Pilot Water Quality Objectives and Allowable Contaminant Loads for the North Saskatchewan River

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EXECUTIVE SUMMARY

To enable the goal of maintaining or improving water quality in the North Saskatchewan River (NSR), water quality objectives (WQOs) have been established for the Industrial Heartland reach, inclusive of the river mainstem from Devon downstream to Pakan. The WQOs apply specifically to the long-term river network (LTRN) monitoring sites at Devon and Pakan sites, and are based on ambient in-stream concentrations, except where ambient concentrations exceed the most stringent federal/provincial water quality guidelines. WQOs are the basis for calculating maximum allowable loads (MALs) and provide a measure against which long-term changes can be assessed. The median and 90th percentile values for ambient data were used in this study. These benchmarks are useful in supporting the water quality management direction of maintaining or improving the current water quality in the Devon to Pakan reach of the river.

As the emphasis is on downstream water quality, MALs have been developed for the Pakan location, based on the site-specific WQOs. The MAL is a measure for gauging whether in-stream pollutant loads are seasonally compatible with water quality objectives and consequently, water quality management goals. Once MALs are established, ongoing monitoring data can be used to calculate and evaluate changes in pollutant loads against benchmarks. Data presented in this report confirm that a wide range of instream load values make up the total NSR load; hence, to be protective of water quality objectives and informative for post-implementation monitoring, MALs encompass a broad range of in-stream conditions. Setting appropriate water quality benchmarks that integrate the influence of variable flows can minimize the effect of episodic exceedences on our ability to evaluate improvements in water quality. As the MALs represent long-term objectives, some exceedences are expected, while still maintaining longer-term goals. Accordingly, the MALs documented here identify an “extreme” load as a 90th percentile, and a long-term median (50th percentile) load established by the analysis of measured instream loads. The load duration methodology used in this study applies the cumulative frequency of historic flow data from a range of years combined with WQOs to establish MALs (loading targets for various flow conditions). In simple terms, historic flows provide the basis for identifying pollutant loading capacity, as this analysis accounts for variation of allowable loads over a range of known conditions.

The thresholds presented here represent 21 water quality variables that are likely to be altered, or are already elevated in the river; these are practical indicators based on available monitoring information. This exemplifies pilot development of objectives and their pragmatic application in MAL development. The pilot suite of objectives is by no means exhaustive. Recognizing that issues of local or regional concern may require the investigation of additional pollutants, a more extensive list of priority variables is presented, and should be assessed going forward.

Ongoing monitoring and evaluation will continue to guide an implementation strategy to effectively reach water quality and aquatic health goals for the NSR. The practical application of MALs will be a regulatory process that enables a tiered management system of investigation and potential mitigation management action when water quality issues escalate. Specifics of management and implementation processes are beyond the scope of this document, which describes methodologies for deriving water quality objectives and resultant allowable loads for the NSR.

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GLOSSARY OF TERMS AND ACRONYMS

AEH	Aquatic ecosystem health
Ambient	Existing *in-stream* conditions
AESRD	Alberta Environment and Sustainable Resource Development
AEW	Alberta Environment and Water
BNR	Biologic nutrient removal
ASWQG	Alberta Surface Water Quality Guideline
CCME	Canadian Council of Ministers of the Environment
CEQG	Canadian Environmental Quality Guideline
GoA	Government of Alberta
IH	Industrial Heartland
IH Reach	The instream section of the NSR extending from Devon to Pakan
Instream	In the North Saskatchewan River or its tributaries
Load	Mass flux; determined from the concentration of a water quality variable (e.g., mg/L) and flow (m^3/sec); typically expressed as kg/day.
LTRN	Long-Term River Network
MAL	Maximum allowable load: The maximum amount of a pollutant 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 pollutant.
NPS	Non-point source
NSR	North Saskatchewan River
NSRP	North Saskatchewan Regional Plan
NSWA	North Saskatchewan Watershed Alliance
PAL	Protection of aquatic life
PS	Point source
PPWB	Prairie Provinces Water Board
SSWQO	Site-specific water quality objective
SWQG	Surface Water Quality Guideline (federal/provincial)
TMDL	Total maximum daily load
USEPA	United States Environmental Protection Agency
VOC	Variable of concern
WMF	Water Management Framework
WQO	Water quality objective

1. INTRODUCTION

The *Water Management Framework for the Industrial Heartland and Capital Region* has strategic objectives that include “maintain or improve the current water quality in the Devon to Pakan reach of the river”; and “minimize the impact or footprint on the North Saskatchewan River...” (AENV, 2008; AESRD, 2012b). To meet these goals, water quality management will incorporate maximum allowable pollutant loads, based on site-specific water quality objectives (WQOs) developed for variables of concern in the North Saskatchewan River (NSR). In support of this, the Government of Alberta has moved forward with initiatives to:

- evaluate the present state of the aquatic environment in the NSR; and
- assess effects on instream water quality and ecosystem health resulting from potential industrial and municipal development.

Recent and ongoing instream studies have generated extensive information on pollutant loadings to the NSR and the status of water quality, sediment quality, and biologic communities (e.g., benthic invertebrates and periphyton) in the river (e.g., AENV, 2011). In tandem with these studies, engineering evaluations were undertaken to outline the feasibility of options for integrated regional water/wastewater treatment systems (e.g., AENV, 2010; 2011).

To enable the practical evaluation of contaminant load management options going forward, and to ensure that that Water Management Framework goals for water quality are met, site-specific water quality objectives (WQOs; concentration-based) and resultant maximum allowable loads (MALs; mass per time-based) have been developed, based on a pilot suite of pollutants. The MALs discussed herein represent a conservative, mass-balance approach. They provide a measure for gauging whether instream contaminant loads are seasonally compatible with water quality objectives and consequently, with water quality management goals.

The Industrial Heartland assessment reach for the WQOs and Maximum Allowable Loads (MALs) discussed in this document is the North Saskatchewan River mainstem from Devon to Pakan (Figure 1). However, as MALs reflect in-river conditions, they integrate loadings from all sources upstream of Pakan including the NSR mainstem, its tributaries, and point sources.

Why use the Maximum Allowable Load approach?

- It is consistent with the cumulative effects management approach for achieving instream water quality objectives;
- provides a quantitative analytical foundation for water quality management;
- enables integration of stakeholders and initiatives under a common goal to achieve regional contaminant load management;
- provides a crucial link between sources and water quality objectives; and
- it is a pragmatic approach – widely employed in other jurisdictions.

How is this approach applied? Steps:

- identify critical places and times (e.g., Pakan);
- identify water quality Variables of Concern (VoCs);
- determine water quality objectives by reach;
- calculate instream maximum allowable loads for individual variables;
- calculate overall loading reductions required to achieve instream MALs;

- identify relative partitioning of existing point- and non-point sources; and
- determine equitable load distribution among sources using regulatory approvals; e.g.,
  - major point sources during low flows; and
  - variable strategies for higher flows.

This report outlines technical work, focusing on the first five steps above. Step six (partitioning of sources) will be further addressed through ongoing supplementary studies, a number of which have been completed or are ongoing. Some, referenced in this report, include water quality and aquatic health studies (e.g., summarized in AENV, 2011; and similar work presently underway); trend assessments (Anderson, 2012), and contaminant loading evaluations (Kessler, 2013). Such studies directly support the development and implementation of water quality objectives and allowable loads.

Ongoing monitoring and evaluation will continue to guide an implementation strategy to effectively reach water quality and aquatic health goals for the NSR. The practical application of MALs will be a regulatory process that enables a tiered management system of investigation and potential mitigation management action when water quality issues escalate (e.g., Figure 2). Specifics of management and implementation processes are beyond the scope of this document, which describes methodologies for deriving water quality objectives and resultant allowable loads for the NSR.

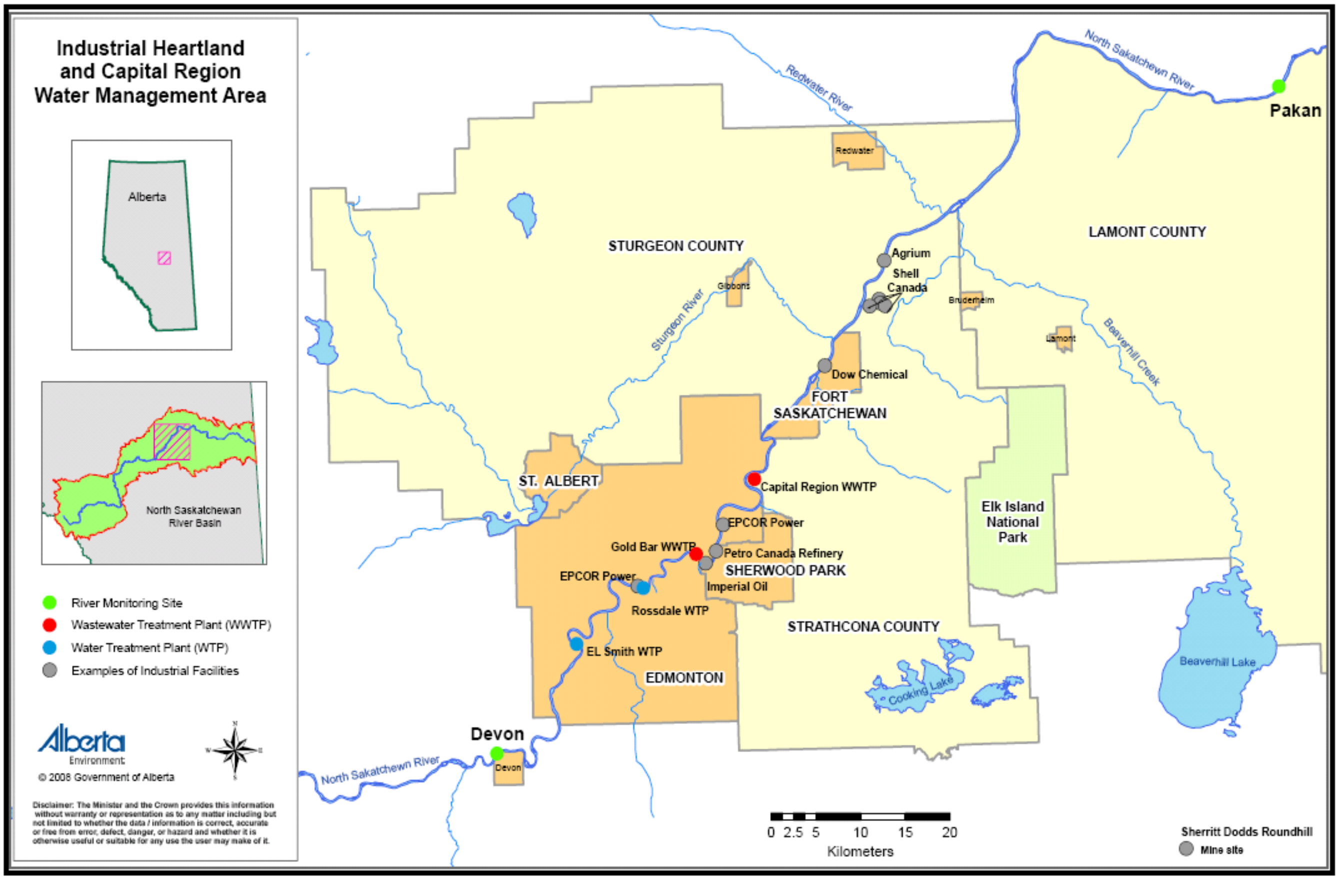


Figure 1. General map of the North Saskatchewan River - Industrial Heartland Reach.

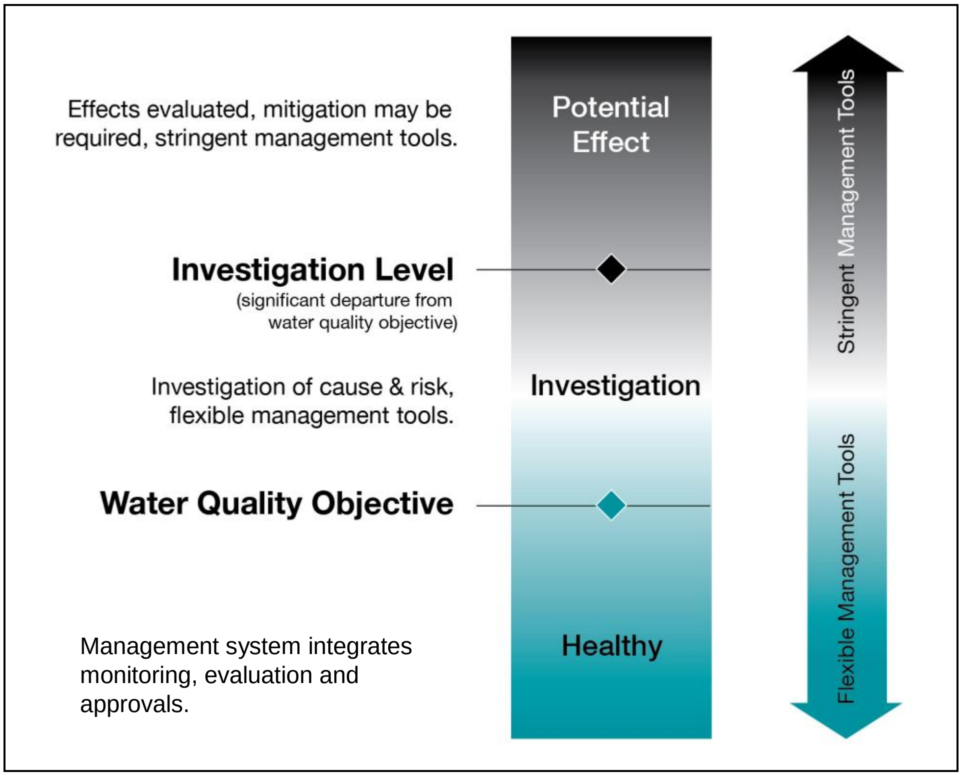


Figure 2. Threshold-based management model.

2. SITE AND PILOT VARIABLE SELECTION

The objective of water quality management for the NSR in the IH region is to maintain or improve the current water quality in the Devon to Pakan reach of the river, with the emphasis being on the downstream water quality at Pakan (AESRD, 2012b). Accordingly, the Long-Term River Network (LTRN) sites at Devon and Pakan were selected as upstream and downstream points of reference (respectively) for development of pilot WQOs. MALs were developed for the reach, specific to the Pakan site. LTRN sites were selected because consistent long-term data exist for these locations and in the case of Pakan, the river has been shown to be generally (or near to) well-mixed, relative to major point source discharges in the Capital Region (e.g., Pelechi et al., 2012).

The nature of indicators (variables) used to support evaluations depends on a variety of factors, including: program objectives, resource constraints, current and proposed human activities, and basin characteristics. In identifying variables of concern for the NSR/IH reach, a key goal was to establish which variables are likely to be the most representative and practical indicators of potential change or trends based on available monitoring information.

The following LTRN data were used in identifying variables of concern (VoCs):
- Devon (upstream of Capital Region):
    - 01/2000 – 12/2008
- Pakan (downstream of Capital Region):

  - 01/2006 – 12/2008 for nutrients and bacteria (this reflects the period following significant major wastewater treatment plant upgrades in the Capital Region, relevant to these variables); and
  - 01/2000 – 12/2008 for other variables, including metals and major ions.

Selection of VoCs was based on the following considerations:

- instream or effluent exceedence of Federal-Provincial Guidelines (AENV, 1999; CCME, 2012);
- instream exceedence of NSWA Draft Water Quality Objectives (NSWA, 2010);
- identification as VoC in previous scenario modelling, based on mixing zone analysis (AENV, 2010);
- substantial increase in water quality pollutant values at Pakan, relative to Devon (e.g., > 20% in median and/or 90th percentile);
- increased detection of trace contaminants downstream relative to upstream; and
- elevated overall point-source loads relative to overall tributary loads (ratio of effluent to tributary load increased substantially at low flows; e.g., > 1.5 times).

Selection, as per the individual criteria above, resulted in a large number of variables (> 100) identified as VoCs. This included nutrients, physical parameters, metals, organic compounds, and "emerging" contaminants such as pharmaceuticals, perfluorinated compounds, etc. These priority variables were investigated in engineering and feasibility studies to assess removal efficiencies derived from potential wastewater management options (AENV, 2010; 2011). To enable the practical development objectives for a pilot suite of variables, the VoC list was refined based on combining criteria above, and on professional judgement.

The most important site-specific variables to consider are those that are predicted to be altered, or are already elevated in the environment. With this in mind, it is emphasized that the VoCs list identified here is not exhaustive and that there may be issues of local or regional concern that require the investigation of other variables and consequent development of WQOs. Accordingly, the broader suite of priority VoCs previously identified (AENV, 2008; 2011) will be assessed in future work, as will newly-identified substances (e.g., based on new approval applications or ongoing monitoring and evaluation efforts). Appendix A lists pilot VoCs for development of WQOs and MALs discussed in this report. A broader list of VoCs is given in Appendix B.

3. WATER QUALITY OBJECTIVES

Water quality objectives (WQOs) are a yardstick for identifying where water quality issues exist and for determining the effectiveness of pollution control and prevention programs. WQOs form the basis for calculating maximum allowable loads (MALs), and provide a measure against which long-term changes can be assessed.

The *Water Management Framework for the Industrial Heartland and Capital Region* has strategic objectives that include “maintain or improve the current water quality in the Devon to Pakan reach of the river”; and “minimize the impact or footprint on the North Saskatchewan River...” (AENV, 2008; AESRD, 2012b). This conservative approach forms the foundation for development of the water quality objectives (WQOs) outlined in this document. The WQOs presented here are based on empirical analysis of existing conditions in the NSR mainstem. Their derivation is generally consistent with the approach used by the North Saskatchewan Watershed Alliance (NSWA) in developing proposed water quality objectives to ensure non-degradation from current conditions (NSWA, 2010).

Applying conservative principles, water quality objectives for the NSR at Pakan and Devon were derived by selecting the most stringent of:

- use-specific guidelines; and
- percentile values derived from river water quality data collected at Devon and Pakan LTRN sites (see also Section 3.1).

The WQOs described in this document are based on ambient instream concentrations, except where ambient concentrations exceed federal/provincial surface water quality guidelines (SWQG). In such cases the default WQO is the SWQG. This does not necessarily trigger an immediate need for management action; e.g., where exceedences are often related to episodic or run-off events. Such cases require further evaluation of instream conditions, and the nature of influences on upstream water quality (e.g., refinement of knowledge for consideration in watershed management planning).

Water quality objectives and guidelines for pilot VoCs are provided in Appendix A for Pakan and Devon sites. WQOs for Devon are provided for reference; water quality data for the Devon site represent a relative measure of existing conditions upstream of the IH reach. They are provided as benchmarks for consideration of incremental improvements, e.g.: sensitivity analyses to test improvements greater than that achieved through Pakan-based WQOs; and, benchmarks for consideration in watershed management planning

WQOs have been developed so as to allow MAL calculations to proceed, supporting implementation of the IH Water Management Framework (AEW, 2008). These WQOs are not meant to pre-empt WQOs that may be developed under other water management initiatives, such as the North Saskatchewan Regional Plan.

Context on nutrient objectives

Elevated nutrients, while most likely not posing a toxicological threat, can significantly alter the ecology of aquatic systems. If nutrient concentrations (phosphorus and nitrogen species) have a low probability of influencing trophic state, then water quality objectives can be considered to be met. However, in some cases further nutrient reductions may be desirable in some reaches to meet management goals.

Recent studies indicate that epilithic algal and benthic invertebrate communities of the NSR are generally in better condition at sites upstream, relative to sites within and downstream of the Capital Region. This is supported by positive correlations between nutrients (phosphorus and nitrogen) and indicators such as benthic chlorophyll α (Clearwater, 2010). Based on measured epilithic algal chlorophyll α levels, literature-based criteria classify the trophic status of the NSR as generally eutrophic at sites downstream of 50th Street Bridge to the Saskatchewan border, and oligotrophic to mesotrophic at upstream sites (to headwaters). Using total phosphorus as an example, the open-water WQO derived for Pakan is 0.03 mg/L (Appendix A), which is representative of a mesotrophic range (Dodds et al., 1998).

The WQOs presented here represent existing river conditions, and so assume maintenance of present ecological condition based on consistency in water chemistry (river loads). Evidence of functional response to nutrients by biota (such as benthic algae) is needed to further evaluate whether chemically-based WQOs are consistent with improving or maintaining ecological conditions in the NSR. For example, what is the response of benthic algae to increasing or decreasing river phosphorus? Recent literature on biologically-derived thresholds indicates that a transition from mesotrophic to eutrophic conditions occurs at instream total phosphorus (TP) levels of about 0.02 to 0.06 mg/L (e.g., Chambers, 2012; Dodds, 2006; CCME 2004). Canadian studies at the regional scale suggest that the transition occurs at about 0.03 mg/L (TP) based on benthic algal growth, and may be somewhat lower for benthic invertebrates (Chambers et al., 2012). Additionally, there is a substantial increase in NSR epilithic Chl α at Pakan, relative to Devon, coincident with increased nutrient concentrations. To illustrate, in recent years, median epilithic Chl α values for the August to November period are approximately 150 mg/m^2 and 7 mg/m^2 at Pakan and Devon, respectively.

Work is in progress to further evaluate biotic response to nutrient enrichment in the NSR through the application of the NSR water quality model (AENV, 2010). This work estimates NSR epilithic Chl α in response to changes in river nutrient loads (Muricken, in prep).

3.1. Methodology

The WQOs described herein were developed in accordance with *Guidance for Deriving Site-Specific Water Quality Objectives for Alberta Rivers* (AEW, 2012). Simple statistical measures using ambient (existing) river data were applied to calculate WQO values. The use of existing data enables the development of site-specific objectives that are realistic and attainable, yet protective of the river's quality; e.g.:

- The data provide an understanding of how water quality varies from year-to-year, season-to season, and upstream and downstream of the Capital Region; and

- Instream water quality reflect the influence of major efforts that have taken place to reduce nutrients and bacteria in the river (e.g., implementation of biologic nutrient removal at wastewater treatment plants). This influence is evident in trend assessments and other evaluations of instream NSR water quality (e.g., Appendix C; Anderson, 2012).

As long-term data exist for NSR sites at Devon and Pakan, these were used to derive site-specific objectives. As many instream constituent concentrations are influenced by season, WQOs were developed for open water and ice-covered seasons (April to October and November to March, respectively). WQOs were derived based on the following data from LTRN sites:

- Devon (upstream of Capital Region):
  - 01/2000 – 12/2011
- Pakan (downstream of Capital Region):
  - 01/2006 – 12/2011 for nutrients and bacteria (this reflects the period following significant major wastewater treatment plant upgrades in the Capital Region, relevant to these variables); and
  - 01/2000 – 12/2011 for other variables, including metals and major ions.

The median (50th percentile) and 90th percentiles of ambient data have been proposed and used in Alberta (AEW 2012 and references therein), and in federal-provincial agreements in development of WQOs (e.g., Prairie Provinces Water Board WQOs for the NSR at the Alberta Saskatchewan Border). These are useful benchmarks where the management direction is to maintain or improve water quality to a condition that can be described by statistics from available data (as in this case). Accordingly, seasonal objectives were derived for the NSR using the 50th and 90th percentiles based on the datasets noted above.

50th percentile:
This value reflects typical conditions (median), and provides a measure against which long-term changes in water quality can be assessed. In principle, at least 50% of values should be below the 50th percentile, with no degrading trend in long-term data. For bacteria, geomean values were used instead of 50th percentiles.

90th percentile:
This represents more extreme conditions associated with peak flows or episodic events, and provides a measure against which long-term changes in water quality can be assessed. In principle, at least 90% of values should be below the 90th percentile, with no degrading trend in long-term data.

For future reference, note that comparison of ancillary river data (e.g., data collected by other agencies) to the WQOs in this document assumes that data collection and analytical methods are consistent with those employed by AESRD in collection and analysis of data used to derive WQOs.

The following principles are germane in consideration of the WQOs described here, which apply on a site-specific basis (i.e., at the Devon and Pakan LTRN sites):

Variables with non-toxic properties for aquatic life
Site-specific objectives (WQOs) for substances that do not have toxic properties at

probable concentrations in surface waters were derived based on evaluation of existing instream data (e.g., phosphorus).

Variables with potentially toxic properties for aquatic life
Procedures outlined in the *Water Quality-Based Effluent Procedures Manual* (AENV, 1995) apply in defining mixing zones for point source discharges to the NSR. Typically, existing surface water quality guidelines (AENV, 1999a) must be met at mixing zone boundaries. However, site-specific conditions may require mixing zone evaluations on a constituent- and season-specific basis. Such determinations are beyond the scope of this document.

Variables with implications for recreational safety
As above, federal/provincial guidelines should be adopted in consideration of mixing zones. WQOs were derived based on evaluation of existing instream data (e.g., bacteria).

Use-Specific Guidelines

The most sensitive use-specific guidelines are typically for protection of aquatic life (PAL), though in some cases guidelines for human health (e.g., for bacteria) or other uses were applied (Appendix A).

Adoption criteria for the designation of guidelines in this report are based on work in progress to prescribe updated protocols for water quality guideline development in Alberta (L. Noton (AESRD), pers. comm.). Variables were reviewed to identify guidelines that are available from CCME, USEPA, and other jurisdictions (e.g., provincial).

4. MAXIMUM ALLOWABLE LOADS

The Maximum Allowable Load (MAL) is a measure for gauging whether instream contaminant loads are seasonally compatible with water quality objectives and consequently, water quality management goals. Once MALs are established, ongoing monitoring data can be used to calculate contaminant loads. These can be evaluated relative to established load management plans to determine progress in maintaining or reducing watershed loads to levels required by the MAL for specific seasons or river flow regimes. Comparative evaluations of water quality data with established MALs should be done at an appropriate frequency to support both the regulatory/approvals process and timely evaluation of instream conditions (e.g., three to five years). The regularity of the evaluation process will depend, in part, on the nature and availability of monitoring data. Hence, monitoring design should account for evaluation requirements related to WQOs and MALs.

Data presented here confirm that a wide range of daily load values make up the total NSR load under a MAL scenario. Selecting, for example, a load based solely on annual percentiles of water quality as objectives does not address variability inherent to river systems and may disregard a significant portion of available loading capacity, or conversely, exceedence of loading capacity.
For example, despite the partitioning of WQOs to specific percentiles and seasons (e.g., open water and ice-covered), relatively short-term exceedences occur for many variables, driven by peak flows and/or run-off events (Section 5). In such cases, the focus must be on understanding

the nature of exceedences such that appropriate management action can occur, whether regulatory, cooperative measures (e.g., some non-point issues), or other mitigation strategies.

As the MAL represents long-term objectives, some exceedences are expected, while still maintaining the longer-term goals. Setting appropriate objectives that integrate the influence of variable flows can minimize the effect of episodic exceedences on our ability to evaluate improvements in water quality. To be protective of water quality and informative for post-implementation monitoring, MALs must encompass a broad range of instream conditions. Consequently, the MALs documented in this report identify an extreme or “instantaneous” load (90th percentile) and a long-term median load (50th percentile) established by the analysis of observed instream data. In simple terms, this analysis accounts for variation of allowable loads over a range of river conditions.

4.1. Methodology: Load Duration Analysis

Development of MALs is challenged by the technical estimation of both existing and allowable loads for the river. Various approaches could be applied to derive MALs, ranging from complex modelling to simple derivation of loads based on average annual conditions (USEPA 2007a, b). Fundamental approaches for MAL development include: applying models to simulate conditions within the river and watershed; and, using available empirical (measured) data in a statistical analysis of water quality and flow (e.g., load duration curves). Hydrodynamic and watershed models have been developed for the NSR (AENV 2009, 2010; Tetratech, 2012). However, given the wide range of pollutants under consideration, many of which are not yet reliably calibrated in models, and uncertainty in integrated modelling, a simple practical approach is desirable to enable timely development of thresholds and implementation of management goals. Model development at AESRD remains ongoing for the NSR, and a collaborative watershed modelling approach going forward, to include stakeholders in the basin, is desirable to assess the potential benefits of various restoration and best management scenarios.

The main advantage in using load duration curves (LDCs) is the ability to discriminate contaminant loading based on flow. The duration curve approach is particularly applicable to rivers such as the NSR, because river flow is an important factor in the determination of loading capacities. This method accounts for how temporal flow patterns affect changes in water quality over the course of a year; i.e., seasonal variation that must be considered in MAL development. Duration curves also provide a means to link water quality concerns with key watershed processes. Basic principles of hydrology can help identify the relative importance of factors such as storm events, which directly affect water quality.

An underlying premise of the LDC approach is correlation of water quality impairments to flow conditions. The LDC alone does not consider specific stressors, or fate and transport mechanisms, which may vary depending on watershed or contaminant processes and characteristics. Such factors may include sediment transport, biological cycling of nutrients, chemical transformations, etc. In addition, representation of cause and effect, beyond that constrained by analysis of instream loads and flow is not addressed, as instream MALs represent net (or cumulative) water quality for a specific river site. Various approaches can be applied to support MAL development and implementation where factors other than flow significantly affect the loading capacity of a water body, or where watershed processes must be better understood to enable implementation of contaminant load management (e.g., through load allocation, and/or the management of diffuse (NPS) loading). Exploration of such relationships drives the need to develop and apply more complex methods including process-based models. However, the application of models that can reliably and quantitatively represent all relevant instream and watershed processes is a significant challenge. Practical and technical constraints require that the representation of an aquatic system is consistent with available information, time, resources and scientific understanding. Hence, timely development of management tools must address the challenge of balancing the needs of a particular initiative at an appropriate level of accuracy and reliability.

The load duration methodology looks at the cumulative frequency of historic flow data over a range of years, and relies on using observed flows and water quality objectives to establish loading targets for various flow conditions. Load duration curves are widely used to develop allowable loads, such as Total Maximum Daily Loads, where numeric water quality criteria are applicable. This approach involves calculating allowable loads over the range of flow conditions expected to occur in the river reach of interest (e.g., USEPA, 2007a, 2011).

Hydrology provides the basis for identifying contaminant loading capacity. Water quality variables are, for many variables, related to river flow rates, and loads are proportional to flow (i.e., load equals flow multiplied by concentration). For example, suspended sediment concentrations typically increase with rising flows as a result of increasing erosion and scour at higher current velocities. Other variables, such as chloride, may be less affected by river flow or more concentrated at low flows (e.g., diluted by increased water volumes at higher flows).

A flow duration curve relates flow values to the frequency (like "% of time") that values have been met or exceeded (Figure 1). The use of "frequency" provides a uniform scale ranging between 0 and 100, thereby representing the full range of river flows through the designated period. Low flows are exceeded a majority of the time, while extreme high flows are exceeded infrequently.

To derive MALs, a numeric water quality objective (concentration) is converted into a distribution (curve) of allowable loads as a function of daily flow. On the load duration curve, intervals are identified that are used to indicate general hydrologic condition (e.g., wet versus dry).

The approach involves the following steps:

1. A flow duration curve for the water body is developed by generating a flow frequency table and plotting the data points. The data reflect a range of natural occurrences from extremely high flows to extremely low flows (Figure 3).
2. The flow duration curve is translated into a load duration (or MAL) curve by multiplying each flow value by the water quality objective for a particular contaminant, then multiplying by a conversion factor to derive kg/day. The resulting points are plotted to create a load duration curve (Figure 2).
3. Each ambient water quality (sample) value is converted to an instantaneous load by multiplying the sample concentration by the average daily flow on the day the sample was collected. Then, the individual loads are plotted as points on the MAL graph and can be compared to the objective, or load duration curve.

4. Points plotting above the curve represent deviations or exceedences from the objective and the allowable load. Those plotting below the curve represent compliance with the objective and the allowable load.
5. Flow intervals can be grouped into zones. Here, five zones are delineated representing high flows (0 to10%), wet weather (or moist) conditions (10 to 40%), mid-range flows (40 to 60%), dry conditions (60 to 90%), and low flows (90 to 100%). For each of these flow categories, a daily load can be identified as expression for the MAL (e.g., using the 50th or 90th percentile objective). This is the mid-point of the load duration curve for a particular flow zone.

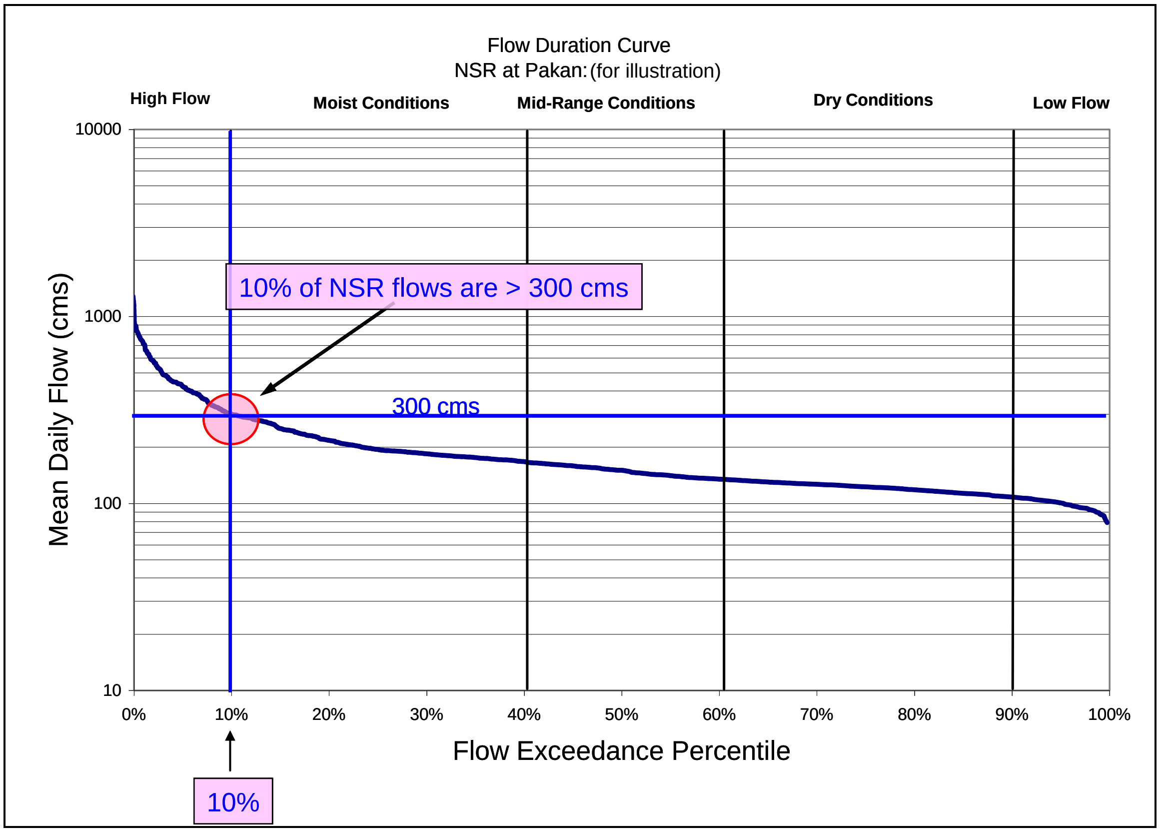


Figure 3. Example flow duration curve: NSR at Pakan.

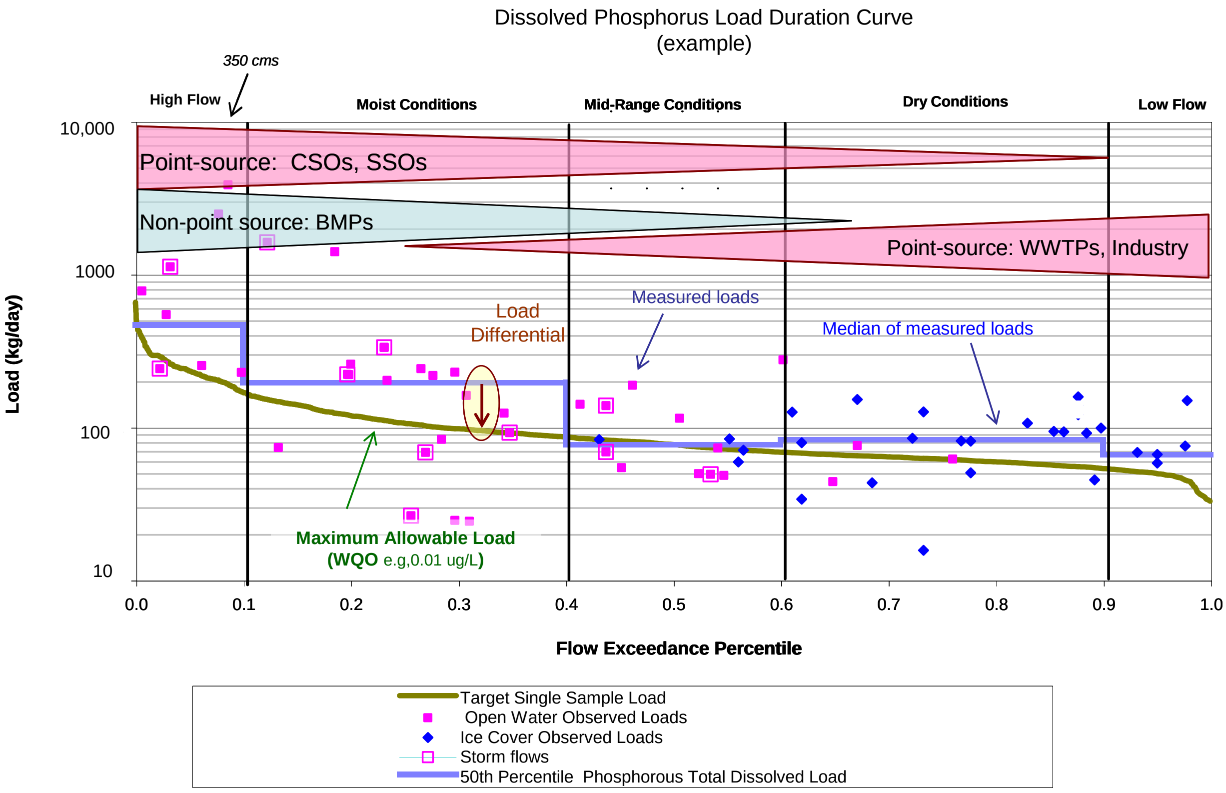
Plots of instantaneous loads, calculated from ambient (sampled) water quality data and daily flows (at the time of sampling), display patterns that describe the nature of contaminant loads over the range of flow conditions represented by the graph. The load duration approach can be used to calculate a series of allowable daily loads. Exceedence (or impairments) observed in the low flow zones typically indicate the influence of point sources, while those further left generally reflect diffuse (non-point) sources or stormwater contributions. Data may also be separated by season (e.g., spring runoff vs. summer base flow). In the case of the NSR, lowest flows are generally manifest in the ice-covered season.

Figure 4 is an example load duration curve to provide some context and explanation of the various symbols and lines used in the graph. The symbols are as follows:

- water quality samples on the LDC curve are noted as diamonds or squares.

  - samples taken during winter conditions (November through March) are noted with a diamond.
  - samples taken during the open water season are noted with a square symbol.
  - samples collected during local storm events are noted with a double square symbol. Storm events were delineated as a 50% increase in daily flow (relative to preceding days) from the major City of Edmonton storm water outfalls.
- The curved line represents the MAL, based on the WQO.
- The horizontal blue lines represent the median or 90th percentile load for measured values within each flow category.

The area beneath the MAL curve can be considered as the instream loading capacity for a given water quality constituent. The difference between this area and the area representing current loading conditions is the is the discrepancy between existing conditions and water quality targets. Conversely, this may also delineate available loading capacity where current loading conditions are lower than the MAL. Samples in exceedence at the right side of the graph occur during low flow conditions, and significant sources might include local point sources such as WWTPs, industrial discharge, and in some cases stormwater discharge (e.g., during episodic early melt events). Exceedence on the left side of the graph occurs during higher flow events, and potential sources are related to land use. For example, phosphorus and bacteria during these events may be washed off upland areas with runoff.



Developed using long-term fixed station ambient water quality monitoring data

Figure 4. Load duration curve (LDC) example.

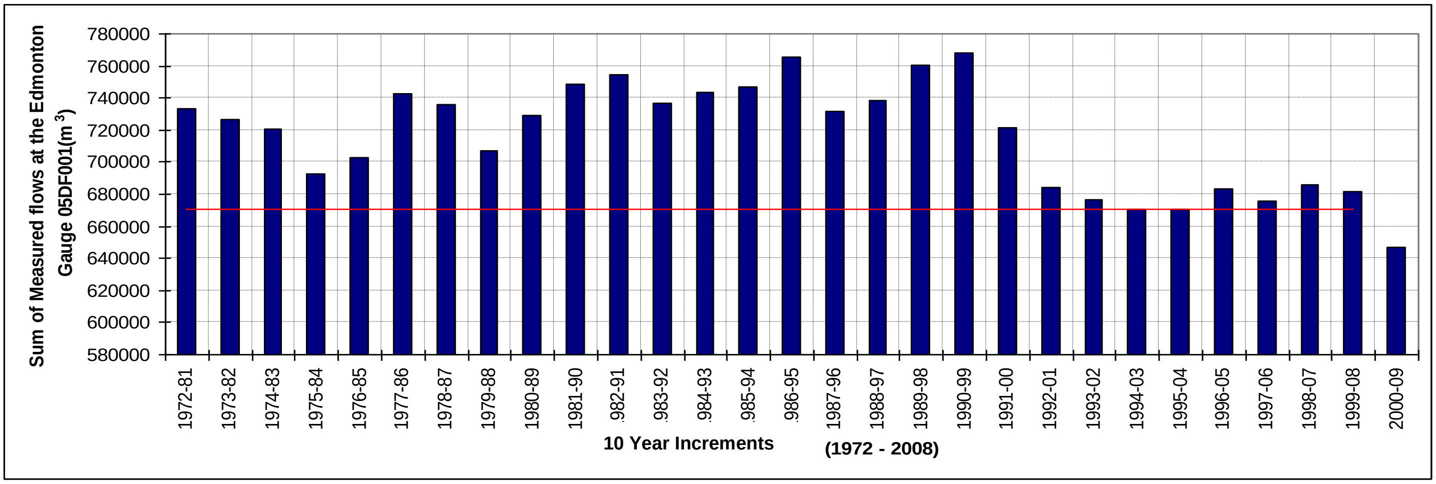
LDC Tool and Error Measures:

The LDCs presented in this report were calculated using computer code originally developed at the University of Texas (Johnson and Whiteaker, 2009). The code was subsequently modified by ESRD staff to support NSR evaluations. The tool provides a reproducible method to estimate instream loads and relative reductions required to meet instream objectives. A technical report on the LDC calculation program is in preparation (AESRD, 2012).

Error was calculated for observed loads (as in the LDC graphs given in Appendix E) based on the estimated 90% confidence interval for the 50th or 90th percentiles using the central limit theorem (binomial distribution; Conover 1980). MAL values shown in various tables through this report are marked as to whether they fall within the 90% confidence interval of the sample data set. As reductions are calculated by equating percentiles of existing loads and the MALs, the confidence interval provides a measure of whether MAL and sample datasets are statistically similar. Where this (hypothesis testing) suggests that the datasets are statistically similar, there is less confidence in proposing a load reduction.

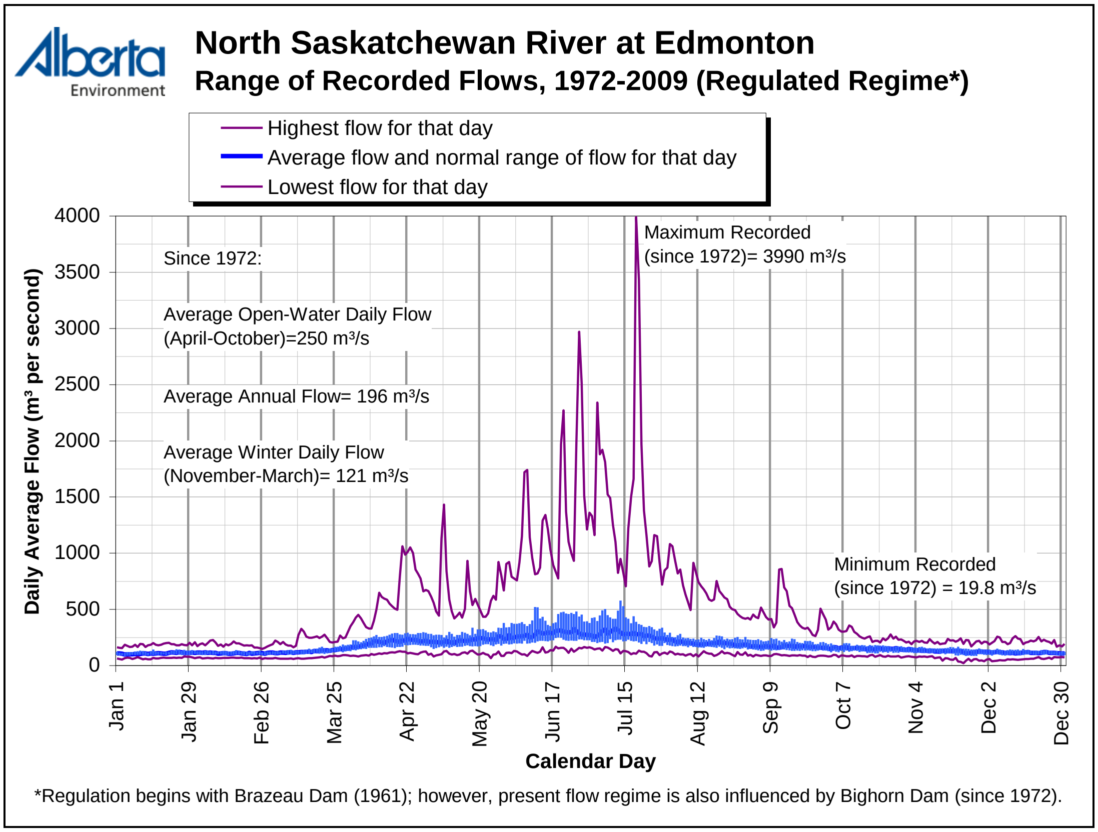
4.2. Flows

Flow conditions for deriving NSR MALs are based on mean daily flows measured at the Edmonton gauge (05DF001; EC, 2011) for the period from 2000 through 2011. These are adjusted to locations upstream (Devon) and downstream (Pakan), taking into account inputs (e.g., tributaries) and withdrawals. To illustrate, measured flows are plotted in Figures 5 and 6.



Red line indicates the minimum sum of ten-year flows, post-Bighorn Dam, measured at the Edmonton Gauge (1995-2004).

Figure 5. NSR flows measured at Edmonton (10-year rolling sum).



*Regulation begins with Brazeau Dam (1961); however, present flow regime is also influenced by Bighorn Dam (since 1972).

Figure 6. Range of recorded flows measured at Edmonton: 1972 – 2009.

4.3. Maximum Allowable Load Values for the NSR

Table C-1 (Appendix C) summarizes calculated NSR MALs (based on the foregoing methodology), and relative reductions indicated from existing conditions. Appendix C also presents WQOs and corresponding MALs (for Pakan) by flow range for individual VoCs (Tables C-2 and C-3). Appendix D presents descriptive information for individual variables, including: summary statistics; graphical illustrations of seasonal concentrations and loads; and load duration curves.

5. CONSIDERATIONS FOR IMPLEMENTATION OF MALS

The maximum allowable loads and associated contaminant load reductions described in this report are regional, and relate to cumulative in-river conditions at Pakan. Their application is intended to support contaminant load management consistent the Industrial Heartland Water Management Framework (AENV, 2008, 2012b). Compliance with water quality guidelines and objectives in the North Saskatchewan River is presently dependent on approval conditions specific to individual dischargers. The MALs presented here do not supersede such conditions, or necessarily prescribe regulatory intent.

Source Characterization

Combined with contaminant loading calculations by discharger and sector in the Industrial Heartland (e.g., Kessler, 2013; example shown in Figure 7), optimized wastewater management solutions have been identified in engineering studies to support ongoing improvements to NSR water quality (AE, 2012). Collaborative opportunities exist to further identify cost-minimizing allocations and to compare cost distributions under different allocation scenarios, going forward.

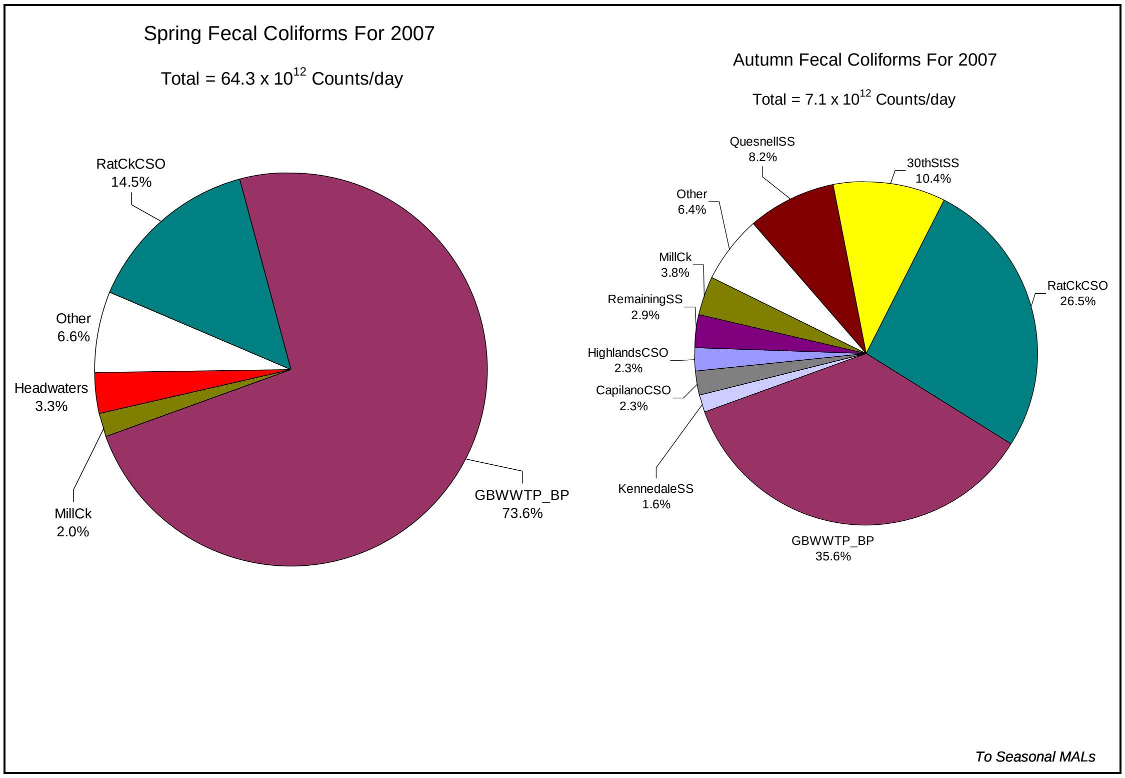


Figure 7. Fecal Coliform loading in the NSR by source, for two time periods in 2007, as a fraction of total loading (after Kessler, 2010).

Incremental Improvements and Benchmarks

It is important to understand incremental waste load reductions that could be achieved. Devon-based WQOs, presented in the appendices, provide foundational benchmarks to support testing of improvements greater than that achieved through Pakan-based WQOs. Conversely, federal and provincial guidelines (CEQG, ASWQG) and associated MALs are also presented. These values can be used for some variables to determine which are at risk of exceedence and therefore of greatest priority. However, this does not apply for all VoCs, as CEQG and provincial guidelines are not available or appropriate for all constituents.

High Flows

High (peak) flows must be considered in context in the application of MALs to point-source management, partly due to their high variability. Given the significant influence from upstream (non-point) sources at high flows (> 90th percentile), load management for many contaminants under such conditions must be considered in regional planning initiatives with regard to land use management and related practices to control non-point source pollution.

It is evident from measured data that suspended solids loads in the river, driven by variable flows, have a substantial influence on concentrations of metals, nutrients, and other water quality constituents, as a large proportion of many constituents are exist in or are adsorbed to particulates. This results in frequent exceedences of water quality guidelines and objectives, exemplified in Appendix C, as high calculated load reductions to meet objectives at high flow regimes. Given the episodic and variable nature of high flow loads, these “reductions” must be considered in context, and as tentative, especially where identified at less than the 0.1

exceedence percentile. This is especially problematic for metals, for example, as present guidelines and objectives depend on the total measured fraction, rather than dissolved. In future, the use of total fractions (e.g., for metals) may be de-emphasized such that objectives are based on fractions that are more biologically relevant. However, few Canadian guidelines presently exist for dissolved or other more “bioavailable” fractions, and for the present, pilot objectives have remained consistent with the fractions (e.g., total) as prescribed by federal/provincial guidelines.

As monitoring and evaluation continues, water quality objectives for very high flows may be refined and/or targeted to specific variables and sources. A working example is TSS; in this case water quality objectives presented here only apply to flows of less than 350 cms (less than the ~ 0.1 exceedence percentile).

5.1 Implementation: the NSR Watershed, Uncertainty, and Adaptive Management

The effectiveness of actions that occur based on MAL recommendations will be validated through ongoing monitoring and evaluation. Information derived from such analyses can guide changes to management strategies to more effectively reach goals for water quality and aquatic ecosystem health. Application of evaluative tools, such as models, loading calculation tools, and statistical techniques is ongoing and should continue at both local and watershed scales (e.g., AENV, 2010; TetraTech, 2012; Kessler, 2013; Anderson, 2012). This supports an adaptive planning management approach, informed by comprehensive knowledge.

Uncertainty is a common concern in estimates of loading thresholds (MALs, TMDLs, etc.) and in predictions of the effectiveness of management actions. As evaluations of water quality are abstractions of reality, answers are always accompanied by uncertainty. With uncertainty comes the potential consequence that implementation actions for improving or maintaining water quality may prove ineffective and potentially wasteful of resources. This eventuality can be addressed by an adaptive approach going forward (“learning while doing”), which involves development of a water quality implementation plan, based on the outcomes identified by the WQOs/MALs presented here. This would drive ongoing assessment of efficiencies and costs of remedial actions (already addressed, in part in previous studies; e.g., AE, 2012), improvements in predictive power (as models are expanded and enhanced based on new information), and revisions to the implementation plan as information is available. Moreover, new information may necessitate changes in water quality objectives and consideration of additional pollutants.

The context for implementing an allowable load approach is more comprehensible for point sources than for unregulated non-point sources. Implementing maximum allowable loads will trigger a regulatory process with respect to point source discharges. However, watershed management is a key element for managing pollutant loads caused by factors other than regulated pollutants (NPS). The question, “if action X reduces pollutant loads by Y, will water quality objectives be met?” relies on predictive assessments that utilize models and related evaluations. Such studies at various scales (site-specific, reach-specific, or watershed) provide a way to organize knowledge and then use that knowledge to answer this central question.

In the absence of regulatory requirements, achievement of desired water quality goals for run-off and other non-point source pollution is challenging. However, uncertainty in evaluations that support management decisions can be reduced over time through ongoing and iterative evaluations (including modelling) of water quality response to load reduction (PS and NPS) and the implementation of remedial actions. A continued focus on reducing uncertainty should be inherent in an implementation plan, through targeted monitoring and evaluation. Learnings from ongoing science can then be incorporated into more informed decision making. This is a way to make progress in meeting water quality goals while also increasing our confidence in stressor-response relationships, and in the potential effectiveness of planned actions.

For the NSR, point- versus non-point source loading values are generally well-partitioned for some of the more “common” pollutants, such as nutrients. (e.g., Kessler 2010, 2013). However, relationships between NPS and receiving waters are complex and not well-defined, and the variable and transient nature of run-off that drives NPS pollution confounds present evaluations. This drives large uncertainty in predictions of cause and effect relationships in the NSR watershed. Though the general timing and nature of runoff over large areas of the NSR has been somewhat constrained (Tetratech, 2012), our knowledge of stressors and their specific influence on water quality (for example in sub-watersheds) is incomplete.

As the NSR basin is a large system with multiple stressors, site-specific and watershed-scale studies initiated by various groups must work in tandem to provide comprehensive information that supports fair and effective allocation of loads to achieve water quality goals. This requires a conscious, well-directed effort, with sufficient resources to learn and revisit water quality management decisions over time. As implementation proceeds, and new knowledge is incorporated, any element of water quality management might be revised, including management actions and regulatory requirements. With this in mind, available data, WQOs and resultant MALs should reviewed and updated on a regular cycle, for example, every three or five years.

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