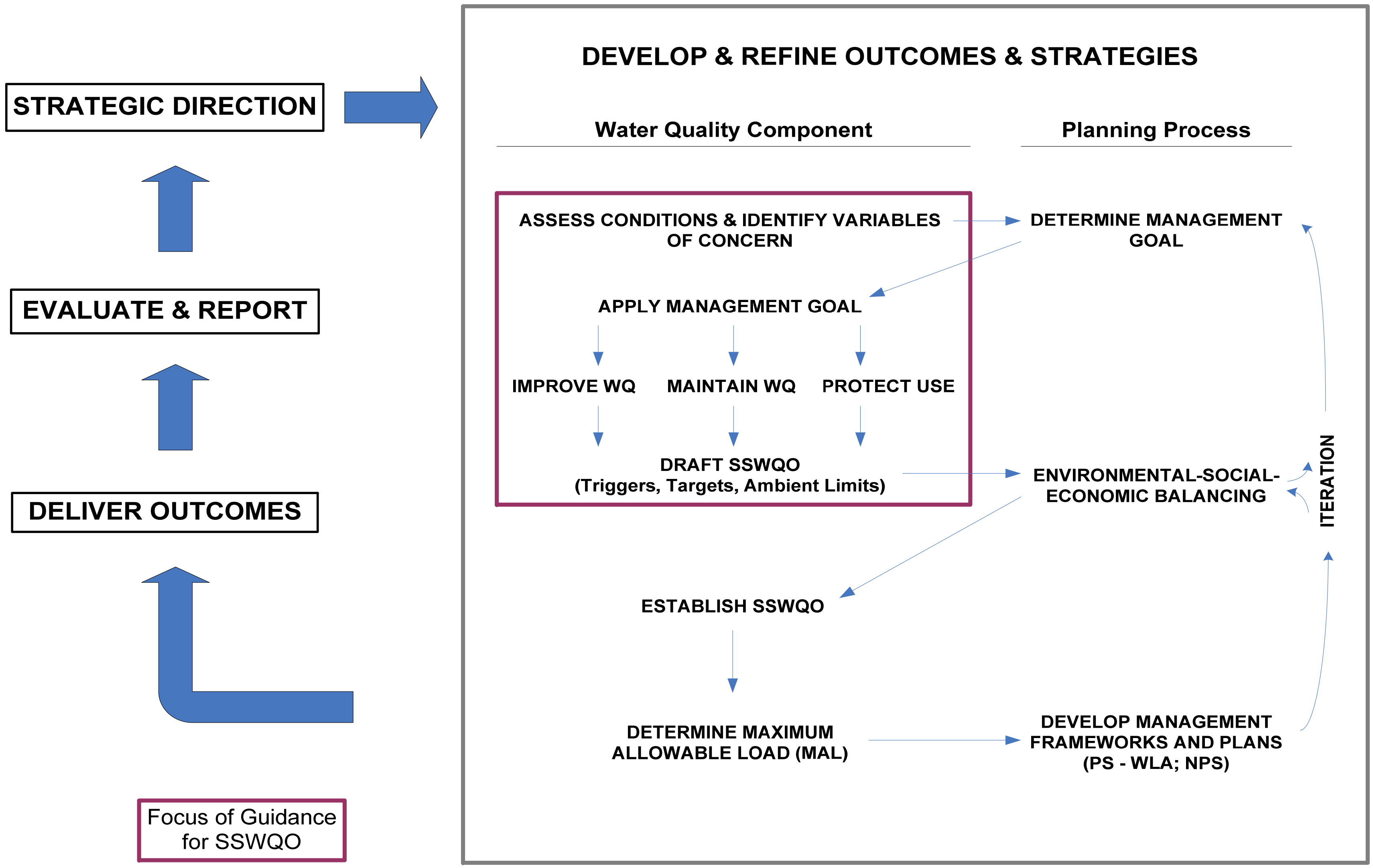

Figure 1 Water quality in the planning step of Cumulative Effects Management

2.0 FOUNDATIONAL CONCEPTS ABOUT SURFACE WATER QUALITY MANAGEMENT

As the Alberta population increases and the economy expands, human pressures on aquatic ecosystems can be expected to rise. This makes it increasingly important to develop water management systems and plans that can recognize, anticipate and mitigate environmental pressures, particularly if water becomes an increasingly scarce resource. Such plans must incorporate sound, up to date information and knowledge about natural and man-made factors that influence aquatic ecosystems.

2.1 Natural Features of Aquatic Ecosystems

There is a high degree of spatial and temporal variability in aquatic ecosystems resulting from broad differences across the province in climate, hydrology, geology and soils, topography, and terrestrial vegetation. Most large rivers in Alberta have natural increases in turbidity, suspended solids, metals, phosphorus, and other elements associated with solids, as water flows from headwaters to the lower reaches. Natural variability over time is strongly influenced by seasonal and year-to-year differences in weather, precipitation, and longer-term changes in climate. The lower, stable flows tend to occur during periods when runoff is low, usually in fall and winter. Levels of suspended solids and associated substances tend to be lowest during such times. Snowmelt, rain, and runoff in spring and summer can result in rapid and substantial increases in flows, suspended solids and associated substances. Glacial melt and groundwater inputs help to sustain flows in the headwaters of many large rivers during the dry summer months and may contribute, respectively, significant amounts of suspended and dissolved solids. Prairie rivers and streams that arise from local runoff and ground water typically tend to have low flows in summer, fall, and winter. Rivers and streams arising in the boreal region usually have higher levels of organic carbon and are brown-coloured.

2.2 Human Influences on Aquatic Ecosystems

Human activities may exert stresses on water quality and other elements of aquatic ecosystems. These activities generally fall into three broad categories: flow regulation and water withdrawal; land use and landscape alterations; and release of contaminants into the environment.

Flow regulation and withdrawal may result in lowered peak flows, lowered summer-fall flows, and augmented winter flows. This may reduce the dilution capacity for effluents in summer, but increase it in winter. Lower peak flows may reduce natural erosion and suspended solids transport in rivers, and reduce ‘flushing flows’. Aquatic habitat may be altered as a result of changes in flow regime.

Human activities can contribute man-made chemicals to surface waters, or they can increase the loading of naturally occurring substances. Contaminants may originate from point sources (PS: discrete and identifiable inputs, such as effluents), or non-point sources (NPS: diffuse, such as overland run-off, or atmospheric deposition). Point source loadings (the amount, or mass, of contaminants discharged per unit time) are more straightforward to measure and control, whereas non-point sources loadings are more difficult to quantify and manage because of their diffuse and episodic nature (e.g., runoff events).

Land use affects the mass of contaminants that is conveyed to surface waters in run-off, especially where soils are exposed, or where land is paved or drained. A wide range of contaminants may be involved, some of which may occur naturally (e.g., nutrients, metals, salts, suspended solids, pathogens). Human activity can increase their loading to aquatic ecosystems. Other contaminants may be synthetically produced (e.g., pesticides, pharmaceuticals, personal care products, wetting agents, flame retardants) and released through point or non-point sources. Aerial deposition of anthropogenic contaminants (e.g., mercury, acidifying substances, and nitrogen compounds) may also be significant for some surface waters.

2.3 Key Elements of Surface Water Quality Management

The purpose of surface water quality management is to manage cumulative contaminant loadings from PS and NPS in an integrated fashion so as to achieve the goals and outcomes for water quality and aquatic ecosystem health. The management of river water quality also needs to be integrated with the management of river flows. In flowing waters, the amount of water (discharge) is an important limiting factor for the dilution or assimilation of anthropogenic contaminant loadings. Flow must be considered in water quality management: changes in flow regime have implications on water quality that need to be taken into account in the management of point source loading. As well, non-point sources of contaminants such as nutrients, bacteria, and pesticides should be integrated into management plans, along with the more obvious point sources.

Water management requires an integrated and holistic approach to manage water quantity and quality at the watershed or sub-basin scale (USEPA 2006). Key elements are:

- Assess watershed conditions, issues, and variables of concern;
- Determine environmental goals and establish water quality objectives;
- Develop and implement contaminant and, where relevant, flow management plans;
- Monitor, evaluate, and report on progress; model future scenarios to support management plans; and
- Adapt and improve in water quality management.

These main elements typically have considerable detail within them, involve much iteration, and will include socio-economic considerations. The place of water quality objectives development in this overall system is depicted in Figure 1.

3.0 DEFINITIONS AND PRINCIPLES

Following are terms, definitions and principles recommended for use in drafting water quality objectives. In defining the terms we have attempted to:

- Minimize new terms and keep definitions as basic as possible;
- Maximize consistency with existing terminology (e.g. CCME); and
- Align terminology with Acts, Regulations, and guidance where available (e.g. GOA 2011).

If additional terms are used in the drafting of objectives, they should be defined as precisely as possible. The definitions used here are also listed in the Glossary (Section 7).

Surface Water Quality Guideline

A Surface Water Quality Guideline (SWQG) is a numerical concentration or narrative statement which is recommended to protect a specific use of water.

Guidelines such as those developed by CCME (1999; 2007) and AENV (1999b) are intended to provide consistent, science-based recommendations for the protection of various water uses at the national or provincial scale, but do not consider site-specific conditions, or socio-economic factors. Water quality guidelines are science-based policy tools and a cornerstone of water quality management. Nonetheless, SWQG have a number of limitations in the sense that they apply to single elements or compounds, do not account for interactions among contaminants (cumulative toxicity, synergism or antagonism), or food web effects (bioaccumulation or biomagnification). Hence, they do not guarantee the expected level of protection if incorporated as the sole tool in water quality management plans. Also, they are not available for all water quality variables. SWQGs could be developed for specific sites, and would be termed site-specific guidelines (AEP 1996; CCME 2003a; 2007). However the cost and length of time involved make this rarely advisable, unless such guidelines are urgently needed to serve as objectives (see below).

Site-Specific Water Quality Objective

A Site-Specific Water Quality Objective (SSWQO) is a numerical concentration or narrative statement which has been established for specified waters, and which has an action and/or a management commitment.

In order to maintain consistency with historic and national usage 'Objective' is recommended as the generic term for established values or narratives. More specific terms include triggers, targets, and ambient limits, which can also be thought of as tiered objectives (see below). In contrast to guidelines, Site-Specific Water Quality Objectives apply to specific locations (sites, river reaches); have been established by means of Approvals, Water Management Plans, Regional Plans, or other policies/practices; and carry some action or management commitment. Establishing water quality objectives involves the science-based procedures outlined in this document and also socio-economic considerations (AEP 1996). The latter are not addressed here but occur during regional or other planning processes (Figure 1; and GOA 2011). In reality, all water quality objectives will be site-specific, because objectives that apply throughout the province are not appropriate. Established SSWQO in Alberta to the end of 2011 include:

- Athabasca River dissolved oxygen (DO): The provincial guidelines of 5 and 6.5 mg/L are established as the objectives for the river upstream of Grand Rapids in winter. The management commitment, included in pulp mill Approvals, is to intensify the control of BOD in mill effluent in the event winter DO is threatened.
- Prairie Provinces Water Board (PPWB): Site-specific water quality objectives are established for trans-boundary reaches on the eastward flowing rivers, under the PPWB agreement (PPWB 1991). The commitment is to monitor, report, and if necessary investigate exceedances of the objectives, and as appropriate to manage the upstream watershed in such a way that the objectives are achieved.
- Highwood River temperature and DO: Objectives for summer water temperature and DO are established for the lower Highwood River (AENV 2008). Water diversions from the river are managed so as to minimize the exceedance of temperature and DO objectives.
- Bow River Water Quality Objectives: The Bow River Basin Council (2008) has developed SSWQO for the Bow River mainstem and some tributaries. Council members and AENV have committed to work towards the achievement of these objectives.

In cumulative effects management and LUF or other planning processes, SSWQOs are the desired outcomes for water quality management, once they are established in plans, management frameworks, or the like (Figure 1). They can be used in a planning mode to define allowable point and non-point source contaminant loads, and in a monitoring mode to identify water quality exceedances and issues. They contain a commitment to action and/or management, otherwise they would only be refined guidelines.

Ambient Limit

In surface water quality, an ambient limit is a level or condition beyond which the most sensitive use may not be protected.

Ambient limits are generally meant to define the boundary not to be exceeded because the risk to aquatic ecosystem health and water uses is too high and unacceptable. Significant efforts and resources are to be expended to prevent ambient conditions from exceeding limits (GOA 2011). The limits are often equivalent to the SWQG for the most sensitive use, unless natural water quality is worse than the guideline. Ambient limits should be carefully distinguished from the term 'limit' that is used in effluent regulation (AEP 1995; 1996).

Target

In surface water quality a target is a concentration or narrative statement that management aims to achieve or do better than.

Targets are most akin to the historic meaning of water quality objectives. They represent the desired water quality condition, at which management would be directed, and so for example would dictate the maximum allowable load (MAL) of a specific contaminant. Targets could be equal to or more stringent than a limit, but would not be less stringent (Figure 2).

Thresholds

The use of 'thresholds' in environmental management has been included in recent documents. (e.g., GOA 2008b; AENV 2008). Threshold is a general term, has been defined in ALSA (see the Glossary in Section 7), and there may be various thresholds (e.g., targets, limits, triggers) and correspondingly various meanings. It is recommended that more precise terms than threshold be used, and their meaning clearly defined.

Trigger

A trigger is a condition which, if exceeded, results in some action being taken (e.g., intensified monitoring; risk assessment; contaminant management).

Triggers can serve as warning signals of environmental change. They can be set at levels appropriate to the management goals, issues and water quality conditions of the location. Trends may also serve as triggers. For a given variable multiple triggers with different response commitments could be established, depending on the degree of environmental risk at each level. This can provide an earlier evaluation and proactive management response, thereby helping to keep conditions from reaching or exceeding ambient limits. This can also provide clarity and certainty regarding the management response.

The general relationship of triggers, targets, and limits for selected situations is illustrated in Figure 2, and discussed further in Sections 4 and 5.

Water uses to protect:

In keeping with the general intent of the Environmental Protection and Enhancement Act (EPEA), the Water Act, AENV (1999a), and the WfL Strategy, all existing and potential uses of water should be protected. These include:

- Aquatic life;
- Agricultural (irrigation and livestock watering);
- Recreation and aesthetics;
- Raw water for drinking water supply; and
- Industrial water supply.

The first three have numerous guidelines in existence, and the protection of aquatic life (PAL) guidelines are often the most stringent, indicating that aquatic life is often the most sensitive use. Guidelines for untreated drinking water supply are few, but objectives can be developed where warranted. Although mainly relevant to potable water treatment plants, they can also be relevant to local domestic use of surface water. Guidelines for industrial water supply are rarely needed for surface waters, although there may be instances where this is warranted.

Minimum level of protection:

Because all uses of water should be protected, no water quality objective should be any less stringent than the most sensitive use-protection WQ guideline. Exceptions would be where natural water quality is worse than the most sensitive WQG, in which case the natural water quality should be the objective or a site-specific guideline derived. Meeting use-protection guidelines in areas where natural water quality is worse than a guideline would be unrealistic and unachievable. In cases where water quality is presently degraded beyond the guideline by human activity, the management direction should be to improve water quality. Taking into account environmental risk and socio-economic considerations, the ultimate objective generally should be the SWQG (or better). Remedial management targets could lay out scheduled expectations for improvement.

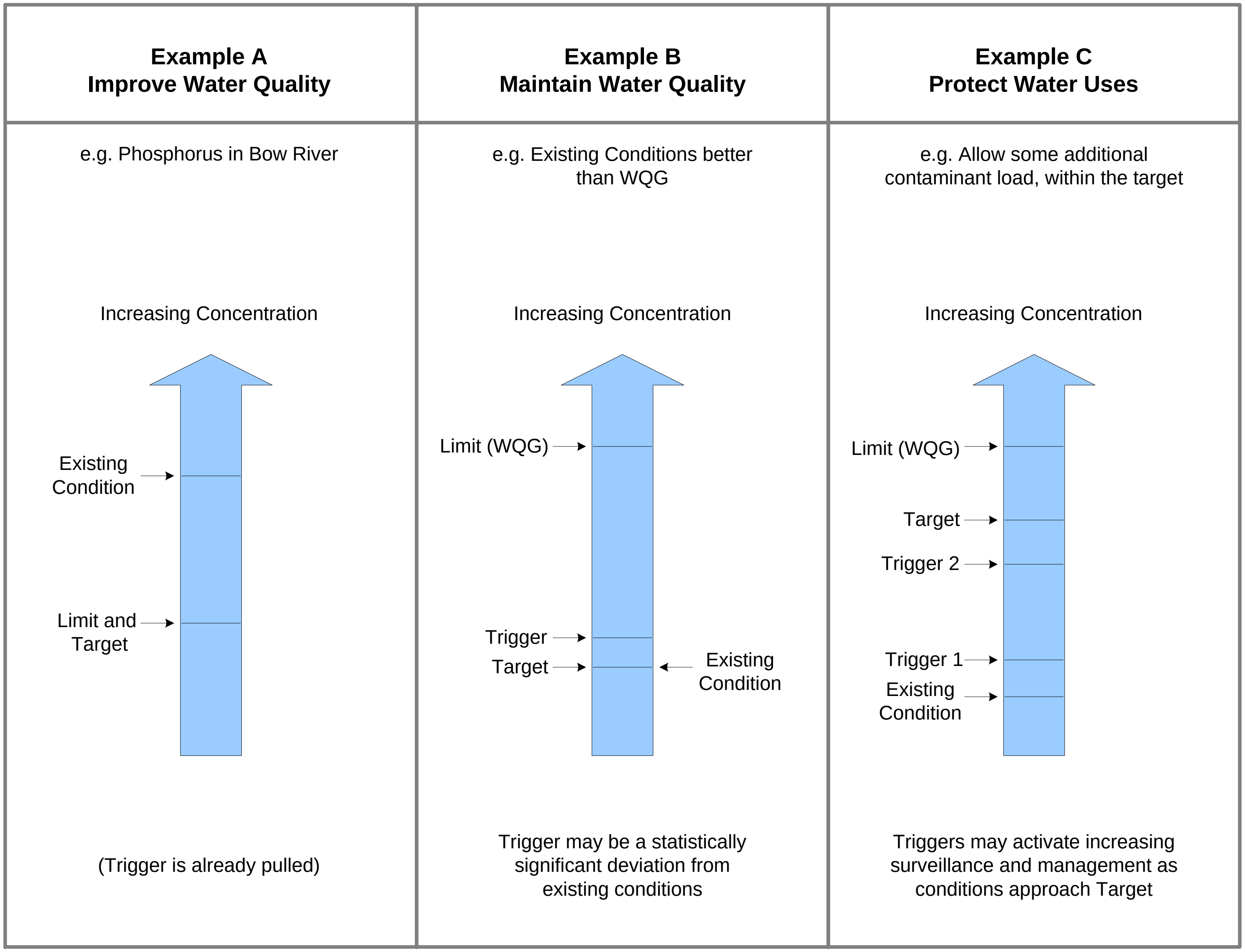

Figure 2 **Selected relationships between triggers, targets, and limits**

4.0 DERIVATION OF WATER QUALITY OBJECTIVES

4.1 Introduction

This section describes the typical steps involved in drafting water quality objectives in support of a "*maintain or improve* "approach to water quality management. A decision tree is provided in Figure 3 to describe and aid part of the process, and examples are included in Section 8. The 'use protection' approach is dealt with in part by the *Water quality-based effluent limits procedures manual* (AEP 1995).

As noted previously, once water quality objectives are drafted they may then be considered from a socio-economic perspective in the regional or other planning process, before final establishment (Figure 1 and GOA 2011). Those iterative processes, which involve scenario assessment, modelling, management planning, and socio-economic-environmental balancing are not addressed in this document, but would influence the SSWQO that are finally established. Also, there may be situations where an existing water management framework, or other established plan (e.g. the Bow Basin Watershed Management Plan – BRBC 2008; the Highwood River Water Management Plan – AENV 2008), already specifies SSWQOs and/or management approaches, and these may take precedence over, or influence the procedures outlined here.

Because SSWQOs have action and/or management commitments associated with them, these should be considered during the derivation process. Objectives may be tiered into triggers, targets, and ambient limits (Figure 2), and their intent and utilization needs to be clear. Utilization of SSWQOs can be in two modes:

- Planning: wherein the SSWQOs would allow calculation of a maximum allowable load (MAL) of a contaminant, which would form the basis for planning and contaminant load management in the watershed.
- Monitoring and management: wherein ongoing monitoring data are compared to triggers, targets and limits to determine exceedance and whether increased investigation, identification of cause and/or management action is warranted.

This is discussed further in Section 5.

4.2 Identify Variables of Concern

Understanding what causes longitudinal and temporal change in river water quality and aquatic ecosystem conditions is the first step in protecting aquatic ecosystem health. This involves understanding the sources of natural and man-made substances and conditions, as well as what influences concentration, fate, and effects on water quality and aquatic biota. This is essentially characterizing the watershed and its issues, which can then allow us to focus on the important water quality variables. Two main steps are involved, and the level of detail will depend on the scope and intensity of the overall planning initiative:

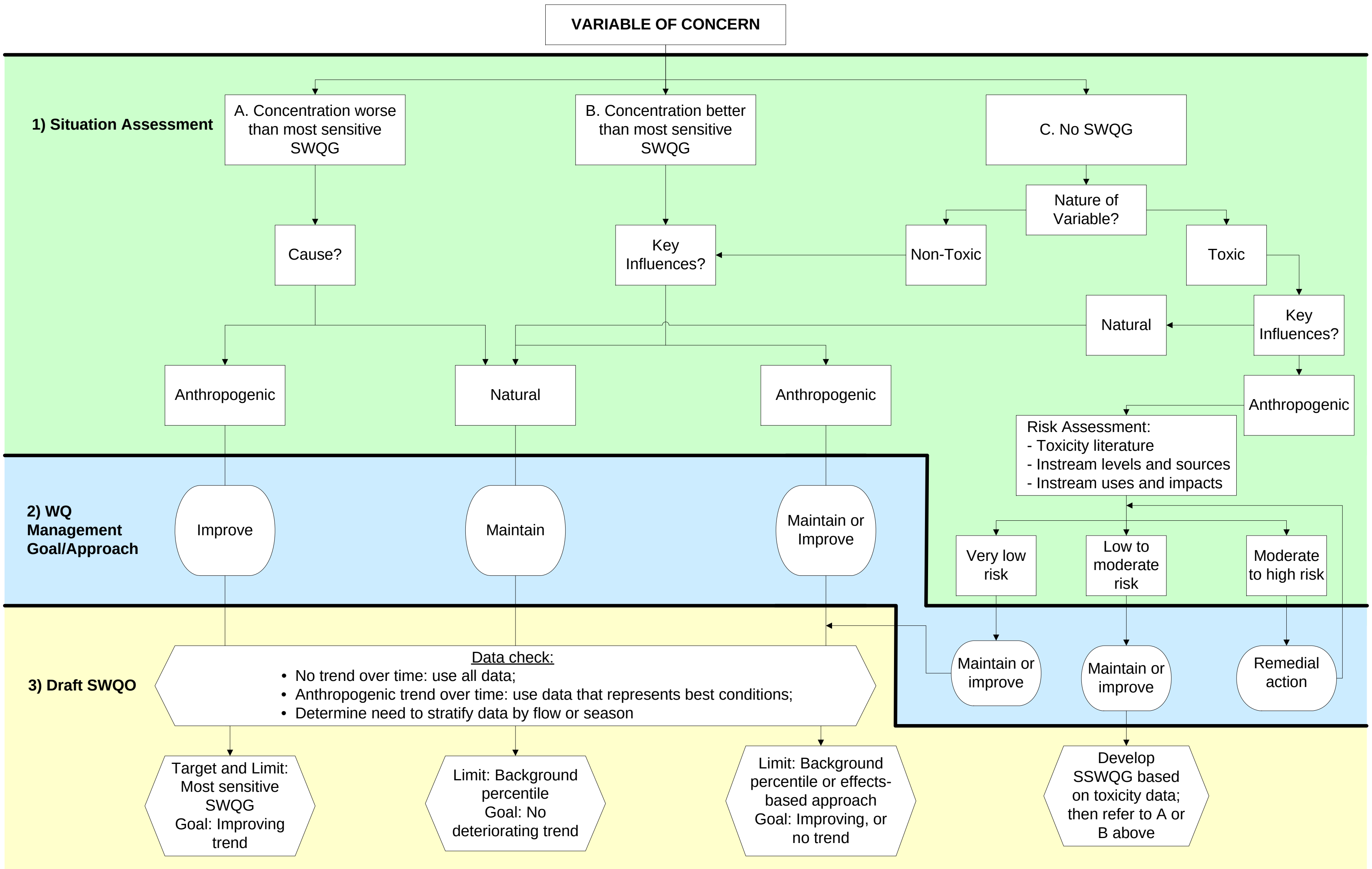

Figure 3 Steps and decisions in drafting water quality objectives to maintain or improve water quality

Assemble Existing Information

- Define natural drainage basin characteristics including natural features such as watershed boundaries, climate, hydrology, geology, topography, soils and landscapes, and natural vegetation;
- Identify man-made features and activities, such as agriculture, forestry, urban and rural population distribution, infrastructure, resource extraction, and industry;
- Assemble aquatic ecosystem data, such as flow, water quality, sediment quality, habitat and biota; and
- Identify and describe major stressors, i.e. estimate point and non-point source loadings, flow withdrawals and returns.

Define Reaches and Water Quality Concerns

- It is usually necessary to partition major rivers into reaches for water quality management. Define the reaches based on natural and man-made features, and the availability of water quality and other relevant data;
- Evaluate water uses (including human use and maintenance of aquatic ecosystem health) and water quality issues (both currently, and in the foreseeable future);
- Identify the water quality variables that are issues or are the best indicators of the issues (e.g., Stantec 2005). Ultimately, water quality variables for which SSWQO are needed (the variables of concern) should be related to anthropogenic stresses (i.e., be amenable to management), environmental risk, and/or be directly linked to the outcomes of management plans. The process of drafting and establishing SSWQO (Figure 1) is complex and time consuming – objectives are not needed everywhere nor for all variables, and it is important to prioritize the issues and work; and
- Identify data or information gaps for the development of SSWQO and initiate appropriate monitoring as resources allow.

4.3 Situation Assessment

After identifying the variables of concern for which water quality objectives are to be derived, the next steps depend on the state of the variable of concern compared to its guideline, and the importance of human influence on the variable. Existing conditions are usually first compared to the most sensitive guidelines (these are the long term values in the case of PAL guidelines). For many variables, three alternative situations are possible (Figure 3), and are outlined below. An important exception occurs with the nutrients nitrogen and phosphorus. Although these two variables have guidelines (AENV 1999b), they are general values carried forward from older documents, and are not necessarily relevant to specific sites. Nitrogen and phosphorus should be dealt with under Section 4.3.3 and Situation C below, 'no guideline available' (Figure 3).

4.3.1 A. Ambient Concentrations worse than the Most Sensitive Guidelines

When instream concentrations of a variable exceed (are worse than) the most stringent SWQG (Situation A in Figure 1), the cause of the exceedance needs to be determined.

1. If it can be ascertained that the cause is natural, then a percentile approach can be used to describe background conditions (Section 4.5).
2. If human activities are the cause of SWQG exceedances then the ambient limit has been exceeded and corrective measures are needed to achieve the principle of protecting all water uses. The management goal is to improve water quality, at least to the SWQG. Seeing no improving trend, or even a continued trend towards deterioration, should trigger further management. Although this should be the overall direction, it is also recognized that there will be situations where it is difficult to distinguish between natural and human influences on water quality, and also difficult to manage the human influence.

4.3.2 B. Ambient Concentrations better than the Most Sensitive Guideline

In a situation where the most sensitive SWQG is met it is still important to understand what is the key influence on instream concentrations (Situation B in Figure 3).

1. If natural causes are the main determinant of water quality, then this situation is essentially equivalent to that described for situation A above (i.e. natural – Figure 3).
2. If human influences are important, two possibilities exist:
   - To maintain water quality, existing conditions may become the draft objective (target). These may be described by percentiles or other statistics (Section 4.5).
   - Where contaminant management can be enhanced, the overall management goal may be to reduce anthropogenic loadings and "improve water quality". This would be desirable if there are indications that anthropogenic loadings are affecting aquatic biota or processes.

4.3.3 C. Water Quality Guideline Is Not Available or Not Appropriate

The most complicated situation occurs when guidelines for a variable of concern are not available or not appropriate (Situation C, Figure 3). As noted, the nutrients nitrogen and phosphorus fall into this situation. Persistent and bioaccumulative substances may also fall here and if they are of concern, may require procedures beyond the scope of this guidance.

First the nature of the variable needs to be reviewed. Is it toxic or non-toxic? What are the key influences on its occurrence? Is it natural, or is it introduced or augmented in the aquatic environment as a result of human activities? If the variable is non-toxic, the situation is equivalent to that described in the second case above (Situation B) and the variable can then be considered as per the steps in Figure 3.

If the substance is toxic in nature, but also occurs naturally in the environment (e.g., some metals or naturally occurring trace organic compounds, such as polycyclic aromatic hydrocarbons - PAHs) and the ambient concentrations are such that they do not appear to be anthropogenic, then the situation is again equivalent to B in Figure 3. However, if the contaminant of concern is man-made, a risk assessment may be required. This may include: a literature review to evaluate potential ambient toxicity; sampling programs to improve the understanding of sources and ambient concentrations; and effects monitoring to evaluate the impact on aquatic life and other water uses. The goal of the risk assessment would be to rank the risk presented to various uses by the variable of concern and to tailor management responses accordingly. For example, if the risk assessment indicates that the likelihood of impact on the aquatic ecosystem is very low for a given compound (based on toxicity data, measured ambient concentrations and biological responses), the risk rating would be qualified as low. Conversely, if the risk assessment indicates that a toxic compound occurs at concentrations that could result, or actually have resulted in alterations of the aquatic ecosystem, then the risk would be qualified as low to moderate, or moderate to high, respectively. Ranking risk can be complicated and in some cases a more formalized procedure may be necessary.

1. If the risk is very low in Situation C (Figure 3), this is equivalent to that described in Situation B for man-made contaminants (Figure 3), with the overall management goal to improve, or at least maintain water quality.
2. If the risk is low to moderate in Situation C (Figure 3), it may occasionally be advisable to develop a site-specific water quality guideline, or objective, based on toxicity data and/or modification of an existing guideline (e.g., AEP 1996; CCME 2003a; 2007). If a site-specific water quality guideline (SSWQG) or a SSWQO is developed, then the situation assessment can be done, and would end up as situation A or B (Figure 3). Again the overall management goal would be to maintain or improve water quality.
3. If there is moderate to high risk in Situation C (Figure 3) for one or more uses of the water, then this is an important management situation that requires corrective action.

4.4 Management Direction or Approach

As noted, the process outlined in this guidance applies to a "*maintain or improve*" approach for water quality. If the management approach is to *"protect uses"* while potentially allowing increased contaminant load, then the use-protection guidelines or a more stringent value, may become the SSWQO (target) that dictate allowable loads (AEP 1995). Nonetheless, in such a management approach the procedures herein could also apply in developing triggers to be used in a monitoring mode. A 'use protection' approach does not necessarily mean 'polluting up to' the guideline: a target may be established that is more stringent than the guideline or ambient limit (Figure 2C).

How the management direction influences the process of deriving SSWQO has been noted in previous sections and steps, and is also depicted in the management block (#2) in Figure 3. Note that, for a given site or location, different approaches could be applied to different variables of concern, depending on the situation of each variable, overall goals, priorities, and the realities of load management. Further, socio-economic-environmental balancing and iterative steps in the planning process may influence the management approach that is finally chosen before SSWQO can be established (Figure 1).

4.5 Methods to Draft Site-Specific Water Quality Objectives

Following from the situation assessment and management approaches of the preceding sections, four procedures to derive SSWQO (targets) are outlined further below.

4.5.1 SSWQO Derived From Generic or Site-Specific Water Quality Guidelines (SSWQG)

Surface water quality guidelines for the protection of specific uses have been developed by various agencies (AENV 1999b, CCME 1999, CCME 2003a, USEPA 2009). Guidelines are based on scientific knowledge of use-specific requirements. For example, PAL guidelines are for the most part based on toxicity testing and are derived so that they protect all (CCME 1991), or 95% of species tested (CCME 2007). Guidelines are generic in the sense that they are the first yardstick to be considered for any surface water body, but do not take into account variability due to differences in water body types, local species composition and sensitivities, nor synergistic, antagonistic, or cumulative action of contaminant mixtures. As a result, guidelines may be over-, or under- protective. Despite these limitations the use of existing guidelines is generally more feasible than the derivation of site-specific guidelines (SSWQG), which requires substantial resources. Furthermore, SSWQG may have the same limitations as generic guidelines. Nonetheless, the derivation of SSWQG may be justified for situations where environmental impacts are associated with contaminants that lack generic guidelines (see Situation C in Figure 3). AEP (1996), BC Environment (1997) and CCME (2003a; 2007) provide protocols relevant to the derivation of site-specific water quality guidelines and objectives.

Treatment costs for some water uses (e.g. drinking water) increase considerably when some aspects of raw water quality deteriorate. For example, if total organic carbon (TOC) exceeds 3 mg/L, more expensive treatment technology may be required than if TOC < 3mg/L. Such technology-based treatment needs can be utilized to derive SSWQO. When using SWQG to derive SSWQO, and in order to protect all water uses, guidelines associated with the most sensitive use (i.e., most protective) should be adopted. When the most sensitive guideline is adopted as a SSWQO (the water quality target), it would also be an ambient limit (Section 3 and Figure 2).

4.5.2 SSWQO Derived From Background or Existing Conditions

Background conditions generally mean natural conditions. Depending on the river, conditions at the upstream end of a river reach are sometimes considered to be mostly natural, or at least little influenced by human activity. Existing conditions are whatever exists. These may already include human effects, which may (or may not) reflect conscious socio-economic-environmental trade-offs and decisions. It is important to understand what controls water quality in the reach of interest (Section 4.2) and be clear about what is meant when using these terms.

Statistical measures can be applied to derive SSWQO from existing or background conditions (U.S.EPA 2001; PPWB in progress; CCME 2003a). The median (50th percentile), 90^{th} and 95^{th} percentiles have been proposed and used in Alberta in recent planning (e.g., AENV 2011; SSRBP 2009; NSWA 2010; Golder 2011). These are useful when the management direction is to maintain or improve water quality to a condition that can be described by statistics from available data. Block 3 of Figure 3 summarizes some of these steps. The median depicts the central tendency of the data, whereas the 90^{th} or 95^{th} percentiles provide a measure of peak events against which ongoing monitoring data can be compared. The choice of the 95^{th} rather than the 90^{th} percentile to define ‘extreme or peak‘ conditions may be perceived as offering a lesser level of protection. However, in practice it is the nature of the management response triggered by exceedances of the objective that defines the actual level of protection achieved. Another consideration when selecting percentiles is consistency within the larger basin. In updating water quality objectives at trans-boundary water quality monitoring sites, the PPWB has recently adopted the 90^{th} percentile in SSWQO development. Alignment with such interprovincial initiatives increases consistency in how water quality management is approached.

The calculation of percentiles implies the availability of long-term data sets that capture ambient variability over time. A contiguous ten-year data record is often considered the desired minimum for trend assessment and this is also desirable for drafting SSWQO from existing data. However, it is recognized there may be many situations where this length of data is not available. A network of long-term monitoring sites has been established on major provincial rivers, but these sites may not always be located in the most desirable location for effective water quality management. There may be a need to establish more strategically located monitoring locations (Section 5). Acquiring long-term data may require a minimum of about 5 yrs, depending on local variability in water quality. Interim objectives could be generated from water quality data from nearby sites (extrapolate/interpolate), or by utilizing water quality simulation models.

In many Alberta rivers, concerted efforts have already been made to reduce impacts on water quality from human activities, particularly from point sources. These management steps have resulted in measurable improvements in river water quality, as depicted by step trends in the long-term data. In such cases it is recommended that data reflecting these improvements be used to derive the SSWQO, for a 'maintain water quality' approach. It is also possible that water quality may deteriorate for natural reasons, or at least for reasons beyond immediate human influence (e.g. increasing dissolved salts due to declining flows as a result of climate change). Such cases will need careful evaluation of cause, consideration of probable trends (modeling could be useful), and judicious development of realistic objectives.

River water quality can vary considerably over time in response to temperature changes (ice cover – open water) and changes in flow due to snowmelt and runoff events. If concentrations of water quality variables exhibit substantial differences between open water and ice cover periods, seasonally, or are flow dependent, it may be advisable to stratify the data accordingly and define percentiles and SSWQO for each relevant period or condition. For example, the PPWB are generally developing distinct SSWQO for the ice cover (Nov – Mar) and open water (Apr – Oct) periods. For flow dependent variables the NSWA (2010) derived open water objectives for different flow conditions. Such stratification would require there be sufficient data for each condition to provide adequate confidence in the statistics.

Only valid data should be used in the derivation of objectives from background or existing conditions. The deletion of outliers (e.g., all values greater than 3 times the standard deviation), is not recommended, particularly for flow dependent variables in relatively unimpacted areas. High values for flow dependent variables tend to be associated with non-point source loadings and their deletion could set unrealistic expectations on non-point source control. Further, the numbers derived from existing data and proposed as SSWQO need to be clearly explained as to whether they are triggers, targets, or limits and what action, or management is associated with them (Sections 3 and 5; Figure 2).

4.5.3 SSWQO Derived From Local Effects and Outcomes

In cases pertaining to nutrients, there may be a desired outcome identified for aquatic plants (for example) that require nutrient concentrations be below certain values. Usually this occurs where the management direction is to improve water quality. However, it could also occur where the direction is to maintain water quality, or even to protect uses while allowing some additional nutrient loading. In any case, the nutrient – plant relationships are often determined through detailed surveys and/or experimentation, and simulated with water quality models. Objectives derived in this way have been referred to as 'effects-based', even though all use-protection guidelines or objectives are based on effects in some way. The USEPA (2010) uses the term 'stressor-response relationship', with respect to this method. Such SSWQO may be important at specific times of the year (e.g., the growing season for aquatic plants) and may only apply then. The implication of the objective (or lack of) for other times, uses and obligations (e.g., downstream transboundary commitments) must also be considered of course.

A prime example in Alberta is the phosphorus objective adopted in the BBWMP (2008) which was set to maintain DO levels in the Bow River at, or above, the 5.0 mg/L provincial acute guideline (AENV 1999b). Phosphorus was determined to have a significant effect on plant biomass in the river (Sosiak 2002), which in turn strongly influenced DO fluctuations, and the relationships between plant biomass and nutrient levels were quantified with the assistance of water quality models. This relationship was used to draft the SSWQO and is discussed further in the examples in Section 8.

4.5.4 SSWQO Described By Narrative Statement Pertaining To WQ Trends

The management direction to maintain or improve water quality and the aquatic environment implies that:

- no deteriorating trends due to human activity should occur in future;
- the absence of trend indicates that desirable conditions are maintained; and
- trends indicating an improvement are expected when management actions have been taken for that purpose.

An appropriate narrative statement regarding trends can be part of a SSWQO. Trend assessment relies on statistical analysis, for example as described in Hebben (2009).

4.6 Selecting Triggers

The SSWQO dealt with in Section 4 are largely targets and ambient limits. Trigger values may also be set, to support the management direction for the variable of concern. If the intent is to improve water quality and management steps have been taken to this end, then regular evaluation of monitoring data (e.g. trend assessment) should be done to determine efficacy. If no improvement is seen, this should 'trigger' investigation. Similarly if the direction is to maintain water quality, regular evaluation of monitoring data to determine change should be done. If the intent is to protect use, then one or more trigger values can be set at increasing levels of risk (Figure 2C) to warn of environmental change, thus allowing early management to prevent conditions from exceeding targets or ambient limits.

5.0 APPLICATION

As discussed before, site-specific water quality objectives are the quantitative expressions of the desired 'outcomes' for water quality, towards which management can be directed. They can be used when monitoring identifies deteriorating conditions relative to predefined triggers and when planning contaminant load management so as to achieve the SSWQO.

This document provides technical guidance on how to draft SSWQO. Consideration of these draft objectives in a socio-economic context, and their final establishment in regional plans, management frameworks, or other processes (Figure 1), is not addressed here. Nonetheless, there are several implications of SSWQO that need to be considered in the planning process either before they are established, or before they are implemented, as outlined below.

1. Where do they apply?

If SSWQO are established for a reach of river, the preference would be to have them apply throughout, and river water quality would need to achieve the objectives everywhere in the reach. Exceptions may be within mixing zones for approved effluents, or within mixing zones of tributary inflows (where tributary water quality is not as good as the SSWQO). If these or other exceptions are intended, they should be made clear in any SSWQO that are drafted. Of course, there would likely be only one or a few regular monitoring locations to evaluate achievement of the SSWQO (see #4 below), although special surveys could also be conducted to evaluate achievement at other locations.

2. **When do they apply?**

As discussed in Sections 4.5.2 and 4.5.3, SSWQO may be specific to the seasons (e.g., open-water versus ice-cover) and/or the flow situation. These should be clearly set out in any set of draft SSWQO as they will have implications for contaminant load management.

3. How do they apply and what action or management commitment is involved?

This question has a number of implications, and several have been discussed in previous sections. In particular triggers, targets and ambient limits will have various commitments associated with them, and these need to be carefully designed and clearly set out. For example:

- In a monitoring mode what will occur if a trigger is exceeded? What will be done if a limit is exceeded? The response should initially include verification of the exceedance (data inspection and/or re-sampling) and potentially investigation of cause. Further response may depend on environmental risk and could include mitigation and management.

- In a planning mode, the SSWQO (target) will determine the maximum allowable load (MAL) for the variable of concern, and potentially for variables that influence it. Specific seasons or flow conditions may be important in determining the MAL. To maintain water quality, the SSWQO will approximate existing water quality, and therefore no increase in contaminant load could generally be allowed. To improve water quality, the SSWQO would be better than existing water quality, and therefore a reduction in contaminant load would be sought. Even in a 'use protection' mode where some additional loading is allowed, the ambient limits should not be assumed to be a 'pollute up to' ceiling. These intentions need to be incorporated in management plans, particularly load management plans for both PS and NPS as appropriate. Such plans will need to consider the entire watershed. Monitoring and inventories of contaminant loads will be required in such planning, as will water quality simulation models for at least some variables of concern. Models can be used to evaluate the likely effectiveness of various PS and NPS management scenarios in achieving SSWQO, but models also require substantial expertise and data on mainstem, tributary, PS and NPS conditions for their set-up and calibration.

4. What monitoring will be done and how will achievement of SSWQO be evaluated?

To implement SSWQO for a river reach, the locations, variables, and frequency of monitoring need to be planned. If the existing Long-Term River Network (LTRN) is not sufficient to evaluate newly established SSWQO, then resource availability for new monitoring needs consideration, so that monitoring expectations and proposals are realistic. In some cases, there may be insufficient water quality data to support the derivation of SSWQO, so that new monitoring must occur first.

In addition to the collection of monitoring data, evaluation and reporting also needs to be planned, and resources for it considered. This should include statistical methods for determining trends and achievement of objectives, especially any objectives utilizing percentiles derived from the data distribution (e.g. 90^{th} or 95^{th} percentiles). Guidance is being developed on this subject, in support of regional planning (HDR Corp. 2011) and in support of the CCME water quality guidelines (Intrinsik 2011). Monitoring plans should also outline methods for any proposed evaluation of the risks of non-achievement, and outline any investigative survey methods to assess the causes. In other words, a performance evaluation plan should be developed, so that the success of management action can be determined. This should specify how often the evaluation and reporting would be done, and also outline related reporting such as contaminant load inventories.

5. When will SSWQO be reviewed and new variables of concern considered?

Water quality objectives need periodic review. New information continually comes to light, water quality guidelines evolve, new stressors may emerge, and environmental goals may change. Water quality conditions may also change, for reasons not immediately under our control (e.g. climate change). Within practical bounds and consistent with the appropriate management framework or plan, a review schedule for SSWQO should be specified.

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7.0 GLOSSARY

7.1 Definitions

Effects-based guideline or objective: Guidelines or objectives derived from a relationship of concentration to effects.

Guideline: In surface water quality, a numerical concentration or narrative statement which is recommended to protect a specific use of water.

Limit, ambient: In surface water quality**,** a level or condition beyond which the most sensitive use may not be protected.

Maximum Allowable Load (MAL): The maximum amount of a contaminant that a water body can receive while still meeting water quality objectives. Expressed as mass/time, it includes any natural, point-source, and non-point sources of the contaminant.

Non-degradation: No increase in contaminant concentrations nor deterioration in other water quality conditions.

Objective: In surface water quality, a numerical concentration or narrative statement which is established for specified waters, and which has an action and/or management commitment.

Outcome: The result of an intervention, management, or other action; i.e., what is achieved or not.

Site-Specific (SS): In surface water quality, applying to specified waters, such as a river reach, river location, or lake.

Target: In surface water quality, a concentration or narrative statement that management aims to achieve or do better than.

Threshold: **"..**has the meaning given to it in a regional plan and may include a limit, target, trigger, range, measure, index or unit of measurement" (Section 2 (ff) Alberta Land Stewardship Act, October 2009).

Trigger: A condition which, if exceeded, results in some action being taken (e.g. intensified monitoring; risk assessment; point-source management).

Variable: In water quality, a substance in, or condition of, the water. Sometimes referred to as a parameter, it may be physical, chemical, biotic, or radiological.

7.2 Abbreviations and Acronyms

AEH: Aquatic Ecosystem Health
AEP: Alberta Environmental Protection
AENV: Alberta Environment
AEW: Alberta Environment and Water
ALSA: Alberta Land Stewardship Act
CCME: Canadian Council of Ministers of the Environment
DO: Dissolved oxygen

EPEA: Environmental Protection and Enhancement Act
LTRN: Long-Term River Network; a monitoring program of AEW
LUF: Land-use Framework
MAL: Maximum Allowable Load
NPS: Non-point source
PAL: Protection of Aquatic Life.
PPWB: Prairie Provinces Water Board
PS: Point source
SS: Site-Specific
SSWQO: Site-Specific Water Quality Objectives
SWQG: Surface Water Quality Guideline
TN: Total nitrogen
TOC: Total organic carbon
TP: Total phosphorus
USEPA: United States Environmental Protection Agency
VoC: Variable of Concern
WfL: *Water for Life Strategy*
WQG: Water Quality Guideline
WQO: Water Quality Objective

8.0 EXAMPLES

The following examples are based on Alberta situations. The steps for each example follow the steps in Section 4 of this document.

8.1 Metals

Cadmium Levels above the CCME guideline

8.1.1 Situation Assessment and Management Goal

Cadmium levels in the Wolf River have been monitored on a quarterly basis since 1995. Levels complied with CCME guidelines for the protection of aquatic life until 1998 when a pulp mill started discharging treated wastewater to the creek approximately 3 km upstream of the monitoring location. Cadmium levels in the creek increased somewhat and exceeded the guideline occasionally. In late 2003 the plant underwent an expansion and the effluent volume discharged to the creek doubled; dye studies indicate that the effluent is fully mixed at the monitoring location. Exceedances of the cadmium guideline now occur regularly (Figure E-1).

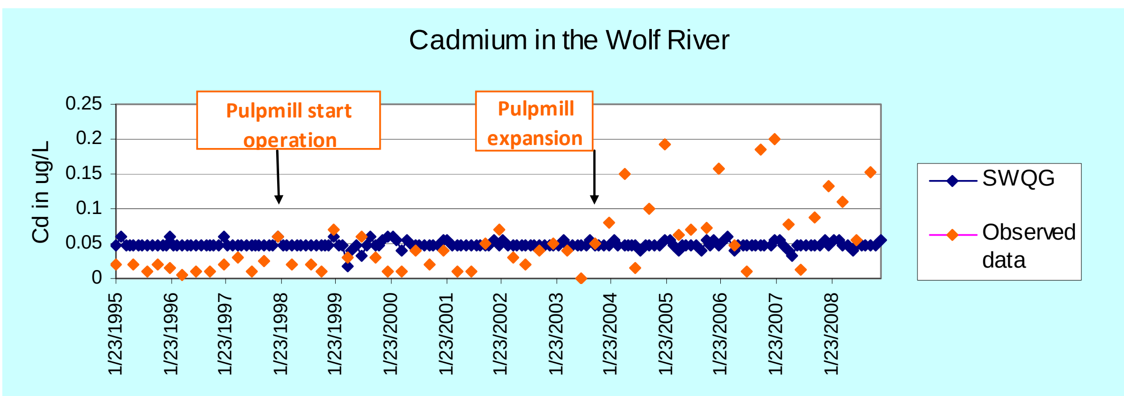

Figure E-1 Cadmium levels in Wolf River compared to Hardness-dependent CCME guidelines for the protection of aquatic life.

Seasonal trends are rather weak, but instream concentrations tend to be higher during periods of low river flow in fall and winter which result in lower in-stream effluent dilution capacity. This is clearly a situation where man-made effluent discharges result in the non-achievement of CCME guidelines for the protection of aquatic life. The management goal is to improve conditions in the river, and the principle of protecting all uses is relevant here. In this case the most sensitive use is aquatic life.

8.1.2 Derivation of SSWQO

The CCME PAL guideline is adopted as the SSWQO, because the objective should be no less stringent than the most sensitive use-protection guideline.

8.1.3 Application

In order to meet the SSWQO/CCME guideline consistently, the loading of cadmium from the pulp mill effluent would have to be reduced accordingly.

8.2 Nutrients

8.2.1 Total Phosphorus (TP) based on Background Levels

Two situations are considered, one upstream and one downstream of a major population centre.

a: TP at Site A (upstream) on River X

Situation Assessment and Management Goal

There are no surface water quality guidelines for TP. It is non-toxic and, upstream of the major population centre, is believed to be primarily of natural origin, based on the evaluation of existing information. The management goal at that site is to maintain current conditions.

Derivation of SSWQO

The following describes the water quality information available for the site:

- Monthly data were available from 1995 to 2009, inclusive;
- Trend analysis following procedures outlined in Hebben (2009) revealed a slight increasing trend in TP levels over time. However this trend was flow dependent and was not evident after flow adjustment of the data (Figure E-2);

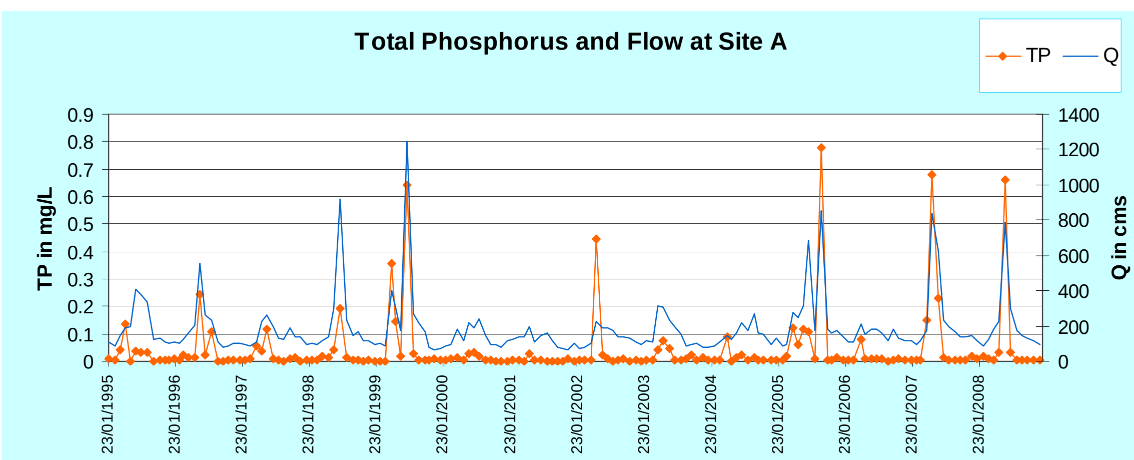

Figure E-2 Time series plot for TP and river discharge at Site A

- TP levels tend to be lower and more stable under ice (mid-November to mid-April) than during the open water season (mid-April to mid-November) (Figure E-3), and a statistical test indicated significant concentration differences between the two periods;

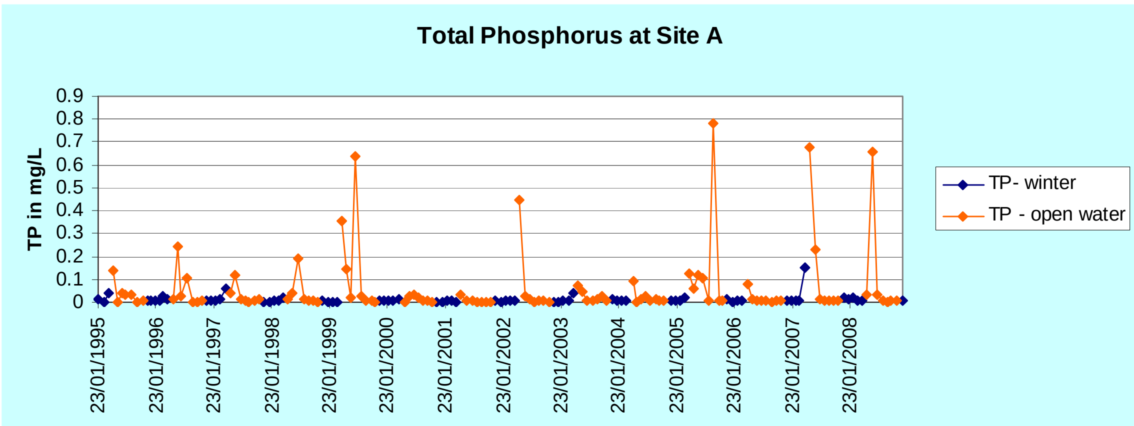

Figure E-3 Time series plot separating data collected under ice cover from open water data (Site A)

- Flow dependency is apparent during the open water season, but less so under ice cover (Figures E-4 and E-5). Most of the data available for the open water season are associated with flows < 350cms. For flows > 350cms, the variability in TP levels increases considerably and there are insufficient data to accurately describe the influence of flows on TP.

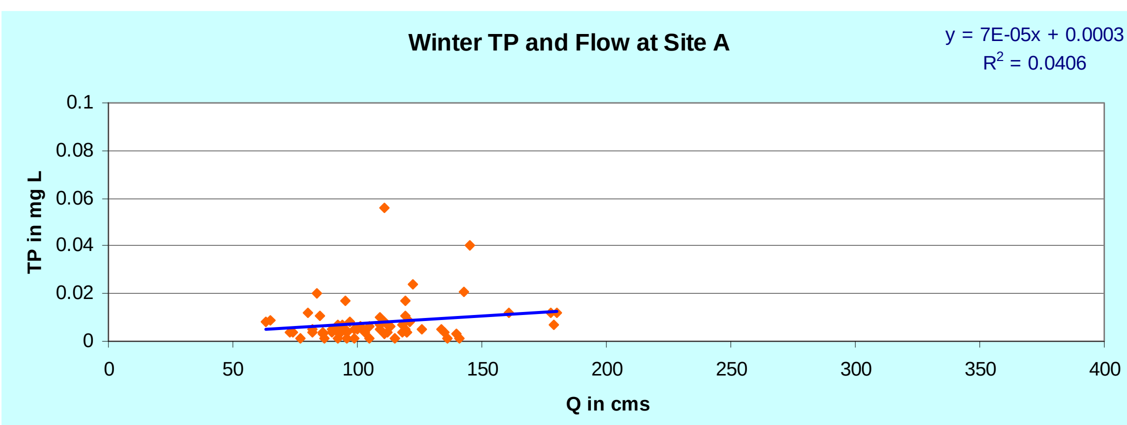

Figure E-4 Relationship between TP and Flow under ice at Site A

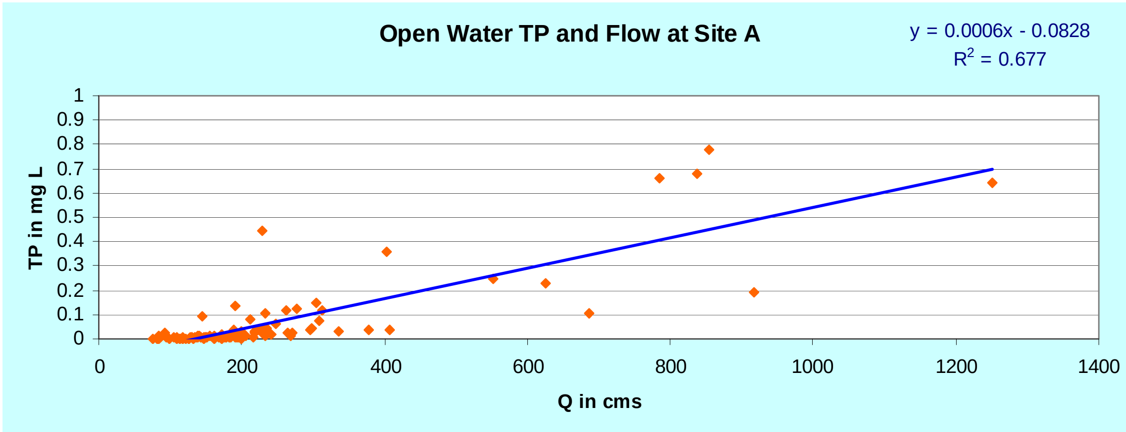

Figure E-5 Relationship TP and Flow during the open water season at Site A

Based on this information the decision was made to:

- utilize the entire data set in the derivation of the SSWQO (no trend after flow adjustment); and
- derive separate site-specific objectives for TP under ice-covered conditions, and for the open water season (Table E-1) For the open water season, objectives apply to flows < 350 cms. More data are needed to derive TP objectives for flows >350 cms. Establishing seperateTP objectives for separate flow regimes recognizes that high flows often naturally raise the concentration of TP. In such conditions TP loads don't then require extra management during high-flow, to meet a more stringent objective derived from low-flow conditions.

Table E-1 Site-Specific Objectives for TP at Site A on River X

	Ice-cover	Open Water (Q<350cms)
'average' conditions (median)	0.005 mg/L	0.007 mg/L
'peak' conditions (90^{th} percentile)	0.016 mg/L	0.074 mg/L

b: TP at Site B (downstream) on River X

Situation Assessment and Management Goal

There are no surface water quality guidelines for TP. TP is non-toxic and, at that location, TP levels are influenced by headwater inflows, sewage effluent, industrial discharges, and non-point sources from urban and rural land uses. The management goal is to maintain water quality conditions, which reflect recent wastewater treatment upgrades.

Derivation of SSWQO

The following describes available water quality information for the site:

- Monthly data were available from 1995 to 2009, inclusive; and
- Examination of a time series plot reveals step-wise declines of TP over time, corresponding to wastewater treatment upgrades. There are also notable differences in TP levels under ice compared to the open water season (Table E-2 and Figure E-6).

Table E-2 Median TP concentrations representing step-wise declines over three successive periods

	Median ice-cover	Median open water
1995 - 1999	0.113 mg/L	0.076 mg/L
1999 - 2006	0.052 mg/L	0.041 mg/L
2006 - 2009	0.019 mg/L	0.026 mg/L

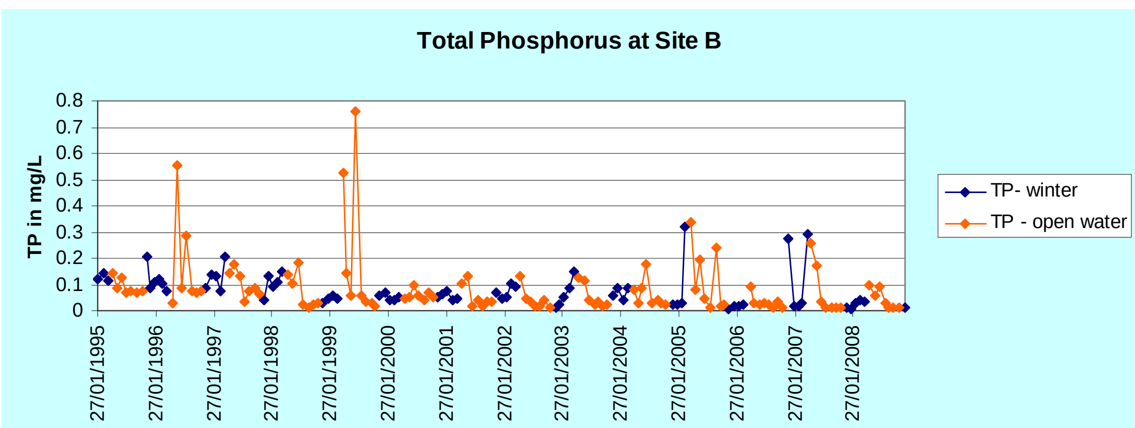

Figure E-6 Time-series plot for TP at Site B on River X

- Similar to Site A, flow dependency is apparent during the open water season, but not under ice cover. There are few TP data points for flows greater than 350cms.

Based on this data check, the decision was made to:

- Utilize the data that represent the best conditions in River X at Site B (i.e., 2006 to 2009: Table E-2); and

- Derive separate site-specific objectives for TP under ice-covered conditions and for the open water season (Table E-3). For the open water season, objectives apply to flows < 350 cms. More data are needed to derive TP objectives for flows >350 cms.

Table E-3 Site-Specific Objectives at Site B on River X

	Ice-cover	Open Water (Q<350cms)
'average' conditions (median)	0.019 mg/L	0.027 mg/L
'peak' conditions (90th percentile)	0.133 mg/L	0.103 mg/L

The data set used to derive these objectives is small and values derived for objectives for peak conditions are somewhat counter-intuitive, i.e., lower for open water than under ice. This may reflect low dilution capacity for TP from point sources in winter, and the fact that higher flow conditions (> 350 cms) were excluded from the data set for the open water. These objectives should be considered as interim until more data are available.

8.2.2 Effects-based SSWQO for nutrients Case Study: Bow River Phosphorus

8.2.2.1 *Situation Assessment and Management Goal*

In the Bow River, excessive growth of epilithic algae and macrophytes, are symptoms of eutrophication associated with the nutrient-rich discharges from Calgary's two wastewater treatment plants. Such dense biomass has an aesthetic impact, and contributed to diurnal and seasonal DO deficits. The low DO contributed to periodic fish kills. To reduce plant biomass and alleviate the problems, phosphorus and nitrogen removal technology were implemented from 1982 to 1983, and from 1987 to 1990, respectively. Total phosphorus loading was reduced by 80% and nitrogen loading (ammonia and nitrite + nitrate nitrogen) by at least 50%. Nonetheless, instream nutrient objectives were needed to more precisely manage nutrient loading and avoid the recurrence of critically low DO levels, thus improving water quality.

8.2.2.2 *Derivation of SSWQO*

An extensive annual monitoring program was initiated in 1979 to document epilithic algal and macrophyte biomass, nutrients and other relevant water quality variables. Sosiak (2002) used this comprehensive data set for the period 1979 - 1996 inclusive, to carry out a detailed analysis on the effects of nutrient reductions and other variables on primary producer biomass. He then developed predictive equations that define the lowest dissolved phosphorus (TDP) levels that would likely induce nuisance epilithic algal biomass.

Building on Sosiak (2002), and utilizing a data set that covers a longer period of record (1983 - 2005), Golder Associates (2007) set up a Total Loading Management Model for the City of Calgary. They estimated that a TDP of 0.015 mg/L would control plant growth sufficiently to maintain DO levels above 5.0 mg/L during the growing season (April to September) (BRBWMP-TC 2008). A TDP concentration of 0.015 mg/L has been adopted as the 'effects-based' SSWQO downstream of Calgary in the Bow River Basin Watershed Management Plan; the 90th percentile (0.054 mg/L TDP) has been adopted as a provisional objective for the winter season (BRBWMP-SC 2008).

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