Vermilion River and Stretton Creek Water Quality at Low Flow

December 2016

North Saskatchewan Watershed Alliance
202 –9440 49th Street NW
Edmonton, AB
T6B 2M9
(587) 525-6820
Email: water@nswa.ab.ca

http://www.nswa.ab.ca

The support of the Government of Alberta and many municipal partners for NSWA operations is gratefully acknowledged.

The North Saskatchewan Watershed Alliance (NSWA) is a non-profit society whose purpose is to protect and improve water quality and ecosystem functioning in the North Saskatchewan River watershed in Alberta. The organization is guided by a Board of Directors composed of member organizations from within the watershed. It is the designated Watershed Planning and Advisory Council (WPAC) for the North Saskatchewan River under the Government of Alberta's *Water for Life Strategy*.

This report was prepared by Anne Marie Anderson, Jennifer Regier, B.Sc. and Marilou Montemayor, M.E.S., P.Ag. of the North Saskatchewan Watershed Alliance. A final draft was produced by Dr. Anne-Marie Anderson, Ph.D. for the North Saskatchewan Watershed Alliance.

Cover photo credit: Bill Trout, Images Alberta Camera Club. (Near Holden, AB.)

Suggested Citation:

North Saskatchewan Watershed Alliance (NSWA), 2016. Vermilion River and Stretton Creek Water Quality at Low Flow. Prepared by the NSWA, Edmonton, AB. Available online at **http://www.nswa.ab.ca/resources/nswa_publications**

Executive Summary

The natural state of the Vermilion River basin has been altered considerably since settlement occurred in the early 1900s. Alterations include land use changes (agriculture, urban and infrastructure development) and significant changes to the basin's hydrology. Impacts on river water quality can result from increased contaminant loading from point source discharges (e.g., municipal wastewater and storm water runoff) and nonpoint source loading of contaminants associated with broad landscape changes (e.g., agricultural activities, deforestation, riparian habitat degradation).

This report summarizes and evaluates water quality data collected from surveys carried out at seven locations on the Vermilion River and two locations on Stretton Creek during July, August and October 2014. Historic and published water quality data for the Vermilion River basin are limited; the intent of this project was to start updating a 20-year-old water quality database. The selection of water quality variables was suitable to describe general instream water quality conditions and identify issues potentially related to human activities. Surveys were only carried out during very low flow conditions, and stagnant water was often encountered. It should be noted that sampling during periods of higher flow would likely yield different results.

Water in the Vermilion River and Stretton Creek can be typified as fresh-water that is well-buffered and very hard. Guidelines for the protection of aquatic life, irrigation and livestock watering for variables related to major ions were generally met although there may be restrictions for the irrigation of sensitive crops. Instream measurements of dissolved oxygen show that at several locations acute and chronic guidelines for the protection of aquatic life were not met some of the time.

Phosphorus and nitrogen are nutrients that can enhance the growth of aquatic vegetation to the point of causing damage to the aquatic ecosystem. Based on high nitrogen and phosphorus concentrations, most sites on the Vermilion River and Stretton Creek would be classified as eutrophic (i.e., nutrient-rich). However, based on planktonic algal pigment levels (i.e., Chlorophyll-*a*) the streams would be classified as meso- to oligotrophic (i.e., conditions which suggest lower levels of nutrient enrichment). This difference may be an indication that in addition to nutrients, other factors influence algal growth (e.g., lack of flow, light limitation, uptake by other aquatic plant communities).

Low levels of suspended solids were observed in these mostly stagnant waters, and most metals occurred at very low levels. Arsenic was the only metal which exceeded guidelines for the protection of aquatic life.

Several pesticide scans were conducted but only three herbicides were detected (2-4-D, bromoxynil and MCPA). The concentrations of these herbicides complied with guidelines for the protection of aquatic life, but MCPA concentrations exceeded irrigation guidelines at three locations. These pesticide results should be interpreted as preliminary information, and several factors need to be considered in any future sampling design: 1) the timing of sampling relative to that of pesticide applications; 2) ensuring that the list of pesticides analysed reflect actual pesticide use in the basin; and 3) ensuring detection limits are suitable for ambient levels anticipated.

E. coli counts are an indicator of fecal contamination by warm-blooded animals. Although only one sample did not meet recreation guidelines, several samples did not meet irrigation guidelines.

A simple scoring scheme was developed to allow comparisons of water quality among sites. It suggests that overall water quality of the Vermilion River and Stretton Creek improves in a downstream direction. The two headwater sites and the site downstream of the Town Vermilion have the poorest water quality and the site near the mouth of the Vermilion River has the best water quality.

High nutrient levels, coupled with dissolved oxygen levels which on occasion do not comply with guidelines for the protection of aquatic life, are indicative of long-term and short-term stresses on sensitive aquatic species. This, in conjunction with observations of degraded riparian habitat (CPP Environmental 2016), justifies advocating for nutrient management in the basin (GOA 2014). Further testing of pesticides and microbiology are also recommended.

Acknowledgements

The North Saskatchewan Watershed Alliance (NSWA) would like to thank members of the Vermilion River Watershed Alliance (formally the Technical Task Team of the Vermilion River Watershed Management Project) for their role as the Project Steering Committee along with the following funders: Lakeland College (cash and equipment); County of Vermilion River (CVR) (field work); and Agriculture & Agri-Food Canada (AAFC) (field training, equipment, field work and mapping).

We thank our project field team: Marilou Montemayor M.E.S., P.Ag (Team lead), Chris Elder (CVR), Sharon Reedyk, M.Sc., (AAFC), and Mary Ellen Shain, M.Sc. (NSWA).

Sincere thanks go to all those who participated in the preparation of this report by researching and assembling information on river flows and elevation, by updating GIS maps, or by providing valuable insights into the river's hydrology and municipal wastewater treatment plants in the basin. In this regard, the assistance of the following individuals is gratefully acknowledged: Cristina Buendia Ph.D. (NSWA), Mara Erickson, M.Sc. (NSWA), Sal Figliuzzi, P.Eng., Candace Vanin, P.Ag. (AAFC) and Gordon Thompson P.Eng. (NSWA).

David Trew (NSWA) provided guidance and leadership in the implementation of this study. His review comments and those of Mara Erickson, M.Sc. and Elisa Brose, B.Sc. (NSWA) helped improve the overall quality of this document.

Table of Contents

List of Tables

List of Figures

List of Appendices

1.0 Introduction

1.1 Background

The Vermilion River Watershed (VRW) is in the south-eastern portion of the North Saskatchewan River (NSR) Basin in Alberta. It was identified as one of the most impacted of the 12 sub-watersheds in NSWA's State of the Watershed Report (NSWA 2005). In response to this assessment, the NSWA initiated efforts to improve conditions in this sub-watershed and facilitated the creation of the Vermilion River Watershed Management Project Steering Committee in 2009. A discussion paper for the development of a watershed management plan was released in October 2011 (NSWA 2011), followed by the completion of the Vermilion River Watershed Management Plan (VRWMP) in 2012 (NSWA 2012).

One of the 5 overarching goals of the VRWMP is to "*Maintain or improve surface water quality in the Vermilion River watershed*"; a primary action under this goal is to "*Improve knowledge of surface water quality in the Vermilion River*". This report summarizes the results of a preliminary water quality assessment conducted on the Vermilion River by the NSWA during 2014.

1.2 Basin Characteristics

1.2.1 Landscape and Climatic Features

The VRW is in the Central Parkland Natural Sub-Region of East Central Alberta. It covers an area of 7,860 km^2, or 14% of the total NSR basin. Coincident historical (1965-69 and 1971-79) flow data for the North Saskatchewan and Vermilion rivers indicate that, on average, the Vermilion River contributes only about 1.4% of the North Saskatchewan River flow at Lea Park (Sal Figliuzzi, P. Eng., personal communication).

Natural Regions are defined geographically based on landscape patterns (e.g., vegetation, soils and physiographic features). According to the Natural Region Committee (2006) the Central Parkland Sub-Region is typified by undulating till plain and hummocky upland. Aspen (*Populus tremuloides)* and prairie vegetation characterize this area. Soils under grassland are usually black Chernozems whereas dark gray Chernozems and Luvisols usually occur under aspen forest.

The Vermilion River is fed by local runoff and groundwater. Flows in the river are highly variable and dependent on climate (Figure 1). Monthly precipitation patterns have a marked peak in July with significant rainfall in June and August. Typically, flows increase in spring during snowmelt and following summer rain storms. In dry years with little snowpack or rain, flows are very low; water may become stagnant and portions of the river bed may dry up altogether (Figure 1). Approximately 70% of the basin drains to local sloughs and wetlands and does not contribute regularly to flows in the Vermilion River (Golder 2009).

A basin planning report produced by Alberta Environment (1974) describes the river gradient as varying along the course of the Vermilion River. Although the river drops an average of three feet per mile, in any particular reach the drop may be as much as six or eight feet, or it may be zero. The Two Hills and Vermilion floodplain areas, for example, and the Holden Drainage District, have extremely low gradients. Also, the reaches of the river at and below the Town of Vegreville and above the Village of Mannville are relatively flat. In contrast, the lower portion of the river upstream of the confluence with the North Saskatchewan River has a fairly steep gradient (Figures 2 and 3).

1.2.2 Human Impacts

The Vermilion River basin includes all or portions of eight rural municipalities (Beaver, Flagstaff, Lamont and Camrose Counties, and the Counties of Minburn, Two Hills, Vermilion River and St. Paul). There are three towns (Two Hills, Vegreville, and Vermilion), seven villages (Dewberry, Holden, Innisfree, Kitscoty, Mannville, Marwayne, and Minburn) and two hamlets (Bruce and Clandonald). The Towns of Vegreville and Vermilion are the largest urban centres. Together, these urban and rural municipalities have a population of 56,977 people (Statistics Canada, 2011, cited in NSWA 2012).

Suitable soils, adequate summer precipitation and a sufficiently long and warm growing season make this area very suitable for annual crop production. Consequently, much of the basin has been intensively cultivated for over a century. Contiguous areas of original Parkland vegetation remain on land that is unsuitable for agriculture because of its topography and soil constraints; such areas represent only 5% of the basin (Natural Region Committee 2006). In addition to annual crops (wheat, barley, canola, pulses), a substantial portion of the basin is used to grow perennial crops (hay, pasture) and sustain local livestock production (Figure 4).

Along with the clearing of forest, development of farms, conversion of land to agriculture and significant alterations to the hydrology of the basin, population centres developed across the basin). To serve these population centres, the construction of roads and other infrastructure became a necessity.

Historically, flooding has been an issue in wet years, particularly for farmers who settled on marshy land. Intense and widespread drainage began in 1919 with the establishment of the Holden Drainage District, a local authority to help farmers drain low-lying lands to increase agricultural production (Milholland 2016). Channelization was undertaken at Vegreville, from Benz Lake to Morecambe and downstream of Morecambe, mainly with the intent to accelerate drainage. The Vermilion River was dammed (Morecambe structure) at the lower end of the Vermilion Lakes in 1976. Currently, the Morecambe structure is operated as a flood management tool and it allows pre-release from the Vermilion Lakes to reduce the impact of major summer rainfall events in the Vermilion Lakes basin. However, the operation of the structure increases the risk that areas downstream will dry up after dry winters (NSWA 2012) and its use has been intermittent. A second structure, the Vermilion Dam, was constructed in 1980-81 to replace an existing dam built in 1950 and provides a recreation reservoir as well as a crossing of the river for Highway 41. The dam provides no flood control potential and the only controlled water releases are through a small sluice gate (NSWA 2012).

The watershed's towns, villages and hamlets require wastewater treatment plants to treat domestic sewage; their total contribution of treated wastewater to the Vermilion River is estimated at 1,525,000 m^3/year (Table 1). The Town of Vermilion uses mechanical treatment and discharges continuously to the Vermilion River with an estimated total discharge volume of 500,000 m^3/year. All other municipalities rely on lagoons which discharge mostly in fall. Combined, fall discharges within the watershed contribute about 0.6 m^3/s to the river; in most years, this represents much of the river flow. Considering estimated effluent quality (Table 1), treated wastewater likely contributes a significant load of contaminants to the river.

Groundwater is an important source of municipal, commercial and industrial water and it supplies water to most rural residents. Groundwater also serves a key role as the source of base flow to the Vermilion River and its tributaries, and it helps maintain water levels in wetlands (Golder 2009).

EPCOR has an extensive drinking water distribution network in the Edmonton Region. This network also pipes drinking water to most municipalities in the Vermilion River drainage basin. Exceptions are Marwayne, Kitscoty, Clandonald and Innisfree which will be serviced at a later date as the network expands (Stephen Craik, Ph.D., EPCOR, personal communication).

1.3 Objectives

Water quality in the Vermilion River was last sampled between 1995 and 1997 (Alberta Environment, unpublished data). The intent of the 2014 sampling program was to update the Vermilion River water quality database. Sampling was also conducted on Stretton Creek to establish information that could be used to document the effects of agricultural Beneficial Management Practices (BMPs) on stream water quality.

2.0 Methods

2.1 Study Design

Seven sampling locations were selected along the Vermilion River at key locations in the basin (Figure 5). Sites were located downstream of major urban centres (Vegreville, Mannville and Vermilion), hydrological features (Vermilion Lakes and the Morecambe structure), at the boundaries of counties and at the mouth of the Vermilion River. Several of the water quality sampling sites corresponded to sites sampled historically (1995 to 1997) although sites V1 and V4 were newly established in 2014 (Table 2). Four of the seven sites were located at or near an active Water Survey of Canada (WSC) gauging station (Table 2).

Sites on Stretton Creek were chosen upstream and downstream of a reach where efforts to protect and enhance riparian health are ongoing. The lower site (STR2) is located a short distance upstream of a WSC flow gauging station. That location was sampled for water quality from 1995 to 2006 as part of province-wide monitoring of agricultural streams (Anderson et al. 1998: Canada Alberta Environmentally Sustainable Agriculture [CAESA], and Lorenz et al. 2008: Alberta Environmentally Sustainable Agriculture [AESA]). This project was intended to provide historical data to evaluate the influence of ongoing riparian protection measures on stream water quality.

Three longitudinal surveys were carried out during July, August and October in 2014 to document water quality at low flow. Capturing runoff due to a rainstorm in July had been anticipated, however, no such event occurred in 2014. Sampling encompassed a broad range of physical, chemical and biological measurements designed to describe general instream water quality conditions, identify issues potentially related to human activities (e.g., nutrient enrichment, bacterial and pesticide contamination) and identify reaches with possible groundwater input.

2.2 Sampling Methods

2.2.1 Field Measurements

Dissolved oxygen (DO), temperature (T), pH and electrical conductivity were recorded at each site (Table 2). Water samples were taken from the middle of the stream when practical. If water levels made mid-stream measurement unsafe, sampling occurred at a point closer to shore.

Flow velocity (m/s) was measured in the middle of the stream using a flow meter and at approximately 60% of the water column depth. Global Positioning System (GPS) readings as well as observations on vegetation, soil erosion and presence of wildlife were noted to characterize the condition of river banks.

2.2.2 Water Chemistry

Water samples were collected at the same locations as field measurements. An intermediate pole-mounted dipper was used to collect water; the water was used to fill individual sample bottles. Sterilized and contamination free sample bottles were supplied by MAXXAM, the laboratory responsible for sample analyses. Samples were kept cool and delivered to the analytical laboratory as soon as possible.

2.3 Laboratory Analyses

Samples were analyzed at MAXXAM for physical, chemical and biological attributes. The list of variables analyzed is summarized in Appendix I, along with reportable detection limits (RDL), reporting units and analytical methods.

2.4 Data Presentation

Data for key variables including field measurements, nutrients, major ions, metals and biological measurements (planktonic chlorophyll-*a* and *E. coli*) were plotted as simple bar graphs.

Water quality measurements were compared to "Environmental Quality Guidelines for Alberta Surface Waters" (GOA 2014), which is the current compendium of guidelines from various jurisdictions. Guidelines have been developed for the protection of aquatic life (PAL), recreation (REC), irrigation (IRR) and livestock watering. Where practical (i.e., guideline is a single value) graphs display the guideline values. Where a guideline has multiple values (e.g., depending on temperature and pH, or hardness), samples that do not comply have been flagged on the graph.

In some cases, (i.e., nutrients, major ions) benchmarks other than guidelines were available to characterize water quality; such benchmarks were also plotted on the graphs. Guidelines, benchmarks and all summarized data are presented in Appendices II and III. A correlation matrix (Pearson Correlation) was produced to depict the level of association among variables (Appendix IV).

3.0 Results and Discussion

3.1 Flow and Water Column Depth

<u>Flow</u>

Flow is a critical component of stream ecology as it influences physical, chemical and biological processes in streams (i.e., deposition/re-suspension of particles, downstream transport, exchange of dissolved oxygen and other atmospheric gasses).

Observations on flow velocity (Appendix III) indicate that surveys were carried out when water was stagnant or flows very low. Measurable flow velocity was recorded at V5 in July, V7 and STR1 in July and August and STR2 in August. Flow at these sites ranged from 0.07 (STR2, Aug) to 0.54 m^3/s (V7, August). Flow velocity was not measurable in any of the three surveys at the remaining sites.

Preliminary flow data from WSC at Vegreville (Station 05EE009) confirm that river discharge was very low at the time of water quality sampling in 2014 (July 7 and 8: 0.029 and 0.018 m^3/s; Aug 27 and 28: 0.010 and 0.011 m^3/s; and Oct 7 and 8: 0.002 and 0.003 m^3/s).

<u>Water Column Depth</u>

Water column depth can influence water quality measurements. For instance, the deeper stagnant water is, the more likely top and bottom differences will be observed in variables such as dissolved oxygen, water clarity and temperature. In turn, such differences can influence water chemistry measurements.

Water column depth ranged from 11 cm (STR1, July) to 124 cm (V1, August). This range could be sufficient to induce some differences in water quality measurements among sites and surveys.

3.2 Dissolved Oxygen

Dissolved oxygen (DO) is a fundamental constituent of surface waters that is critical for the survival of aquatic life. The solubility of oxygen in water is influenced by temperature, salinity, turbulence, atmospheric pressure, photosynthesis, aerobic respiration, and decay of organic matter (Wetzel 1983). Oxygen from the atmosphere and from photosynthesis are the main sources of dissolved oxygen in water. Oxidation of chemical compounds, aerobic respiration and decomposition of organic matter are the main causes of oxygen depletion. Time of day, season, sampling depth and flow influence DO levels and while the three surveys carried out in 2014 establish preliminary data, they do not describe the potential range of instream diurnal or seasonal variability.

Dissolved oxygen levels (Figure 5) showed fairly significant fluctuations among surveys and sites, and acute and chronic guidelines for the protection of aquatic life (GOA 2014) were met only at sites V2, V4 and V7. Acute guidelines were not met in July at V6 and in July and August at STR1. Chronic guidelines were not met in one or more surveys at V1, V3, V5, V6, STR1 and STR2. Failure to meet DO guidelines is an indication of acute or chronic limitations for aquatic life, respectively.

3.3 pH and Alkalinity

pH

pH is defined as the logarithm of the reciprocal of the concentration of free hydrogen ions (Wetzel 1983); it describes the status of water with respect to acidity and alkalinity. Alkalinity is a measure of the water's ability to neutralize acids.

Overall pH levels (Figure 6) showed considerably less variability among surveys and sites than DO. Instream measurements consistently were in the acceptable pH range for the protection of aquatic life (GOA 2014).

Alkalinity

Alkalinity (Figure 7) ranged from 230 mg/L (V1 July) to 530 mg/L (October V5 and Oct STR2). There was no pronounced longitudinal change along the Vermilion River and differences among surveys at individual sites were inconsistent.

Alkalinity in the Vermilion River and Stretton Creek was well above the minimum guideline adopted by GOA (2014). Alkalinity tends to fluctuate widely in surface waters, but usually does not exceed 500 mg/L (CCME 1987); hence some values recorded in the 2014 surveys are relatively high.

3.4 Temperature

Temperature plays a major controlling role in aquatic environments by influencing biological, chemical and physical processes. Temperature (Figure 6) exhibited noticeable and consistent differences within sites based on survey date, but relatively little difference between sites. This illustrates expected changes in water temperatures relative to seasonal air temperature.

3.5 Major ions and related variables

The concentration and proportion of inorganic ions (calcium, magnesium, potassium, sodium, bicarbonate/carbonate, chloride, sulphate and fluoride) and related variables (electrical conductivity, total dissolved solids, hardness, and alkalinity) are useful to characterize surface waters and important to assess the suitability of that water for irrigation and livestock watering. As well, hardness influences the toxicity to aquatic life of some metals.

Weathering of rocks, leaching, seepage and runoff from soils are the major natural sources of hardness and inorganic ions to surface waters. Man-made sources include various industrial and agricultural activities, salting of roads, treatment of domestic drinking water and wastewater.

Major ions and related variables tend to be inversely correlated to river flow. Surveys in 2014 were all conducted at very low flows which precludes an evaluation of the relationship between flows and ambient concentrations. However, because higher major ion concentrations would be expected at low flows, it is likely that the 2014 surveys captured the higher end of the concentration range for the Vermilion River and Stretton Creek.

Electrical Conductivity, Total Dissolved Solids and Salinity

Electrical conductivity (EC) is directly proportional to total dissolved solids (TDS) and salinity. Hence, data for these variables are highly correlated (Appendix IV).

In the Vermilion River and Stretton Creek TDS ranged from 400 to 1100 mg/L (Figure 7); this range is typical of fresh (non-saline) waters. Although irrigation guidelines for TDS are crop-specific, the suggested range of 500 to 3500 mg/L indicates that limitations would exist only for sensitive crops.

Major Ions

Major ions measured in 2014 were calcium (Ca^{2+}), magnesium ((Mg^{2+}), potassium (K^+), sodium (Na^+), carbonate and bicarbonate (CO_3^{2-} and HCO_3^-), chloride (Cl^-) and sulphate ($SO_4{}^{2-}$) (Figure 8). Fluoride (F^-), generally considered a minor ion, was also assessed.

Guidelines for the protection of aquatic life have been developed for chloride (chronic: 120 mg/L) and sulphate (at hardness >180mg/L, guideline for sulphate: 429 mg/L). Both guidelines generally were met in the Vermilion River and Stretton Creek (Figure 8). Irrigation guidelines exist for chloride (range 100 to 700 mg/L) and fluoride (1 mg/L); the livestock watering guidelines for calcium is 1000 mg/L. These agricultural use guidelines were met instream (Figure 8).

Since water is electrically neutral, the overall electric charge of cations (positively charged) cancels the charge of anions (negatively charged). The ionic nature of water can be characterized by converting ion concentrations to milliequivalent (mEq) and graphing individual cations and anions as a percent of the total cation and anion concentration, respectively. Figure

9 shows that water at the seven sites on the Vermilion River mostly was dominated by sodium and bicarbonate (sodium-bicarbonate type water), although some sites (V2, V3, and V4) also had a high proportion of sulphate (sodium-sulphate water). In contrast, water at STR1 is dominated by magnesium, calcium and bicarbonate, with sulphate and sodium becoming more important at STR2 (Figure 10). The higher concentration of sulphate at some sites could possibly indicate groundwater inputs or differences in local geology.

Hardness
Calcium and magnesium ions cause hardness when combined with anions such as bicarbonate, carbonate or sulphate. Hardness in the Vermilion River and Stretton Creek exceeded 180 mg/L (Figure 7) which implies that the water ranks as 'very hard' (Table 3).

Sodium Adsorption Ratio
Sodium, calcium and magnesium are used to calculate the Sodium Adsorption Ratio (SAR) and help determine the suitability of water for irrigation. Based on GOA (2014), SAR equal to or less than 5 is considered 'safe' for irrigation whereas between 5 and 10 it is considered 'potentially safe'. Most samples collected from the Vermilion River fell in the latter range, whereas samples from Stretton Creek have a lower SAR and would therefore be considered 'safe' (Table 4).

3.6 Nutrients and Related Variables

Nutrients are chemical substances required for plant growth. In surface waters, nitrogen and phosphorus are referred to as essential macro-nutrients (Wetzel 1983). They often are in low supply compared to the needs of plants, hence plant growth is limited. The supply of nutrients for plant growth can be greatly increased by human activities such as wastewater discharges and agricultural runoff. The resulting nutrient enrichment is of concern because it can lead to a series of chain reactions which are detrimental to water quality and disruptive to aquatic life. As the nutrient supply increases, aquatic plants can become so abundant that they alter the natural daily and seasonal fluctuations in dissolved oxygen levels. Only fish and invertebrate species which can tolerate such changes survive while the others disappear. When oxygen levels drop to the point that anoxic conditions occur in the river sediment, phosphorus can be released to the water column, further fuelling the problem of nutrient enrichment.

Streams can be classified as oligotrophic, mesotrophic and eutrophic depending on their levels of total nitrogen and phosphorus and the photosynthetic pigment chlorophyll-*a* in phytoplankton (i.e., small suspended algae) (Table 5). Chlorophyll-*a* in benthic (i.e., algae attached to the bottom of streams) is also a measure of productivity but was not measured in this study.

Nitrogen
Nitrogen occurs in inorganic and organic forms in aquatic environments. Inorganic nitrogen includes dissolved nitrate (NO_3^-)-N, nitrite (NO_2^-)-N, ammonia/ammonium (NH_3/ NH_4^+)-N and molecular nitrogen (N_2); organic forms include proteins, amino acids, urea, and methylamines, which may be encountered in dissolved or particulate form in dead or live organic matter. Total

Kjeldahl Nitrogen (TKN) comprises organic nitrogen (particulate and dissolved) and ammonia. Total Nitrogen (TN) is calculated as the sum of TKN and (nitrate+nitrite)-N.

Relatively high levels of total nitrogen were measured in the Vermilion River and Stretton Creek and most of this nitrogen was present as organic nitrogen or TKN (Figure 11). Total nitrogen and TKN had a relatively high level of association (Appendix IV) with TSS (r^2 of 0.50 and 0.43, respectively). Since most of the TKN is organic this suggests that some of the TSS may be live or dead organic matter.

With few exceptions (V2, V3, V6), levels of inorganic nitrogen [(ammonia/ammonium)-N, and (NO_2+NO_3)-N] were below the reported detection limit (RDL) at most sites. Such low levels contrast with historical monitoring that captured a broader range of seasonal and flow conditions. Monitoring of the Vermilion River during 1996-1997 reported a much wider range of concentrations for inorganic nitrogen [(NO_2^- +NO_3^-)-N range: 0.003 - 0.812 mg/L and (NH_3/ NH_4^+)-N range 0.02 - 3.25 mg/L). Summarizing water quality of 8 streams that drain intensively farmed land in Alberta, Lorenz et al. (2008) identified Stretton Creek as having the highest flow-weighted mean concentration for (NO_2^- +NO_3^-)-N (i.e., 0.952 mg/L).

Total nitrogen concentrations measured in 2014 in the Vermilion River ranged from 0.8 to 3.8 mg TN /L which fall within the range reported for agricultural streams that drain intensively farmed land (i.e., 0.765 to 4.001 mg TN /L) (Anderson et al. 1998). Flow-weighted mean concentration in Stretton Creek for the period 1995 - 2006 was 2.969 mg/ TN/L (Lorenz et al 2008).

Dodds et al. (1998) and USEPA (2000) view TN concentration of 1.5 mg/L as the threshold between mesotrophic and eutrophic. Hence, most sites sampled in 2014 would qualify as eutrophic although the lower site on the Vermilion River (V7) and Stretton Creek (STR2) tend to be mesotrophic. However, considering historical data, STR2 would be defined as eutrophic (Anderson et al. 1998; Lorenz et al 2008).

Phosphorus

Total phosphorus (TP) in surface waters occurs in various organic and inorganic forms which may be dissolved (TDP) or particulate (PP) phosphorus. PP comprises phosphorus included in live or dead organisms and phosphorus included or adsorbed to mineral phases of rocks and soil. Large man-made sources of phosphorus in the Vermilion River and Stretton Creek are treated municipal wastewater discharges and agricultural runoff.

In the Vermilion River and Stretton Creek, phosphorus was measured as total and dissolved phosphorus. TP levels in the 2014 surveys ranged from 0.046 mg/L (V7, Oct) to 1.2 mg/L (STR1, Aug)]. Concentrations were highest in July and August and in these surveys most of the phosphorus was in dissolved form (Figure 12). In the October survey, TP concentrations were lower and the proportion of PP was relatively higher.

The range of TP measured in the Vermilion River and Stretton Creek overlaps with the range reported for agricultural streams that drain intensively farmed land (i.e., 0.071 to 0.898 mg TP/L

Anderson et al. 1998). In the 1995-97 surveys, TP in the Vermilion River ranged from 0.045 to 1.46 mg TP/L (Alberta Environment, unpublished data). The median flow-weighted mean concentration for Stretton Creek was 0.433 mg/L (Lorenz et al. 2008). The dominance of TDP in the phosphorus pool is typical for agricultural streams in Alberta and was observed in both the 2014 surveys as well as historical studies (Anderson et al. 1998, Lorenz et al. 2008 and NSWA 2016 draft).

Most sites on the Vermilion River and Stretton Creek consistently had TP levels well over 0.075 mg/L and would be defined as eutrophic based on Dodds et al. (1998) and USEPA (2000). Only a few samples fell within the mesotrophic range (V4 August, and October samples from V6 and V7).

Comparison of nitrogen and phosphorus to guidelines

Because TN and TP are not directly toxic to aquatic life, guidelines for TN and TP are narrative and indicate that "Nutrient levels should be maintained so as to prevent detrimental changes to algal and aquatic plants communities, aquatic biodiversity, oxygen levels and recreational quality" (GOA 2014).

The Vermilion River and Stretton Creek have levels of TN and TP that are typical of nutrient enriched or eutrophic streams. TP and TN are inversely correlated to DO (Appendix IV), suggesting that the level of eutrophication is having a negative influence

on water column oxygenation. This is confirmed by the fact that at times, DO levels do not meet chronic or acute guidelines for the protection of aquatic life. Stresses on the aquatic ecosystem and biodiversity have also been documented in CPP Environmental (2016).

Numerical guidelines are available for forms of nitrogen that can be toxic to aquatic life or other uses. PAL Guidelines for unionized ammonia are temperature- and pH-dependent (GOA 2014). Levels of ammonia recorded in the Vermilion River and Stretton Creek complied with guidelines. Stock watering guidelines for nitrite-N and nitrate-N (10 and 100 mg/L, respectively) are far above recorded instream concentration and therefore not a concern.

Chlorophyll-*a*

Planktonic chlorophyll-*a* (Chl-*a*) is a photosynthetic pigment that is used as an indicator of planktonic algal biomass in surface waters. Chlorophyll- *a* levels in the Vermilion River and Stretton Creek varied considerably among sites and among surveys (Figure 13). Referring to the trophic classification proposed by Dodds et al. (1998) and USEPA (2000), V1 and V2 ranked consistently as mesotrophic while V7 and Stretton Creek sites (with the exception of the October sample at STR2) ranked as oligotrophic. Other sites such as V3, V4 and V6 had samples typical of eutrophic conditions.

Appendix IV indicates that Chl-*a* was more strongly correlated to TSS (r^2: 0.61) than to nutrients (TN: $r^2$of 0.43; TP r^2: -0.15). Relatively low correlations to nutrient levels may indicate that other or additional factors govern planktonic algal growth. These may include depth, turbidity and presence of macrophytes which could limit light penetration and lack of flow which could limit replenishment of nutrient-rich water around plankton cells. As well, other non-planktonic communities of primary producers (e.g., algae which grow on rocks, vegetation or mud) may utilize a significant portion of the available nutrients and respond more strongly to nutrient enrichment.

3.7 Suspended solids

Total suspended solids (TSS) is a measure of the amount of suspended particulate matter. In most rivers, the amount of suspended matter tends to be positively correlated to flow. Hence, one would expect higher TSS levels during periods of runoff sufficiently intense to deliver sediment to the stream or re-suspend sediments from the stream bottom. Such events were not captured in the 2014 surveys and TSS levels recorded in the Vermilion River and Stretton Creek are likely at the low end of variability for these streams (Figure 14). Since water was mostly stagnant one could expect plankton to contribute to TSS levels as suggested by the relatively high correlation between the two variables (r^2: 0.61; Appendix IV).

3.8 Metals

Metals and trace elements are natural components of the earth's crust. Some are very abundant while others are present in trace amounts. They enter surface waters through the weathering of soils and rocks and are present even in surface waters of undeveloped basins. Anthropogenic activities such as mining, sewage discharges and heavy metals industry can contribute metals to surface waters. Once metals enter surface waters they do not degrade. They can be transported downstream, stored in sediments or living organisms and they can become remobilized and available under appropriate conditions. In fast flowing rivers, the concentration of metals is correlated to TSS levels.

Metals are of concern because of their toxicity. Some metals can become concentrated in the tissues of living organisms (bioconcentration) and some can concentrate along the food chain (biomagnification).

All of the 26 metals analyzed in the three surveys were reported as 'total' metals, except for iron (Fe) which was also reported as 'dissolved' iron. The metals were detected at different frequencies:

- Six occurred at concentrations below the RDL: antimony (Sb), beryllium (Be), cadmium (Cd), silver (Ag), thallium (Tl) and tin (Sn);
- Chromium (Cr), cobalt (Co), lead (Pb), selenium (Se) and zinc (Zn) were not detected in several samples and mercury (Hg) was detected at the RDL in a single sample from V2; and
- Aluminum (Al), arsenic (As), barium (Ba), boron (Bo), copper (Cu), total and dissolved iron (Fe), lithium (Li), molybdenum (Mo), nickel (Ni), strontium (Sr), titanium (Ti), uranium (U) and vanadium (V) occurred at measurable concentrations in all samples collected in 2014. Figure 15 depicts concentrations for a selection of these metals in the 2014 surveys.

Guidelines for the protection of aquatic life for irrigation and livestock watering have been developed for several metals (GOA 2014). However, arsenic was the only metal which exceeded guidelines (Appendices II and III, Figure 15). The arsenic PAL guideline of 5 µg/L was exceeded at V1 in August, at V2 in all surveys and at V7 in July and August.

Not surprisingly, considering the very low flows or absence of flow during surveying, the level of association between metals and TSS was very low (Appendix IV). This again suggests that inorganic sediment particles contributed little to TSS levels.

3.9 Pesticides

Pesticides (including herbicides, insecticides, and fungicides) are man-made chemicals which are applied to the environment to control pests that interfere with food production, forestry, as well as aesthetic and/or recreational aspects of the human environment. Once applied, a fraction of the chemicals will adsorb to the target site and will eventually degrade. However, some of the chemicals can move off site via runoff to surface waters and seep into shallow groundwater. Pesticides can also enter the atmosphere adsorbed to dust particles, as fine droplets or gas. Once in the atmosphere these contaminants can travel short or long distances before they are deposited with rain, snow or dust over the landscape.

Pesticides in the environment are of concern because of the potential toxicity to non-target species of single or multiple compounds. Guidelines for the protection of aquatic life, irrigation and livestock watering have been developed for some individual pesticides.

Seventeen phenoxy acid pesticides were measured at V1, V5, V7 and STR2 in July, August and October (Appendix I). Only 3 herbicides were reported at measurable concentrations in one or more samples.

- 2,4-D was recorded in July at V5 (0.071 µg/L) and V7 (0.064 µg/L);
- bromoxynil was detected at V5 in July (0.029 µg/L); and
- MCPA was reported at V1 in July (0.073 µg/L) and August (0.028 µg/L), and in the July samples from V5 (0.17 µg/L), V7 (0.068 µg/L) and STR2 (0.03 µg/L

Reported concentrations complied with guidelines for the protection of aquatic life for 2,4-D (PAL: 4 µg/L), bromoxynil (PAL: 5 µg/L) and MPCA (PAL 2.6 µg/L). However, they exceeded irrigation guidelines for MCPA (IRR: 0.04 µg/L) at V1, V5 and V7.

Compared to provincial historical data (1986 to 2002), the pesticides detected during 2014 sampling are among those detected most frequently in Alberta surface waters; provincially, 2,4-D has been detected in 53% of samples, MCPA in 10 to 50% of samples and bromoxynil in 1 to 10% (Anderson 2005).

In addition to the phenoxy acid herbicides scan, a special scan for diuron, guthion and temephos was requested for each sample. An organochlorine scan was run on July and August samples, and a semi-volatile organic scan, which comprises several pesticides (Appendix I), was applied to the October samples. No detections were reported for any of the three additional scans.

While the 2014 data provide a snapshot of pesticide contamination in the Vermilion River, it would be valuable to take some key factors into consideration in further surveys.

- Detection frequencies are closely linked to overall quantities used in agriculture and municipal and urban pest control. As the pesticide industry continues to produce new products it becomes important to monitor pesticide use and tailor the list of pesticides that are measured in surface waters accordingly. While 2,4,5 TP (Sylvex) and pentachlorophenol may be used locally it is likely that other compounds (e.g., glyphosate or Roundup) are of greater current relevance in terms of quantities used over the landscape. Furthermore, some compounds such as 2,4,5-T and many organochlorines were discontinued in 1980's or earlier (Anderson 1995) and their analysis is of little relevance now;
- The timing of pesticide sampling will also influence the perception of the degree of pesticide contamination. It is notable that of the 8 detections, 7 occurred in July and none in October. June and July are peak months for pesticide detections in Alberta surface waters (Anderson 2005), as this is the main period of application of most herbicides and the time when significant rainfall is usually most likely; and
- Although the semi-volatile scan comprises several relevant herbicides, method detection limits are much higher than for the other scans (Appendix I) and probably well above the environmental range for the two streams. This considerably reduces the significance of the data.

3.10 Micro-Biological Indicators

Coliform bacteria are widely used as indicators of fecal contamination of surface waters. Although total coliforms and fecal coliforms are still routinely measured, *Escherichia coli* (*E. coli*) is a more reliable measure of fecal contamination by warm-blooded animals such as humans, terrestrial and aquatic animals such as livestock, birds, beaver and muskrats.

Recreational guidelines require that no more than 10% of samples taken over a 30-day interval exceed the threshold value of 410 colony forming units (cfu)/100 mL. Irrigation guidelines were derived to address the potential risk to human health of consuming irrigated raw produce and specify that *E. coli* levels should not exceed 100 cfu/100 mL.

E. coli counts in Stretton Creek ranged from less than 1 CFU/100 mL (STR1, October) to 41 CFU/100mL (STR2 July), these values are well below recreational or irrigation guidelines (Figure 16). *E. coli* counts were more variable in the Vermilion River and ranged from 13 CFU/100 mL (July V3) to 410 CFU/100 mL (August V1). The August sample at V1 is the only one that equalled the recreation guideline; counts at all other sites were well below. The irrigation guideline was not met in one or more samples from each site except V3, ST1 and STR2.

4.0 Initial Rating of Site-Specific Water Quality

A rating system was applied to the 2014 water quality data to convey water quality information in simple, relative terms. A similar approach was used by CPP (2016) on 2014 and 2015 TP and TN data. The following steps were involved, with results shown in Tables 6-9:

1. Select variables that are most representative of the key water quality issues (i.e., eutrophication).

    Variables used in the rating scheme are DO, TSS, Chl-a, TN, TP and *E. coli*.

2. Group variable-specific data into quartiles and assign a score to each quartile (Table 6).
    '1' represents data from 75 to the 100th percentile
    '2' represents data from 50 and < 75th percentile
    '3' represents data from 25 and <50th percentile
    '4' represents data from 0 to < 25th percentile

3. Calculate site-specific medians for each variable (Table 7).

4. Assign a score to each median value based on the two previous tables (Table 8).

5. Colour-code each score based on the quartiles for overall scores (Table 9).

This scoring system suggests that water quality in the headwaters (V1), downstream of Vegreville (V2) and downstream of Vermilion (V6) is poorer than at other sites sampled in 2014. There is a noticeable improvement downstream of Two Hills (V3) and downstream of the Morecambe structure (V4), followed by a decline downstream of Manville (V5) and downstream of Vermilion (V6). The lower site (V7) is rated as having the best water quality relative to other sites. Similarly, the lower Stretton Creek site had a better water quality score than the upper site, although both scores fall in the same quartile (i.e., same colour code).

It is important to note that three low flow surveys represent a minimal data set to assess and rate water quality. A larger dataset is needed to assess the robustness of the approach and the reliability of the assessment. Nevertheless, the outcome of this assessment is similar to that reported by CPP (2016) which was based on TN and TP only, but included 2014 and limited 2015 data. The main difference is a higher rating at site V3 in this study.

5.0 Summary and Conclusions

The Vermilion River basin has been altered considerably since settlement began in the early 1900s. Land use changes (agriculture, urban centres and infrastructure) have resulted in significant changes to the basin's hydrology. Impacts on river water quality can result from increased contaminant loading from point source discharges (e.g., such as municipal wastewater and storm water runoff) and nonpoint source loading of contaminants associated with broad landscape changes (e.g., agricultural land, deforestation). Changes in hydrology can influence downstream transport of contaminants and in-stream processing. Furthermore, low flows, which are in part natural to the Vermilion River and its tributaries, create physical, chemical and biological conditions more akin to shallow lakes rather than flowing waters.

Three water quality surveys (July, August and October 2014) were carried out at seven sites on the Vermilion River and two sites on Stretton Creek with the intent of updating a 20-year-old water quality database. Measurements encompassed a broad range of physical, chemical and biological variables suitable to describe general instream water quality conditions, identify issues potentially related to human activities (e.g., nutrient enrichment, bacterial and pesticide contamination), and possibly groundwater input.

Samples were collected from stagnant water or at very low flows, and for the most part in very shallow water; it is important to recognize that three low flow surveys cannot capture the full range of diurnal and seasonal variability that typifies water quality. Regardless, instream measurements of dissolved oxygen show that at several locations acute and chronic guidelines are not met at least some of the time.

Water in the Vermilion River is well-buffered fresh water of the sodium bicarbonate type. Water in Stretton Creek is of the magnesium-calcium-bicarbonate type with a higher proportion of sodium and sulphate at the lower site. Both streams have very hard water. Guidelines for the protection of aquatic life, irrigation and livestock watering were generally met although there may be restrictions for the irrigation of sensitive crops.

Inorganic nitrogen levels (ammonia, nitrite and nitrate) recorded in the 2014 surveys were very low, but organic nitrogen levels (Total Kjeldahl Nitrogen) were high, suggesting that much of the nitrogen was live or decaying organic matter. Based on total nitrogen levels, most sites would be ranked as eutrophic, although the lower site on the Vermilion River and Stretton Creek would be classed as mesotrophic.

Phosphorus in the Vermilion River and Stretton Creek occurred mostly in dissolved form and based on the TP levels most sites would qualify as eutrophic. However, some samples from the lower reaches on the Vermilion River are indicative of mesotrophic conditions.

Trophic classification based on planktonic chlorophyll-*a* is quite different and indicative of meso- to oligotrophic conditions. Although this is, *a priori*, somewhat puzzling, factors such as light limitation and lack of flow could limit planktonic algal growth. As well other aquatic plant communities (macrophytes, and algal communities attached to other plants, stones or bottom sediments) may capture a significant portion of the nutrient pool. Their presence and biomass would need to be considered for a more refined trophic assessment.

Metals analyzed in samples from the Vermilion River and Stretton Creek generally occurred at very low levels, which is not surprising considering the low levels of suspended solids measured in these mostly stagnant waters. Arsenic was the only metal which exceeded guidelines for the protection of aquatic life at some sites.

Few pesticides were detected; however, this could be an artefact of several factors including the timing of sampling relative to pesticide applications, pesticides analyzed versus pesticide use in the basin, and/or reportable detection limits that are far above anticipated ambient levels.

E. coli counts are an indicator of fecal contamination by warm-blooded animals. A single sample did not meet recreation guidelines and several samples did not meet the irrigation guidelines.

A simple scoring system based on variables related to eutrophication, was used to make relative comparisons of water quality among sites. Overall water quality of the Vermilion River and Stretton Creek improves in downstream direction; it is worst at the two headwater sites and downstream of Vermilion and best at the lower site on the Vermilion River.

High nutrient levels, coupled with DO levels which on occasion do not comply with guidelines for the protection of aquatic life, are indicative of long-term and short-term stresses on sensitive aquatic species. This, in conjunction with observation on degraded riparian habitat (CPP Environmental 2016), would justify advocating for the implementation of nutrient management in the basin (GOA 2014) as well as ongoing water quality monitoring.

6.0 Literature Cited

Alberta Environment. 1974. The Vermilion River basin study: A summary Report. Environmental Planning Division. 31 pp.

Anderson A.-M. 1995. Overview of pesticide data for Alberta surface Waters. Appendix4. In: Cross et al. 1995. Selection of Soil Landscape Units and Study Design Considerations for the Surface Water Monitoring Program. Prepared for CAESA Water Quality Committee, Published by Alberta Agriculture, Food and Rural Development, Edmonton. 104p.

Anderson, A.-M., D.O. Trew, R.D. Neilson, N. D. MacAlpine and R. Borg. 1998. Impacts of Agriculture on Surface Water Quality in Alberta. Part II Provincial Stream Survey. Prepared for CAESA Water Quality Committee, Published by Alberta Agriculture, Food and Rural Development, Edmonton. 91p + Figures and Appendices.

Anderson A.-M. 2005. Overview of pesticide data in Alberta Surface Waters Since 1995. Prepared for Environmental Monitoring and Evaluation Branch, Alberta Environment. Edmonton. 172 p.

Canadian Council of Environment Ministers (CCME). 1987. Canadian Water Quality Guidelines. Prepared by Task Force on Water Quality Guidelines.

Dodds, W.K., J.R. Jones, and E.B. Welch. 1998. Suggested classification od stream trophic status: distributions of temperate stream types by chlorophyll, total nitrogen and total phosphorus. Water Research 32(5): 1455-1462.

Lorenz, K.N., Depoe, S.L., and Phelan, C.A. 2008. Assessment of Environmental Sustainability in Alberta's Agricultural Watersheds Project. Volume 3: AESA Water Quality Monitoring Project A Summary of Surface Water Quality in Alberta's Agricultural Watersheds: 1995 to 2006. 487pp. *In* Assessment of Environmental Sustainability in Alberta's Agricultural Watersheds. Volume 3. Alberta Agriculture and Rural Development, Edmonton, Alberta, Canada.

Natural Regions Committee. 2006**.** Natural Regions and Subregions of Alberta. Compiled by: Downing, D.J., and W.W. Pettapiece Government of Alberta. 254p.

http://www.cd.gov.ab.ca/preserving/parks/anhic/Natural_region_report.asp

North Saskatchewan Watershed Alliance. (2005). *State of the North Saskatchewan Watershed Report: A Foundation for Collaborative Watershed Management: Vermilion Sub-watershed*. From

http://nswa.ab.ca/pdfs/vermilion_subwatershed.pdf.

North Saskatchewan Watershed Alliance (NSWA). 2011. Discussion Paper for the Development of a Watershed Management Plan for the Vermilion River Watershed in Alberta. The North Saskatchewan Watershed Alliance Society, Edmonton, Alberta. Available on the internet at h6p://nswa.ab.ca

North Saskatchewan Watershed Alliance (NSWA). 2012. *Vermilion River Watershed Management Plan*. The North Saskatchewan Watershed Alliance Society, Edmonton, Alberta. Available on the internet at http://nswa.ab.ca

GOA 2014. Environmental Quality Guidelines for Alberta Surface Waters. Alberta Government. 53p

Golder Associates Ltd. 2009. Vermilion River water supply and demand study. Prepared for the North Saskatchewan Watershed Alliance.

Golder Associates Ltd. 2016. Aerial Assessment of The Riparian Areas of The Vermilion River AB, And Its Major Tributaries. Prepared for the North Saskatchewan Watershed Alliance. 117 pp plus attachments.

Milholland B.L. 2016. Living in the shed: Alberta's North Saskatchewan River Watershed. North Saskatchewan Watershed Alliance. Edmonton, Alberta, Canada. 304 pp.

North Saskatchewan Watershed Alliance. 2005. State of the North Saskatchewan Watershed Report 2005 - A Foundation for Collaborative Watershed Management. North Saskatchewan Watershed Alliance, Edmonton, Alberta. 202 pgs.

North Saskatchewan Watershed Alliance (NSWA). 2012. *Vermilion River Watershed Management Plan*. The North Saskatchewan Watershed Alliance Society, Edmonton, Alberta. Available on the internet at http://nswa.ab.ca

North Saskatchewan Watershed Alliance (NSWA). 2015. Vermilion River Water Quality Monitoring Project 2014. Prepared by the NSWA, Edmonton, AB.

Statistics Canada. 2011. *Census of Population*. From http://www12.statcan.gc.ca/census-recensement/index-eng.cfm.

USEPA. 2000. Nutrient Criteria technical guidance manual: rivers and streams. United States Environmental Protection Agency Document 822-B-00-002, Office of Water.

Wetzel, R.G. 1983. Limnology. 2nd Ed. Saunders College Publishing, Philadelphia, New York. 767 p. plus references. 7.0 TABLE

7.0 Tables

Table 1. Summary of treated wastewater discharges in the Vermilion River Watershed. (Table contents compiled by G. Thompson, P. Eng., NSWA).

Municipality	Approximate Population Density [1]	Type of Treatment [2]	Receiving Water Body	Discharge	Discharge per day (m^3/d) [3]	Total Annual Discharge (m^3/yr)
Vermilion	4545	Mechanical	Vermilion River	Continuous	1,400	511,000
Vegreville	5758	Lagoon	Vermilion River	~ 20 d in fall	27,000	540,000
Two Hills	1431	Lagoon	Vermilion River	~ 20 d in fall	5,900	118,000
Kitscoty	967	Lagoon	Tyler Lake/irrigation	~ 20 d in fall	6,900	138,000
Manville	803	Lagoon	Vermilion River	~ 20 d in fall	4,300	86,000
Marwayne	667	Lagoon	Unnamed Creek then Vermilion River	~ 20 d in fall	2,900	58,000
Holden	381	Lagoon	Unnamed Creek then Vermilion River	~ 20 d in fall	3,700	74,000
				Total discharge [4]	**52,100**	**1,525,000**

[1] Lagoon discharges from smaller municipalities (< 300 people) such as Bruce, Clandonald, Dewberry, Innisfree and Minburn not included

[2] On average BOD levels range from 10 to 25 mg/L; TSS from 10 to 25 mg/L; and TP levels from 1 to 2 mg/L

[3] Estimates of discharge volume based on watewater production of 0.3 m^3/capita/day

[4] Discharge is equivalent to 0.6 m^3/s in fall

Table 2. Site name, location, establishment information, and site description (including nearby Water Survey of Canada (WSC) hydrometric gauging stations) for sampling sites on the Vermilion River and Stretton Creek in 2014.

Site Name	Legal land description	Latitude	Longitude	Site Background	Site description
V1	SE-13-50-15-W4	53.3083	-112.0625	Newly established in 2014	Headwaters and downstream of Holden and Beaver County. Near WSC station 05EE006.
V2	NE 12-54-14 W4	53.6580	-111.9250	Established in 1995 as MIN2A	Downstream of Vegreville and Minburn County
V3	NW 21-54-11 W4	53.6820	-111.5750	Established in 1995 as TWO2A	Downstream of Two Hills and Two Hill County
V4	SW-32-53-10-W4	53.6190	-111.4510	Newly established in 2014	Downstream of Morecambe Structure and Vermilion Lakes. Near WSC station 05EE010.
V5	SW 6-51-7 W4	53.3750	-111.0380	Established in 1995 as VER1	Downstream of Manville and first site in Vermilion River County.
V6	SW 20-51-5 W4	53.4110	-110.7180	Established in 1995 as VER3	Downstream of Vermilion, 2nd site in Vermilion River County.
V7	NE 11-54-3 W4	53.6550	-110.3360	Established in 1995 as VER6	Vermilion River at Lea Park. Near WSC station 05EE002.
STR1	SW-17-51-02-W4	53.3953	-110.2651	Newly established in 2014	Stretton Creek upstream of BMP area. Near WSC station 05EE007.
STR2	SW-16-52-03-W4	53.4858	-110.3990	Newly established in 2014	Stretton Creek downstream of BMP area.

Table 3. Hardness classification, based on CCME (1987)

Hardness (mg/L as CaCO3)	Classification
0 - 60	Soft
60 - 120	Moderately hard
120 - 180	Hard
Over 180	Very hard

Table 4. Sodium Adsorption Ratio (SAR), based on 2014 data collected at Vermilion River and Stretton Creek sampling sites.

	V1	V2	V3	V4	V5	V6	V7	STR1	STR2
July	4.9	7.4	5.1	3.7	4.6	4.6	4.2	1.0	2.1
August	6.3	7.1	8.9	2.5	6.0	5.5	4.6	1.1	2.8
October	6.3	8.5	8.5	2.7	8.6	5.3	3.7	1.2	3.1

Table 5. Thresholds for trophic classification of streams, based on Dodds et al. (1998) and USEPA (2000).

Variable (units)	Oligotrophic- Mesotrophic Boundary	Mesotrophic-Eutrophic Boundary
Planktonic Chlorophyll-*a* (µg/L)	10	30
Total Nitrogen (mg/L)	0.7	1.5
Total Phosphorus (mg/L)	0.025	0.075

Table 6. Water quality variables, quartiles and scores assigned to each quartile. (Note: for DO where higher concentrations are 'better' than lower concentrations, scores are reversed).

	Water Quality Scoring							
	Best		→				Poorest	
Water Quality Variable	Score 4		Score 3		Score 2		Score 1	
DO mg/L	12.22	9.58	<9.575	7.85	<7.85	6.08	<6.075	1.59
TSS mg/L	1.3	<4.35	4.4	<7.3	7.3	<11	11.0	24.0
Chl-a ug/L	1.2	<6.3	6.3	<13	13.0	<22	22.0	89.0
TN mg/L	0.770	<1.425	1.425	<2.35	2.350	<2.775	2.775	3.800
TP mg/L	0.046	<0.225	0.225	<0.34	0.340	<0.52	0.520	1.200
E. coli i #/100mL	1	<23.5	24	<41	41	<106.5	107	410

Table 7. Site-specific medians for each variable

	Medians per Site								
Water Quality Variable	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**STR1**	**STR2**
DO mg/L	8.96	6.81	7.85	9.35	7.6	6.19	10.4	4.5	7.04
TSS mg/L	16.0	10.0	4.7	5.3	11	7.3	1.3	5.3	8
Chl-a ug/L	24.0	27.0	11.0	17.0	9.3	13.0	2.5	5.7	6.3
TN mg/L	2.500	2.500	2.950	1.400	2.100	2.900	1.300	2.700	1.200
TP mg/L	0.390	0.630	0.230	0.078	0.430	0.390	0.300	0.800	0.240
E. coli #/100mL	230	53	13	57	70	58	93	25	27

Table 8. Water Quality-based site scores based on a variable's quartile score (Table 6) and median value (Table 7).

	Water Quality Scores per Site								
Water Quality Variables	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**STR1**	**STR2**
DO	3	2	3	3	2	2	4	1	2
TSS	1	2	3	3	1	2	4	3	2
Chl-a	1	1	3	2	3	2	4	4	3
TN	2	2	1	3	3	1	4	2	4
TP	2	1	3	4	2	2	3	1	3
E. *coli*	1	2	4	2	2	2	2	3	3
Sum of Scores	**10**	**10**	**17**	**17**	**13**	**11**	**21**	**14**	**17**

Table 9. Relative comparison of water quality at 2014 sampling sites.

Percentiles	Corresponding Score
0	10
25	13
50	14
75	18
100	21

Quartiles	Colour code	
10 to <13		**poorest**
13 to <14		↑
14 to <18		
18 to 21		**best**

	Water Quality Scores per Site								
	V1	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**STR1**	**STR2**
Sum of Scores	10	10	17	17	13	11	21	14	17

8.0 Figures

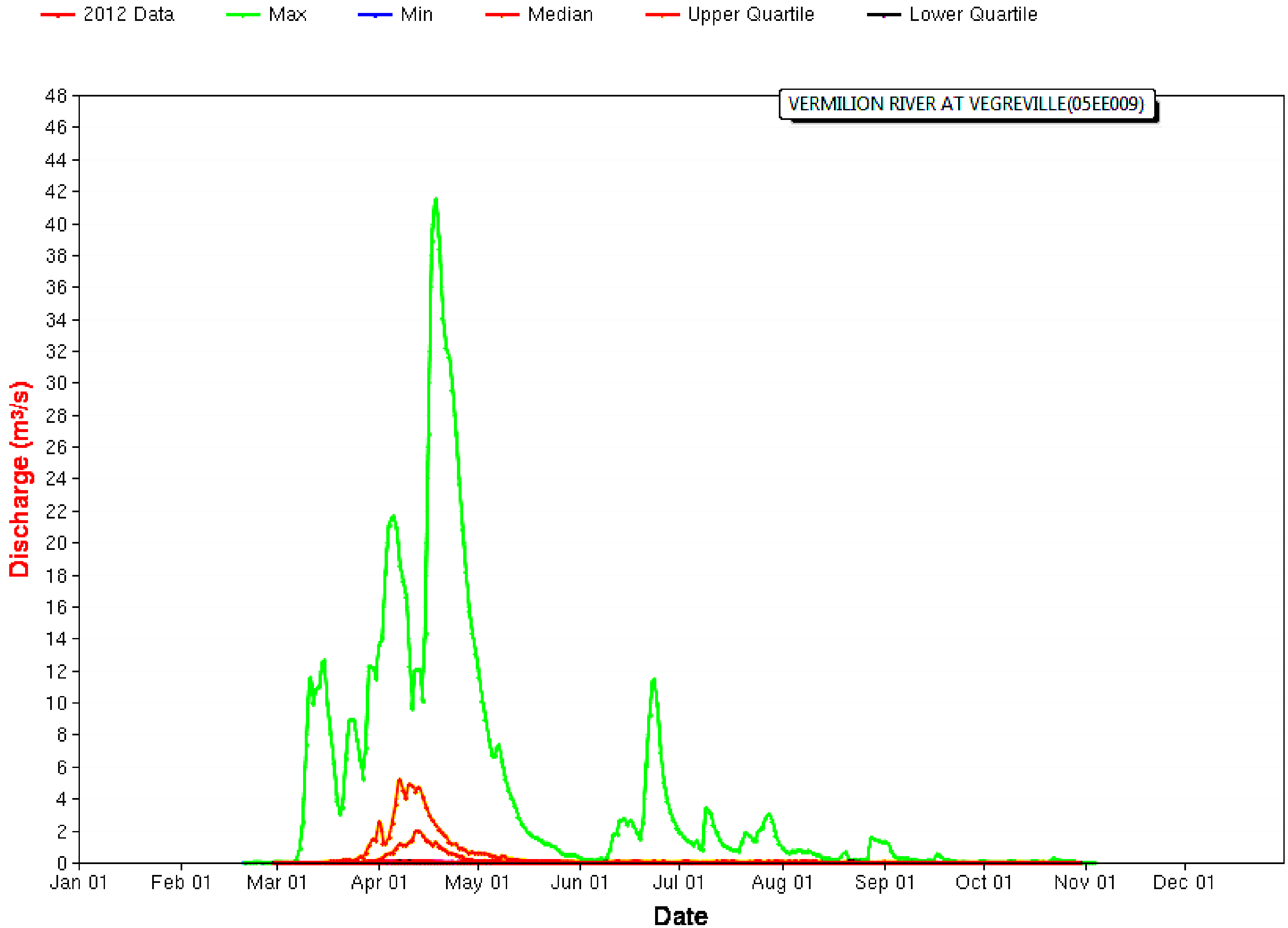


Figure 1. Historical (1987-2012) discharge (m^3/s) for the Vermilion River at Vegreville; Water Survey of Canada (WSC) gauging station 05EE009.

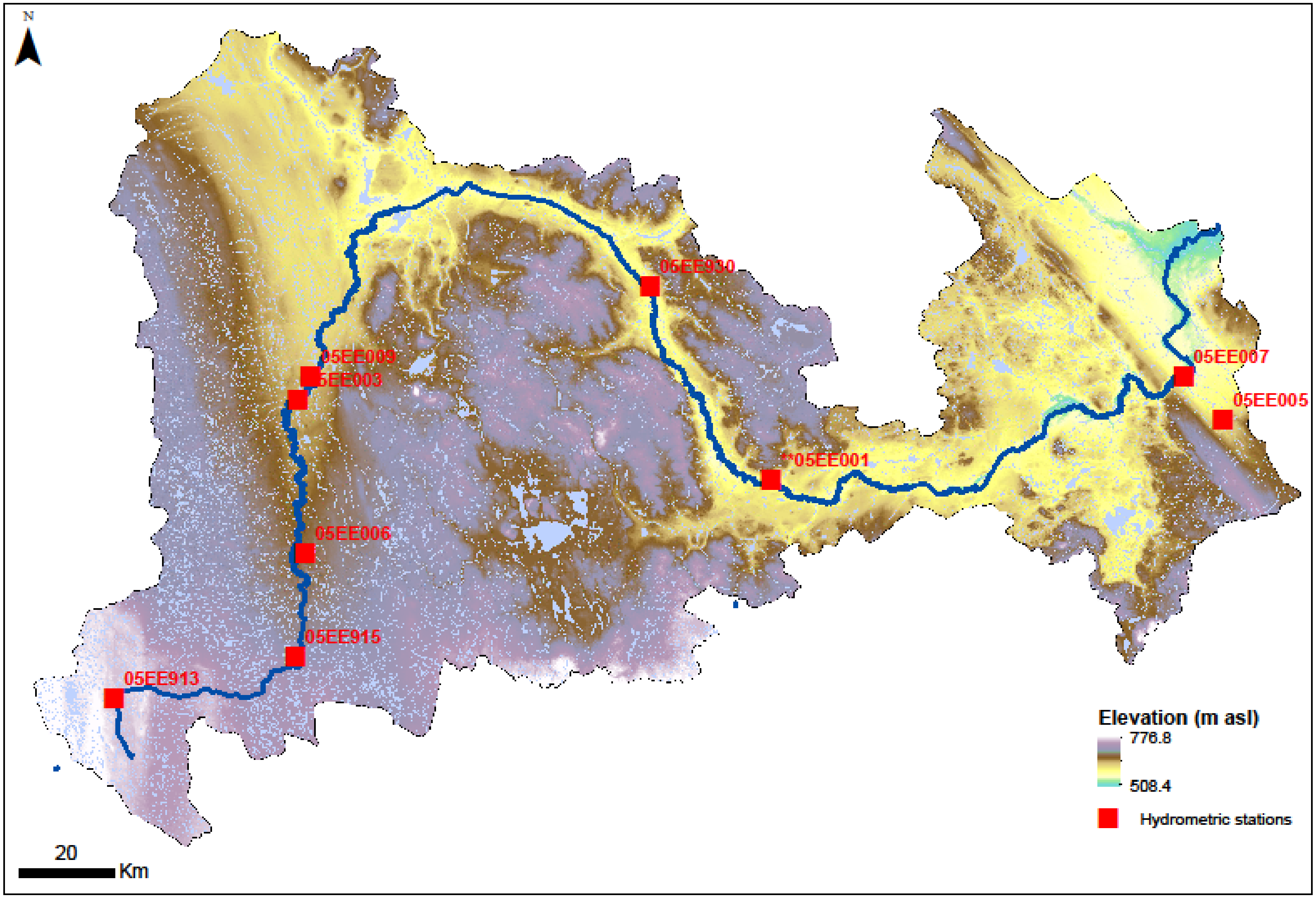


Figure 2. Elevation map for the Vermilion River Basin showing Water Survey of Canada (WSC) gauging stations.

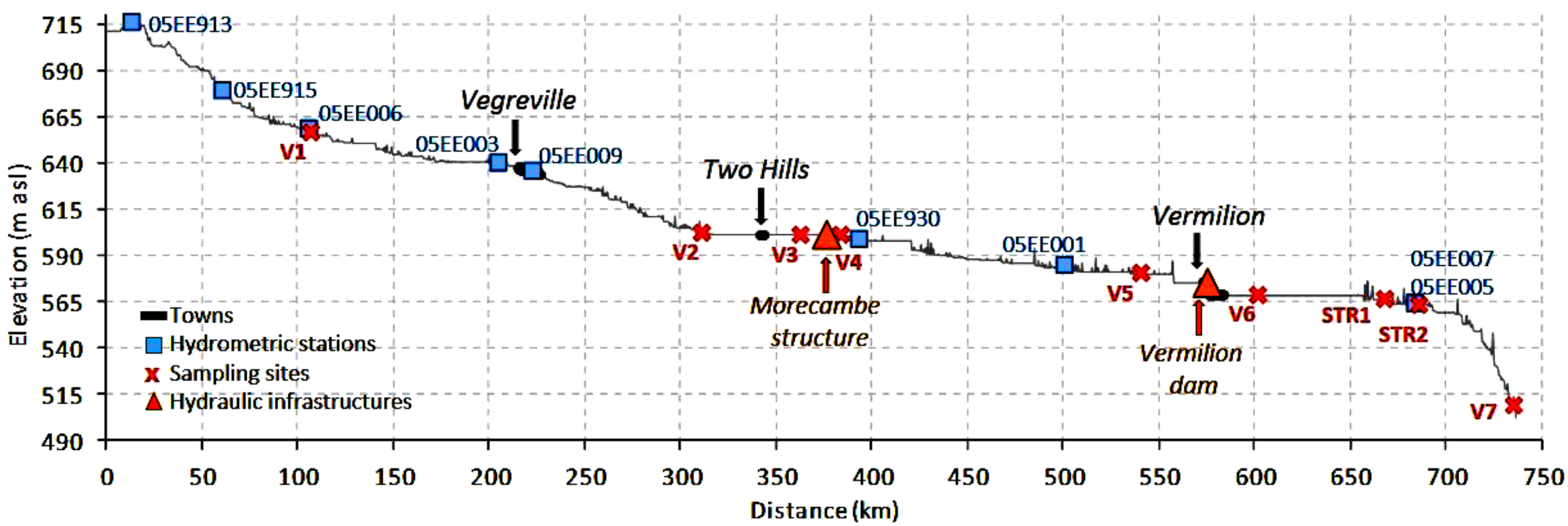


Figure 3. Elevation profile for the Vermilion River showing WSC gauging stations, hydraulic structures, 2014 water quality sampling sites (V1 to V7) and major towns.

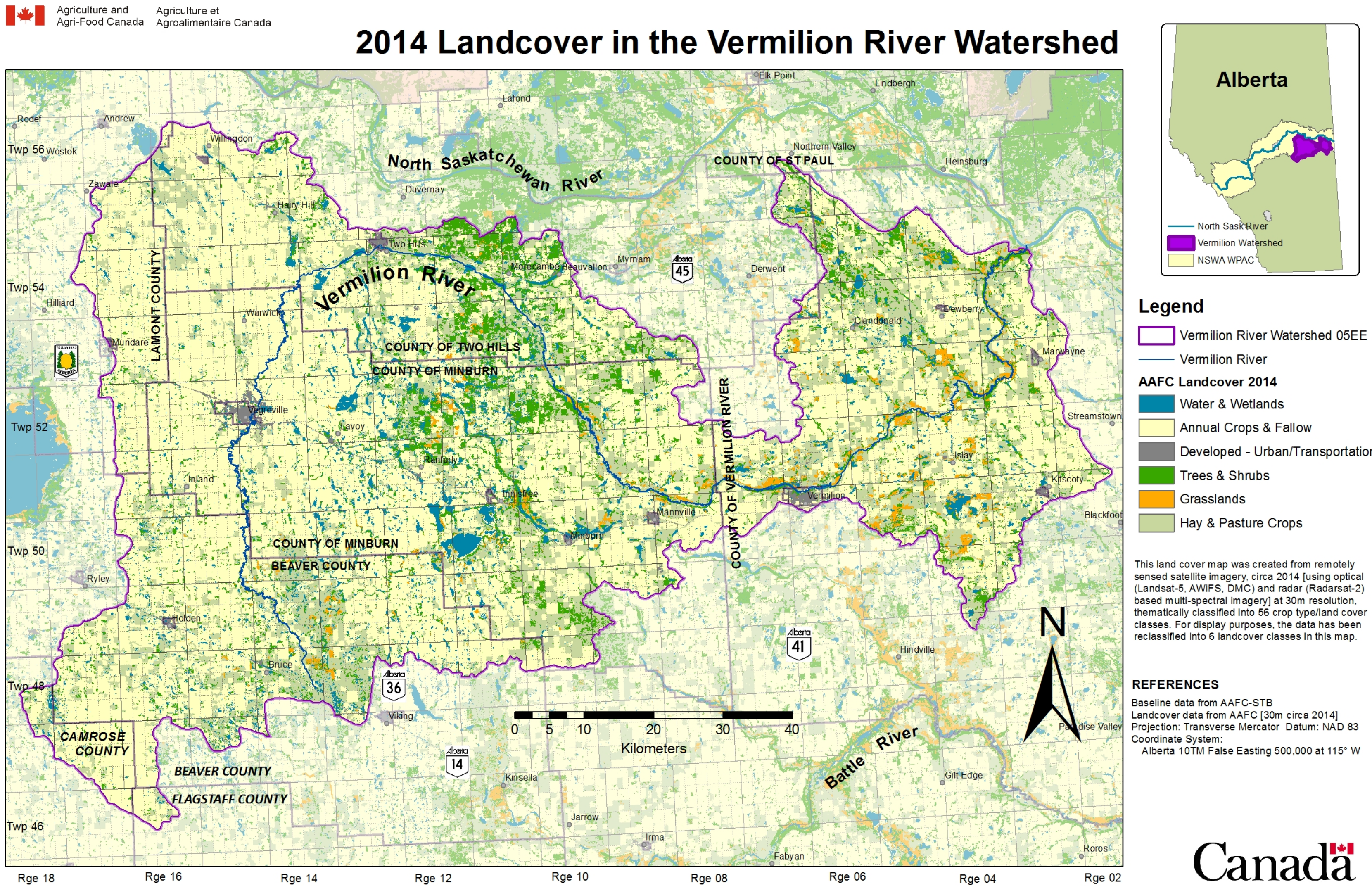


Figure 4. Land cover in the Vermilion River Watershed.

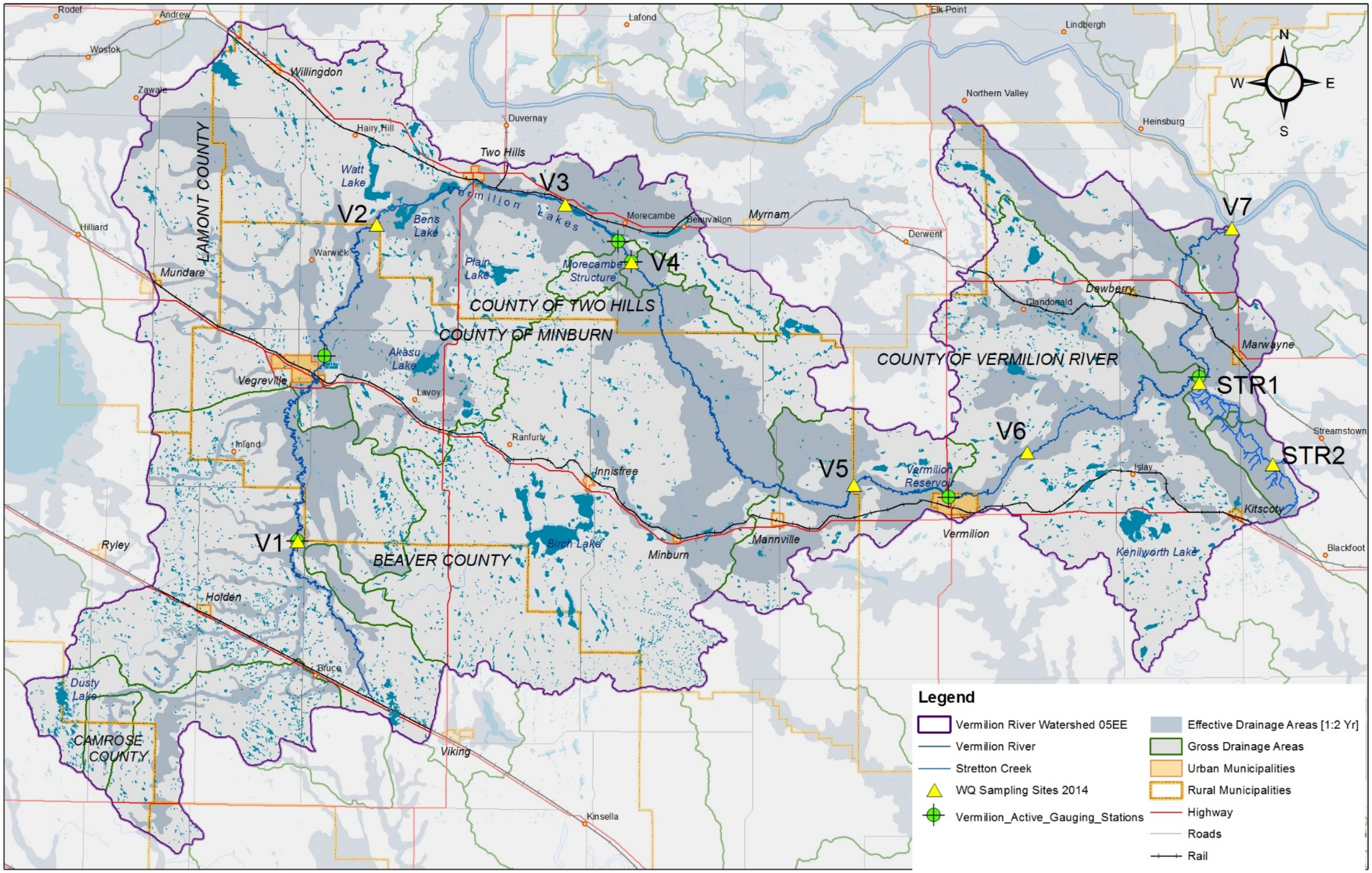
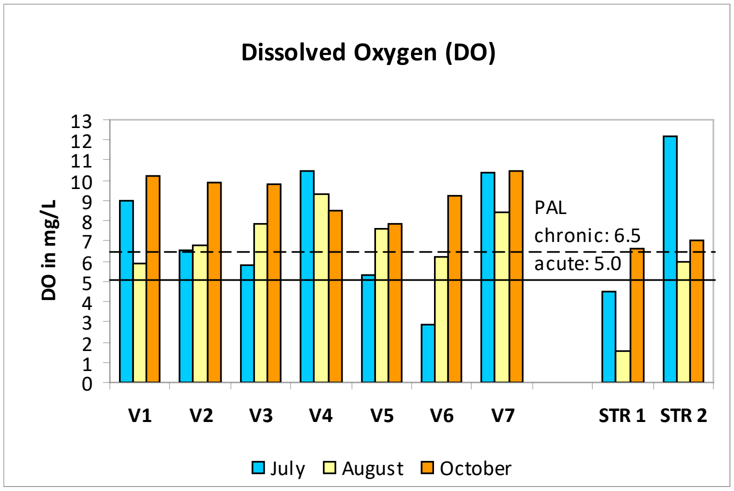
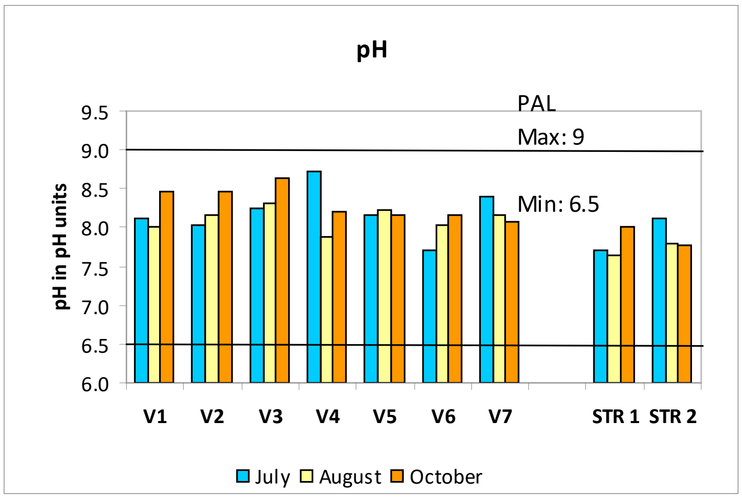


Figure 5. Water Quality (WQ) sampling sites in the Vermilion River and Stretton Creek in 2014. Active Water Survey of Canada gauging stations are also depicted.





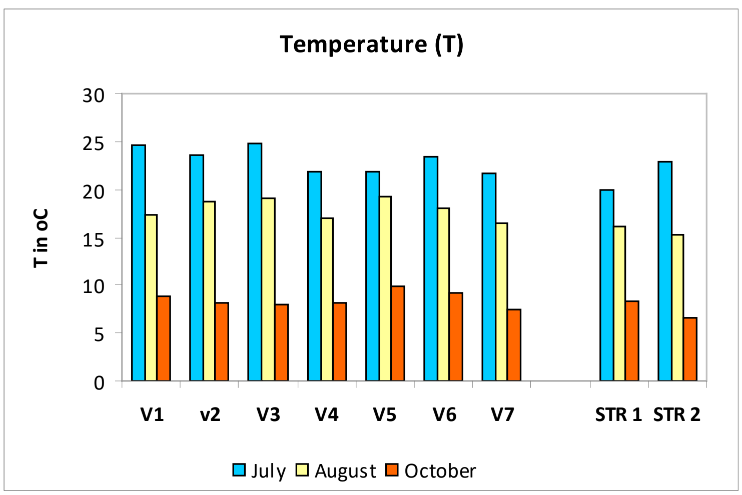


Figure 6. Dissolved oxygen (DO), pH and temperature (T) at Vermilion River and Stretton Creek sampling sites in 2014.

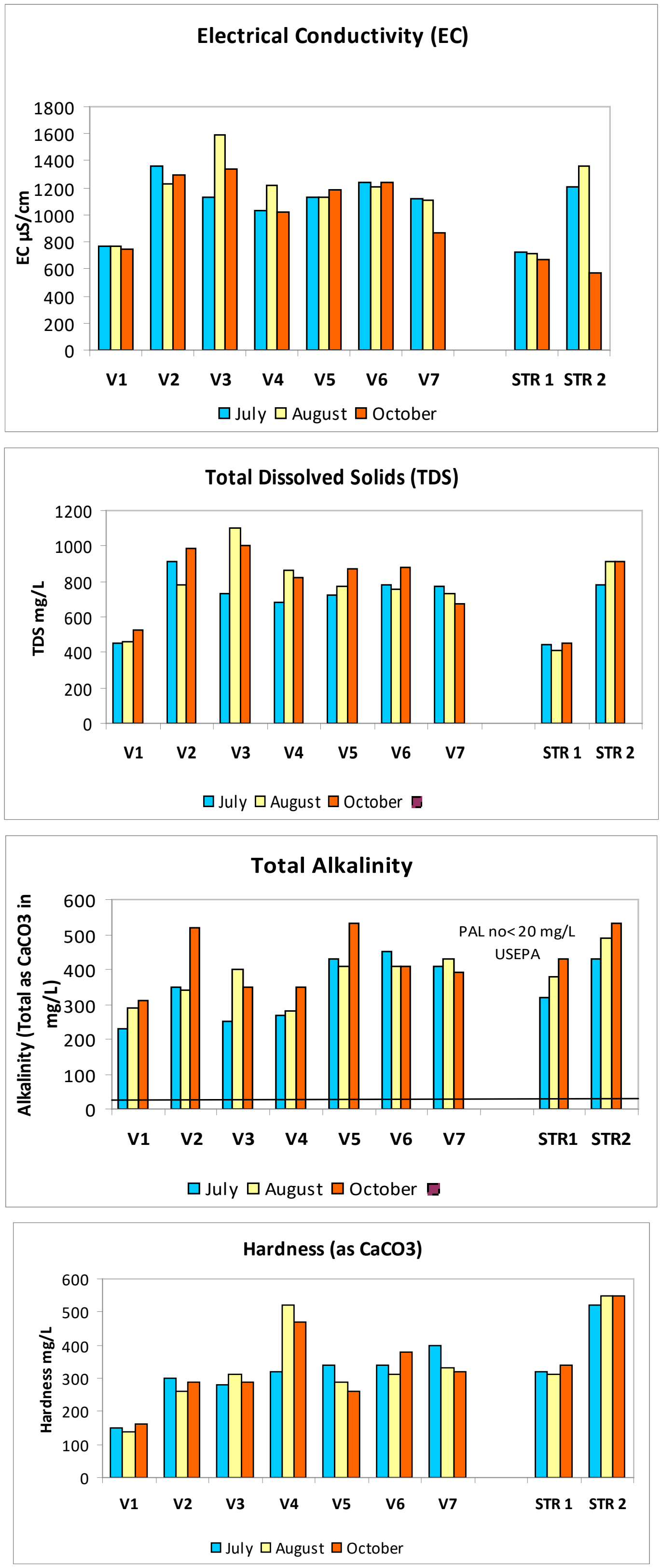


Figure 7. Electrical conductivity (EC), Total dissolved solids (TSS), total alkalinity and hardness at Vermilion River and Stretton Creek sampling sites in 2014.

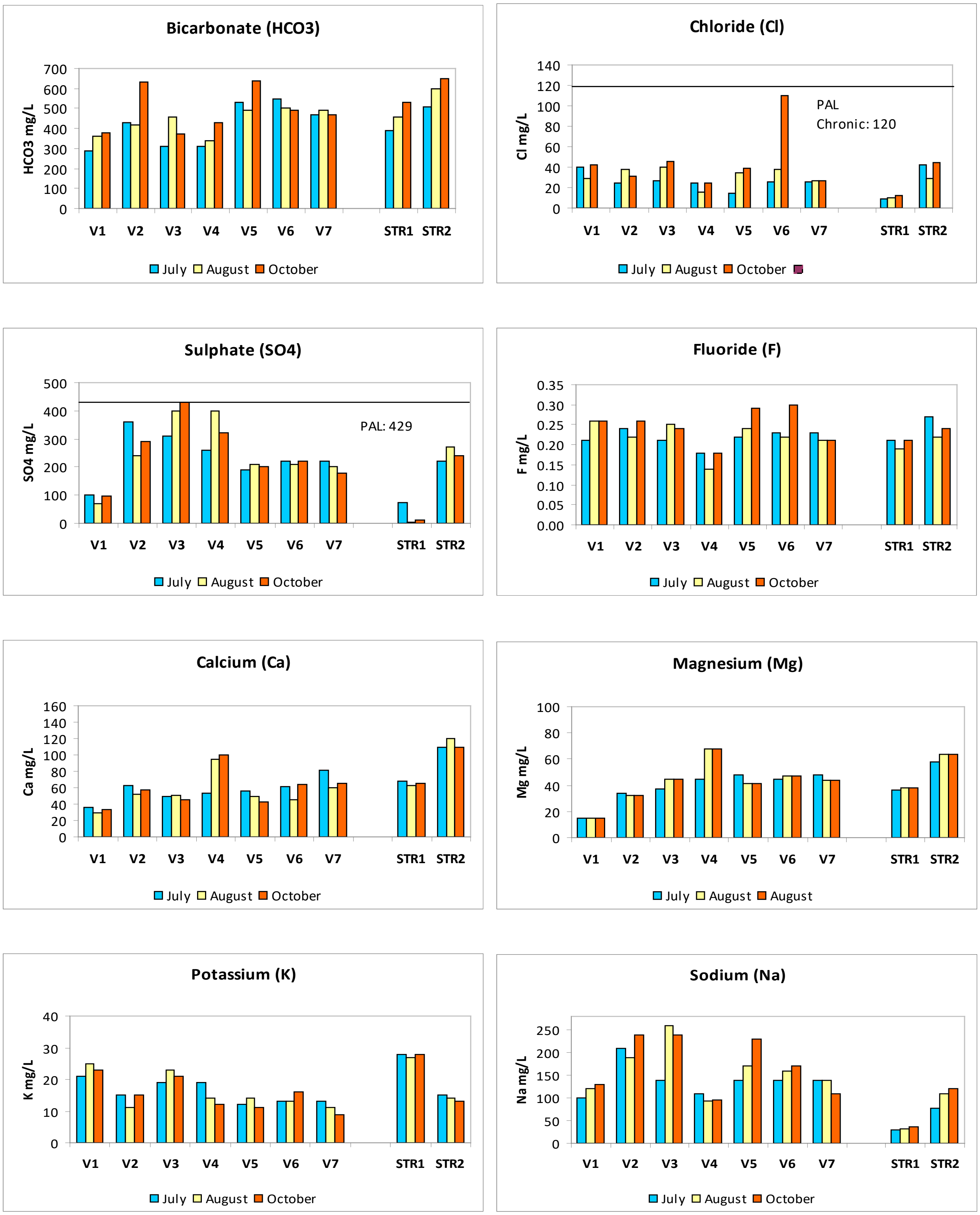


Figure 8. Ionic concentrations at Vermilion River and Stretton Creek sampling sites in 2014.

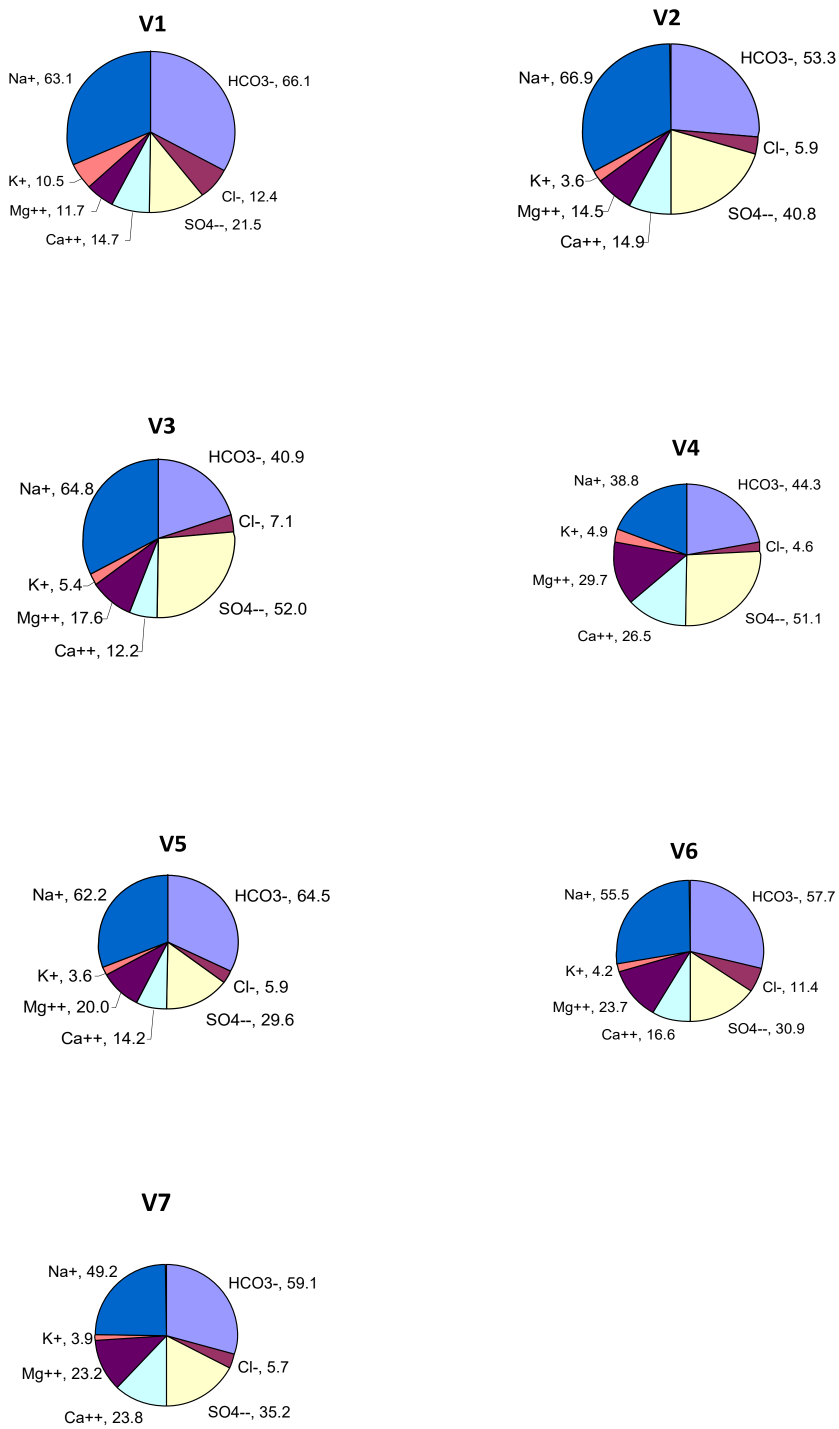
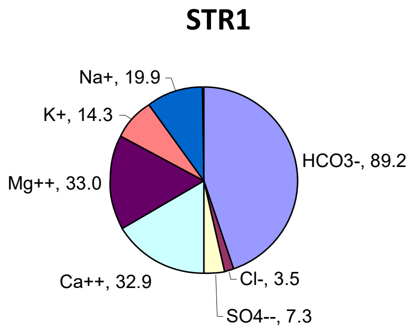


Figure 9. Major ion dominance at Vermilion River sampling sites, based on average concentrations in 2014 and expressed as % milliequivalent for cations and anions.



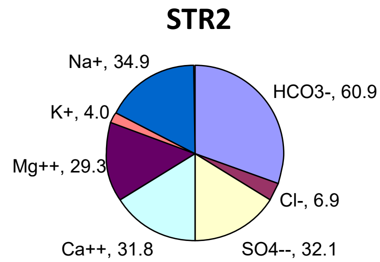


Figure 10. Major ion dominance at Stretton Creek sampling sites, based on average concentrations in 2014 and expressed as % milliequivalent for cations and anions, respectively.

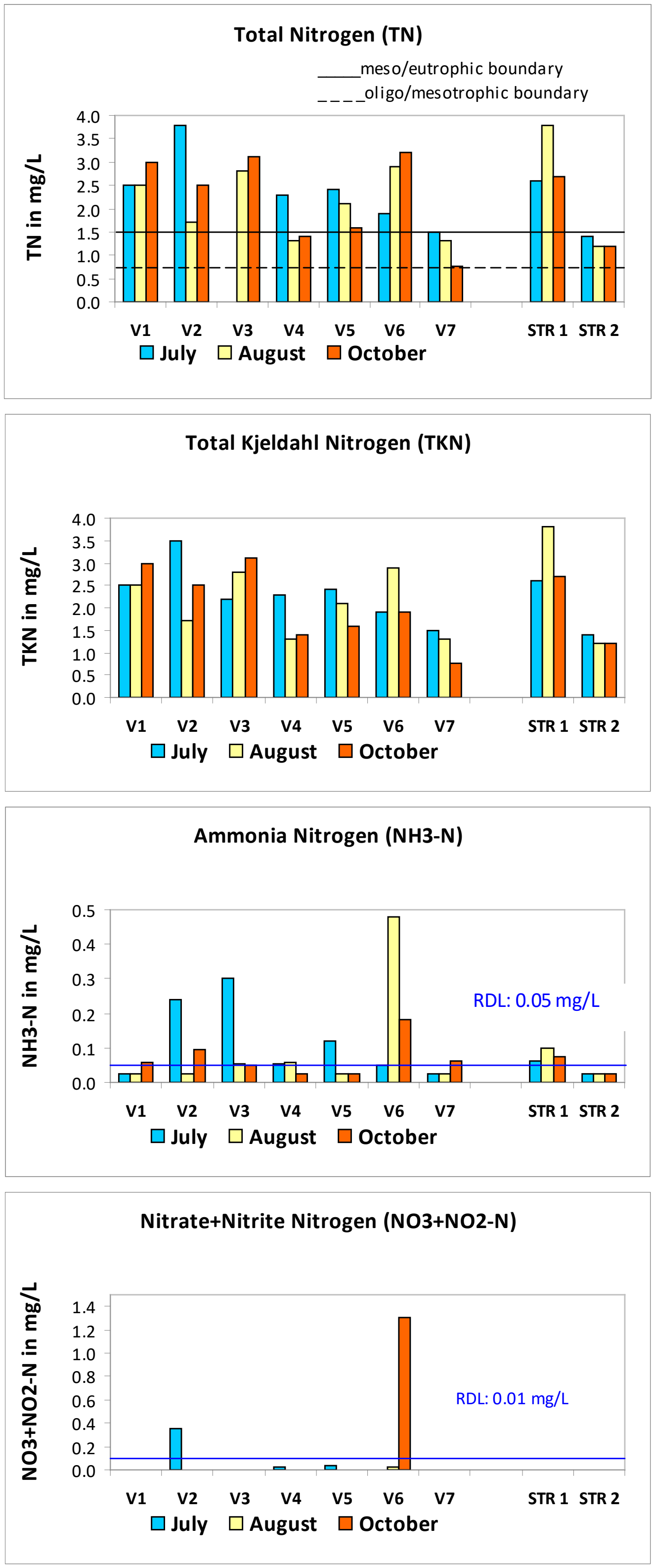
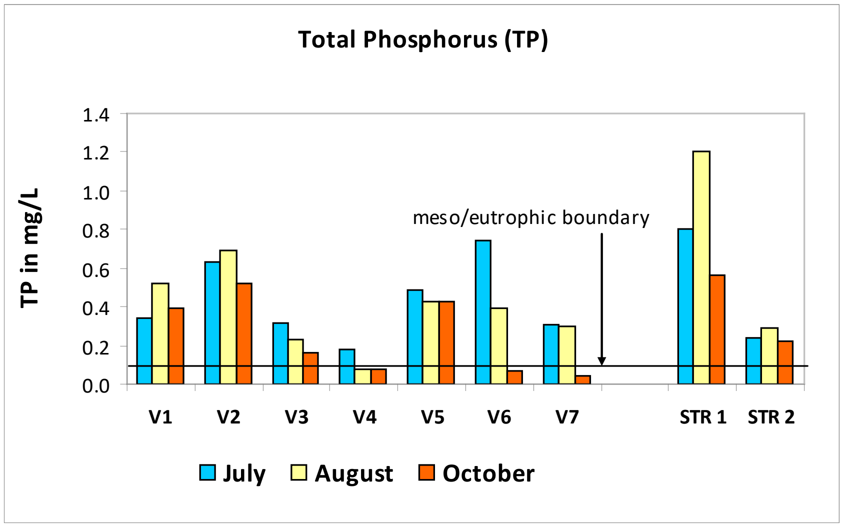
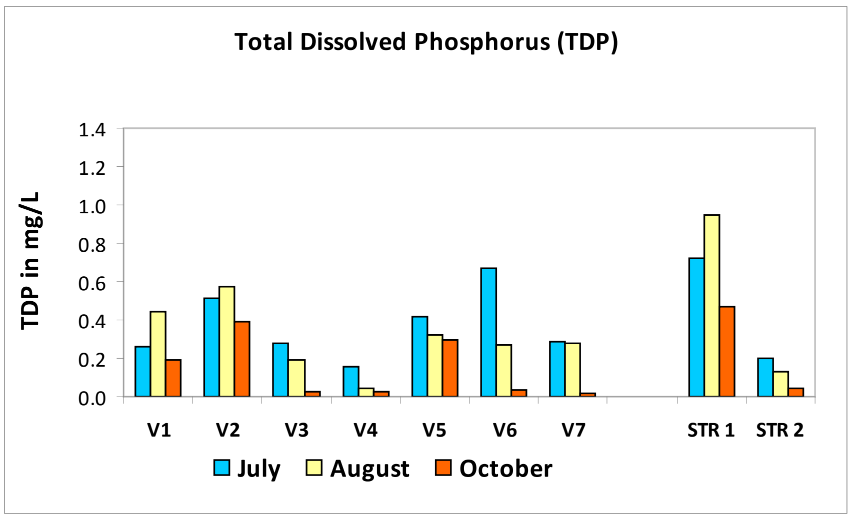


Figure 11. Nitrogen concentration at Vermilion River and Stretton Creek sampling sites in 2014. Trophic boundaries for streams according to Dodds et al (1998) and USEPA (2000)





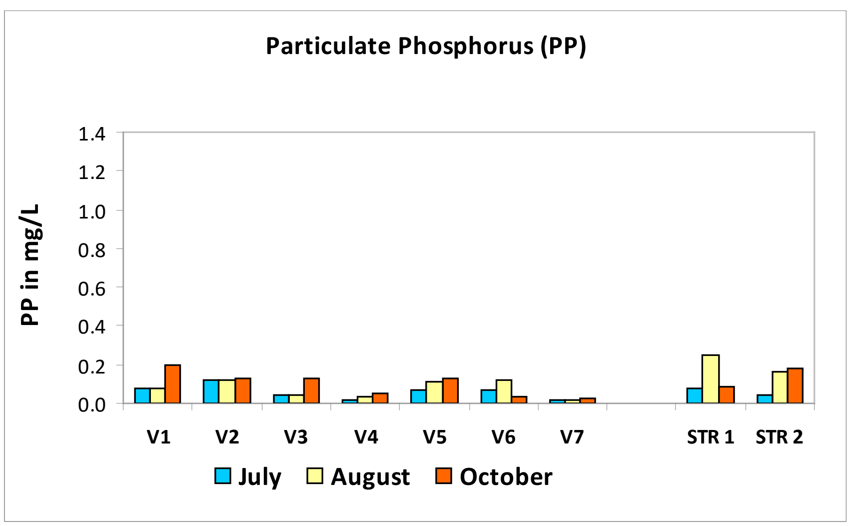


Figure 12. Total (TP), dissolved (TDP) and particulate (TPP) phosphorus concentrations at Vermilion River and Stretton Creek sampling sites in 2014. Trophic boundaries for streams according to Dodds et al (1998) and USEPA (2000)

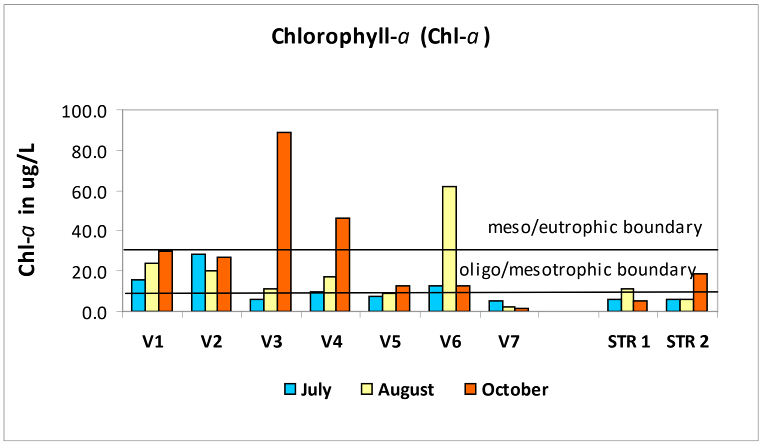


Figure 13. Planktonic chlorophyll-*a* concentrations at Vermilion River and Stretton Creek sampling sites in 2014. Trophic criteria for streams as defined by Dodds et al. (1998) and USEPA (2000).

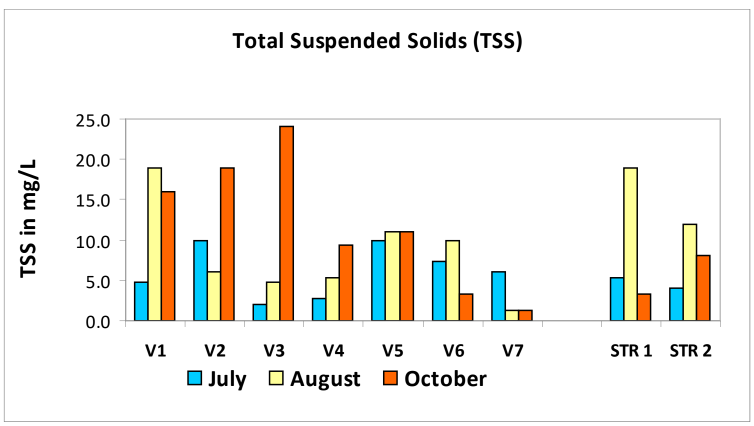


Figure 14. Total suspended solids at Vermilion River and Stretton Creek sampling sites in 2014.

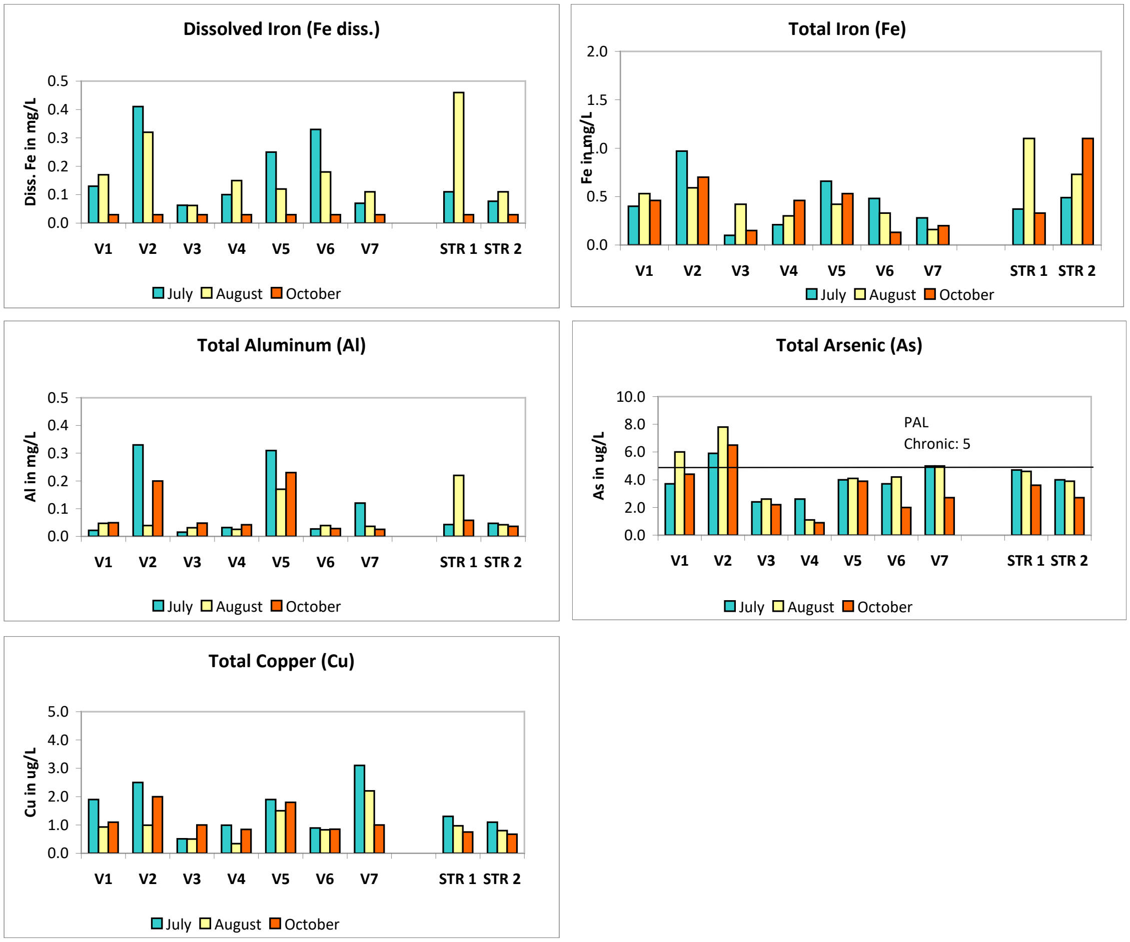


Figure 15. A selection of metals measured at Vermilion River and Stretton Creek sampling sites in 2014.

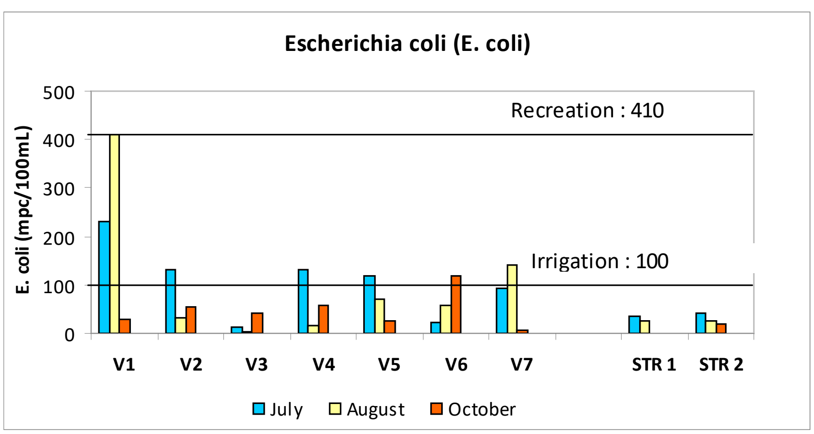


Figure 16. E. coli levels at Vermilion River and Stretton Creek sampling sites in 2014. Recreation (410 CFU/100mL) and Irrigation (100 CFU/100mL) guidelines are shown with black lines.

9.0 Appendices

Appendix I. List of Variables Measured in 2014.

Type	Variable	Unit	RDL[1]	Analytical Method
Field Data and related variables (all sites and surveys)				
	Flow	m/s	0.01	flow meter
	Depth	cm	1	measuring stick
	DO	mg/L	0.01-0.1	ProODO
	Conductivity	uS/cm	0.01-0.1	YSI Model 63
	Field temperature	^oC	0.1	YSI Model 63
	pH	pH	0.01	YSI Model 63
Biological measurements (all sites and surveys)				
	Chlorophyll a	ug/L	0.50	colourimetric
	E.coli DST [2]	mpn [3]/100mL	1.0	membrane filtration
	Fecal Coliforms	CFU[4]/100mL	1.0	membrane filtration
	Total Coliforms **DST**	mpn/100mL	1.0	membrane filtration
Nutrients and related variables (all sites and surveys)				
	Total Suspended Solids	mg/L	1.0	Filtration/gravimetric
	Dissolved Nitrate (N)	mg/L	0.010	colourimetric
	Dissolved Nitrite (N)	mg/L	0.010	colourimetric
	Total Ammonia (N)	mg/L	0.050	colourimetric
	Total Kjeldahl Nitrogen	mg/L	0.050	colourimetric
	Total Nitrogen (N)	mg/L	0.050	colourimetric
	Nitrate plus Nitrite (N)	mg/L	0.010	colourimetric
	Dissolved Phosphorus (P)	mg/L	0.0030	colourimetric
	Total Phosphorus (P)	mg/L	0.0030	colourimetric
Major ions and related variables (all sites and surveys)				
	Total Dissolved Solids	mg/L	10	titration/IC/Colourimetric/ICP-OES
	Alkalinity (Total as CaCO3)	mg/L	0.50	titration/IC/Colourimetric/ICP-OES
	Bicarbonate (HCO3)	mg/L	0.50	titration/IC/Colourimetric/ICP-OES
	Carbonate (CO3)	mg/L	0.50	titration/IC/Colourimetric/ICP-OES
	Dissolved Chloride (Cl)	mg/L	1.0	titration/IC/Colourimetric/ICP-OES
	Dissolved Fluoride (F)	mg/L	0.050	titration/IC/Colourimetric/ICP-OES
	Dissolved Sulphate (SO4)	mg/L	5.0	titration/IC/Colourimetric/ICP-OES
	Hydroxide (OH)	mg/L	0.50	titration/IC/Colourimetric/ICP-OES
	Dissolved Calcium (Ca)	mg/L	0.30	titration/IC/Colourimetric/ICP-OES
	Dissolved Magnesium (Mg)	mg/L	0.20	titration/IC/Colourimetric/ICP-OES
	Dissolved Manganese (Mn)	mg/L	0.0040	titration/IC/Colourimetric/ICP-OES
	Dissolved Potassium (K)	mg/L	0.30	titration/IC/Colourimetric/ICP-OES
	Dissolved Sodium (Na)	mg/L	0.50	titration/IC/Colourimetric/ICP-OES
Metals and trace elements (all sites and surveys)				
	Total Aluminum (Al)	mg/L	0.0030	ICP-MS/OES
	Total Antimony (Sb)	mg/L	0.00060	ICP-MS/OES
	Total Arsenic (As)	mg/L	0.00020	ICP-MS/OES
	Total Barium (Ba)	mg/L	0.010	ICP-MS/OES
	Total Beryllium (Be)	mg/L	0.0010	ICP-MS/OES
	Total Boron (B)	mg/L	0.020	ICP-MS/OES
	Total Cadmium (Cd)	ug/L	0.0050	ICP-MS/OES
	Total Chromium (Cr)	mg/L	0.0010	ICP-MS/OES
	Total Cobalt (Co)	mg/L	0.00030	ICP-MS/OES
	Total Copper (Cu)	mg/L	0.00020	ICP-MS/OES
	Dissolved Iron (Fe)	mg/L	0.060	ICP-MS/OES
	Total Iron (Fe)	mg/L	0.00020	ICP-MS/OES
	Total Lead (Pb)	mg/L	0.020	ICP-MS/OES
	Total Lithium (Li)	mg/L	0.0050	ICP-MS/OES
	Low level Mercury (Hg)	ug/L	0.005	EPA 1631E/245.1 R3m
	Total Molybdenum (Mo)	mg/L	0.00020	ICP-MS/OES
	Total Nickel (Ni)	mg/L	0.00050	ICP-MS/OES
	Total Selenium (Se)	mg/L	0.00020	ICP-MS/OES
	Total Silicon (Si)	mg/L	0.10	ICP-MS/OES
	Total Silver (Ag)	mg/L	0.00010	ICP-MS/OES
	Total Strontium (Sr)	mg/L	0.020	ICP-MS/OES
	Total Sulphur (S)	mg/L	0.20	ICP-MS/OES
	Total Thallium (Tl)	mg/L	0.00020	ICP-MS/OES
	Total Tin (Sn)	mg/L	0.0010	ICP-MS/OES
	Total Titanium (Ti)	mg/L	0.0010	ICP-MS/OES
	Total Uranium (U)	mg/L	0.00010	ICP-MS/OES
	Total Vanadium (V)	mg/L	0.0010	ICP-MS/OES
	Total Zinc (Zn)	mg/L	0.0030	ICP-MS/OES

Appendix I, continued.

Type	Variable	Unit	RDL[1]	Analytical Method
Pesticides (Scan 1) phenoxyalkyl compounds (V1, V5, V7, STR2 in July, August and October)				
	2,4,5-T	ug/L	0.080	GC-MS
	2,4,5-TP	ug/L	0.080	GC-MS
	2,4-D	ug/L	0.050	GC-MS
	2,4-DB	ug/L	0.080	GC-MS
	3,5-dichlorobenzoic acid	ug/L	0.080	GC-MS
	Bentazon	ug/L	0.080	GC-MS
	Bromoxynil	ug/L	0.020	GC-MS
	Chloramben	ug/L	0.080	GC-MS
	Dicamba	ug/L	0.0050	GC-MS
	Dichlorprop	ug/L	0.080	GC-MS
	Diclofop-methyl	ug/L	0.080	GC-MS
	Dinoseb (DNBP)	ug/L	0.080	GC-MS
	MCPA	ug/L	0.020	GC-MS
	MCPP	ug/L	0.080	GC-MS
	Pentachlorophenol	ug/L	0.080	GC-MS
	Picloram	ug/L	0.080	GC-MS
Pesticides (Scan 2) special request (V1, V5, V7, STR2 in July, August and October)				
	Diuron	ug/L	50	HPLC
	Temephos	ug/L	50	HPLC
	Guthion (Azinphos-methyl)	ug/L	10	HPLC
Pesticides (Scan 3) Organochlorine pesticides(V1, V5, V7, STR2 in July and August)				
	Aldrin + Dieldrin	ug/L	0.005	GC-ECD
	beta-BHC ug/L	ug/L	0.005	GC-ECD
	alpha-BHC	ug/L	0.005	GC-ECD
	Aroclor 1260	ug/L	0.05	GC-ECD
	Aroclor 1254	ug/L	0.05	GC-ECD
	Aroclor 1248	ug/L	0.05	GC-ECD
	Aroclor 1242	ug/L	0.05	GC-ECD
	Aroclor 1232	ug/L	0.05	GC-ECD
	Aroclor 1221	ug/L	0.05	GC-ECD
	Aroclor 1016	ug/L	0.05	GC-ECD
	Methoxychlor	ug/L	0.01	GC-ECD
	Hexachlorobenzene	ug/L	0.005	GC-ECD
	Heptachlor epoxide	ug/L	0.005	GC-ECD
	Heptachlor	ug/L	0.005	GC-ECD
	Endrin	ug/L	0.005	GC-ECD
	Endosulfan II	ug/L	0.005	GC-ECD
	Endosulfan I (alpha)	ug/L	0.005	GC-ECD
	Lindane ug/L	ug/L	0.003	GC-ECD
	p,p-DDT ug/L	ug/L	0.005	GC-ECD
	o,p-DDT	ug/L	0.005	GC-ECD
	p,p-DDE	ug/L	0.005	GC-ECD
	o,p-DDE	ug/L	0.005	GC-ECD
	p,p-DDD	ug/L	0.005	GC-ECD
	o,p-DDD	ug/L	0.005	GC-ECD
	g-Chlordane	ug/L	0.005	GC-ECD
	a-Chlordane	ug/L	0.005	GC-ECD
	Dieldrin	ug/L	0.005	GC-ECD
	Aldrin	ug/L	0.005	GC-ECD
	Total PCB	ug/L	0.05	GC-ECD
	Total Endosulfan	ug/L	0.005	GC-ECD
	o,p-DDT + p,p-DDT	ug/L	0.005	GC-ECD
	o,p-DDE + p,p-DDE	ug/L	0.005	GC-ECD
	o,p-DDD + p,p-DDD	ug/L	0.005	GC-ECD
	Heptachlor + Heptachlor epoxide	ug/L	0.005	GC-ECD
	DDT+ Metabolites	ug/L	0.005	GC-ECD
	Chlordane (Total)	ug/L	0.005	GC-ECD
	Toxaphene	ug/L	0.2	GC-ECD
	Oxychlordane	ug/L	0.005	GC-ECD
	Octachlorostyrene	ug/L	0.005	GC-ECD
	Mirex	ug/L	0.005	GC-ECD
	Endrin ketone	ug/L	0.005	GC-ECD
	Endrin aldehyde	ug/L	0.005	GC-ECD
	Endosulfan sulfate	ug/L	0.005	GC-ECD

Appendix I, completed.

Type	Variable	Unit	RDL(1)	Analytical Method
Semivolatile organics (V1, V5, V7, STR2 in October)				
	Methyl parathion		10	GC-MS
	Benzo(a)pyrene		0.090	GC-MS
	Trifluralin		10	GC-MS
	Triallate		10	GC-MS
	Terbufos		5.0	GC-MS
	Simazine		10	GC-MS
	Prometryne		2.5	GC-MS
	Picloram		50	GC-MS
	Phorate		5.0	GC-MS
	Pentachlorophenol		5.0	GC-MS
	Ethyl Parathion		10	GC-MS
	Metribuzin (Sencor)		50	GC-MS
	Metolachlor		5.0	GC-MS
	Malathion		50	GC-MS
	Dinoseb		10	GC-MS
	Dimethoate		25	GC-MS
	Diclofop-methyl		9.0	GC-MS
	Dicamba		10	GC-MS
	Diazinon		10	GC-MS
	Cyanazine (Bladex)		10	GC-MS
	Chlorpyrifos (Dursban)		10	GC-MS
	Carbofuran		50	GC-MS
	Carbaryl		50	GC-MS
	Bromoxynil		5.0	GC-MS
	Bendiocarb		20	GC-MS
	Atrazine + Desethyl-atrazine		10	GC-MS
	Des-ethyl atrazine		5.0	GC-MS
	Atrazine		5.0	GC-MS
	Aldicarb		50.0	GC-MS
	Alachlor		5.0	GC-MS
	2,4-Dichlorophenol		5.0	GC-MS
	2,4-D		10	GC-MS
	2,4,6-Trichlorophenol		5.0	GC-MS
	2,4,5-T		10	GC-MS
	2,3,4,6-Tetrachlorophenol		5.0	GC-MS

(1)RDL: reportable detection limit, (2) DST: defined substrate technology, (3)MPN stands for ‘most probable number’ (4)CFU stands for ‘colony forming units’

Appendix II. GOA (2014) Guidelines for Variables Measured in 2014.

Type	Variable	Unit	Guideline	Origin	Notes
TYPE	**Variable**	**Unit**	**Guideline**	**Origin**	**Notes**
Field Data and related variables					
	Flow velocity in m/s	m/s			
	Water column depth in cm	cm			
	DO	mg/L	5.0 mg/L	AEP 1997	short term guideline; 6.5 mg/L over long term; 8.3 mg/L for mid-May to end June to protect mayfly emergence; 9.5 mg/L for areas and times where larval fish develop within gravel beds
	Conductivity (Lab)	uS/cm			
	Conductivity (Field)	uS/mL			
	Temperature (Field)				
	pH (field)	pH	6.5 to 9.0	USEPA 1996	not altered more than 0.5 units from background
	Total Suspended Solids	mg/L	narrative	CCME 1999; BC 2001	
Biological measurements					
	Chlorophyll a	ug/L			
	E.Coli DST	mpc/100mL	100		Irrigation; 410 recreation threshold
	Fecal Coliforms	CFL/100mL	400	Health Canada	per sample, 200 for 5 sample geodetic mean
	Total Coliforms DST	mpn/100mL			
Nutrients					
	Dissolved Nitrate (N)	mg/L	3.0 mg/L	CCME 2012	long term guidelines; max 124 mg/L short-term to protect from toxicity only, no consideration for eutrophication
	Dissolved Nitrite (N)	mg/L	varies	BC 2001	dependent on chloride levels; no more than 0.60 mg/L if chloride greater than 10 mg/L; 10 mg/L guideline for livestock watering (CCME1987)
	Total Ammonia (N)	mg/L	0.016 mg/L	CCME 2001	unionized ammonia; total (NH3, NH4, N) equation varying with pH and temperature
	Nitrate plus Nitrite (N)	mg/L			
	Total Kjeldahl Nitrogen	mg/L			
	Total Nitrogen (N)	mg/L	narrative	GOA 2014	
	Dissolved Phosphorus (P)	mg/L			
	Total Phosphorus (P)	mg/L	narrative	GOA 2014	
Major ions and related variables					
	Total Dissolved Solids	mg/L	500 to 3500	CCME 1987	irrigation; 3000 for livestock
	Hardness (as CaCO3)	mg/L			
	Alkalinity (PP as CaCO3)	mg/L			
	Alkalinity (Total as CaCO3)	mg/L	20 mg/L	USEPA 1986	minimum, unless natural conditions are less
	Bicarbonate (HCO3)	mg/L			
	Carbonate (CO3)	mg/L			
	Dissolved Chloride (Cl)	mg/L	120 mg/L	CCME 2011	long term guideline; 640 mg/L short term
	Dissolved Fluoride (F)	mg/L			
	Dissolved Sulphate (SO4)	mg/L	varies	BC 2013	dependent on water hardness; max 429 mg/L for very hard water with 181-250 mg/L hard water deposits, 309 mg/L for moderate to hard water (76-180 mg/L deposits), 218 for soft to moderate water (31-75 mg/L deposits), 128 mg/L for very soft water (0-30 mg/L
	Hydroxide (OH)	mg/L			
	Dissolved Calcium (Ca)	mg/L			
	Dissolved Magnesium (Mg)	mg/L			
	Dissolved Manganese (Mn)	mg/L			
	Dissolved Potassium (K)	mg/L			
	Dissolved Sodium (Na)	mg/L			

Appendix II, completed.

TYPE	Variable	Unit	Guideline	Origin	Notes
Metals and trace elements					
	Total Aluminum (Al)	mg/L	5 mg/L	CCME 1987	for protection of agricultural uses: livestock water and irrigation
	Total Antimony (Sb)	mg/L			
	Total Arsenic (As)	ug/L	5 ug/L	CCME 1997	25 ug/L for livestock water, 160 ug/L for irrigation
	Total Barium (Ba)	mg/L			
	Total Beryllium (Be)	mg/L	100 ug/L	CCME 1987	both ag uses
	Total Boron (B)	mg/L	1.5 mg/L	CCME 1987	long term guideline, 29 mg/L short term PAL, 500-6000 ug/L for irrigation, 5000 ug/L for livestock water
	Total Cadmium (Cd)	ug/L	varies with hardness	CCME 1996	8.2 ug/L irrigation; 80 ug/L for livestock water
	Total Chromium (Cr)	ug/L	4.9 ug/L	CCME 1987	irrigation (Cr III); 8.0 (Cr IV); 50 ug/L for livestock water (both types)
	Total Cobalt (Co)	ug/L	2.5 ug/L	EnvCan 2013	long term guideline; 50 ug/L for irrigation; 1000 ug/L for livestock water (CCME 1987)
	Total Copper (Cu)	ug/L	7 ug/L	CCME 1987	200 to 1000 ug/L irrigation (200 for cereals, higher for more tolerant crops); 500 ug/L for sheep; 1000 ug/L for cattle; 5000 ug/L for swine and poultry
	Dissolved Iron (Fe)	mg/L	300 ug/L	CCME 1987	long term guideline
	Total Iron (Fe)	mg/L	5 mg/L	CCME 1987	for irrigation
	Total Lead (Pb)	ug/L	100 ug/L	CCME 1987	livestock water; 200 ug/L for irrigation
	Total Lithium (Li)	mg/L	2.5 mg/L	CCME 1987	for irrigation
	Total Mercury (Hg)	mg/L	3 ug/L	CCME 1987	livestock water
	Total Molybdenum (Mo)	ug/L	73 ug/L	CCME 1999	long term guideline; 10 ug/L for irrigation; 500 for livestock water (CCME 1987)
	Total Nickel (Ni)	ug/L	varies with hardness	USEPA 1995	PAL; varies with hardness; 200 ug/L for irrigation, 1000 for livestock water (CCME 1987)
	Total Selenium (Se)	ug/L	1 ug/L	CCME 1987	PAL longterm; 20 ug/L for continuour irrigation use; 50 ug/L for intermittent irrigation and livestock watering
	Total Silicon (Si)	mg/L			
	Total Silver (Ag)	mg/L	0.1 ug/L	CCME 1987	PAL longterm
	Total Strontium (Sr)	mg/L			
	Total Thallium (Tl)	mg/L	0.8 ug/L	CCME 1998	PAL longterm
	Total Tin (Sn)	mg/L			
	Total Titanium (Ti)	ug/L			
	Total Uranium (U)	ug/L	15 ug/L		PAL longterm: acute = 33; 10 = interim irrigation' 200 for livestock (CCME 1987)
	Total Vanadium (V)	ug/L	100	CCME 1987	both ag uses
	Total Zinc (Zn)	ug/L	30 ug/L		PAL longterm; 1 mg/L for irrigation when soil pH is less than 6.5; 5 mg/L when soil pH above 6.5; 50 mg/L for livestock (CCME 1987)
	Cyanide (CN)	ug/L	5.2	USEPA 1985	free Cyanide; can be applied to total or weak acid dissociable CN as precautionary or screening approach
Pesticides (only those with detections listed here - refer to Appendix 1 for full list analyzed)					
	2,4-D	ug/L	4	CCME 1987	
	Bromoxynil	ug/L	5	CCME1993	
	MCPA	ug/L	0.04	CCME1993	Irrigation; PAL: 2.6 ug/L

Appendix III. Analytical Results for Samples Collected in 2014. Values in bold indicate a guideline exceedance.

Variable	Unit	V1 (BEA1) 2014			V2 (MIN2A) 2014			V3 (TWO2A) 2014			V4 (EE010) 2014			V5 (VER1) 2014		
		08-Jul 3:15 PM	**28-Aug** 1:15 PM	**08-Oct** 2:00 PM	**08-Jul** 2:00 PM	**28-Aug** 12:00 PM	**08-Oct** 12:30 PM	**08-Jul** 12:30 PM	**28-Aug** 11:00am	**08-Oct** 2:00 PM	**08-Jul** 11:45 AM	**28-Aug** 10:00 AM	**08-Oct** 9:30 AM	**08-Jul** 10:00 AM	**27-Aug** 1:30 PM	**07-Oct** 1:00 PM
Field Data and related variables																
Flow velocity in m/s	m/s	no flow	no flow	no flow	no flow	no flow	no flow	no flow	no flow	no flow	no flow	no flow	no flow	0.33	no flow	no flow
Water column depth in cm	cm	68	124	no reading	no reading	no reading	no reading	103	94	no reading	74	21	no reading	86	120	no reading
DO	mg/L	8.96	**5.85**	10.22	6.52	6.81	9.87	5.8	7.85	9.8	10.43	9.35	8.52	5.32	7.6	7.86
Conductivity (Lab)	uS/cm	770	750	880	1400	1200	1600	1100	1600	1600	1000	1200	1300	1100	1200	1400
Conductivity (Field)	uS/mL	772	764	742	1360	1229	1292	1127	1596	1337	1029	1221	1026	1127	1133	1190.5
Temperature (Field)		24.6	17.3	8.8	23.6	18.8	8.2	24.8	19	8	21.8	17	8.1	21.8	19.2	9.9
pH (field)	pH	8.11	8.01	8.47	8.03	8.17	8.63	8.24	8.31	8.63	8.73	7.87	8.20	8.15	8.23	8.16
Total Suspended Solids	mg/L	4.7	19	16	10	6	19	2	4.7	24	2.7	5.3	9.3	10	11	11
Biological measurements																
Chlorophyll a	ug/L	16	24	30	28	20	27	5.7	11	89	10	17	46	7.1	9.3	13
E.coli DST	#/100mL	**230**	**410**	29	**130**	32	53	13	4.1	43	**130**	16	57	**120**	70	27
Fecal Coliforms	CFL/100mL	110	500	25	23	8	47	15	2	31	99	9	50	62	75	14
Total Coliforms DST	mpn/100mL	2400	2000	>2400	>2400	>2400	>2400	2000	>2400	550	1400	>2400	920	>2400	>2400	2400
Nutrients																
Dissolved Nitrate (N)	mg/L	<0.01	<0.01	<0.01	0.3	<0.01	<0.01	<0.01	<0.01	<0.01	0.015	<0.01	<0.01	0.018	<0.01	<0.01
Dissolved Nitrite (N)	mg/L	<0.01	<0.01	<0.01	0.049	<0.01	<0.01	<0.01	<0.01	<0.01	0.012	<0.01	<0.01	0.015	<0.01	<0.01
Total Ammonia (N)	mg/L	<0.05	<0.05	0.057	0.24	<0.05	0.094	0.3	0.055	0.05	0.054	0.058	<0.05	0.12	<0.05	<0.05
Nitrate plus Nitrite (N)	mg/L	<0.01	<0.01	<0.01	0.35	<0.01	<0.01	<0.01	<0.01	<0.01	0.027	<0.01	<0.01	0.033	<0.01	<0.01
Total Kjeldahl Nitrogen	mg/L	2.5	2.5	3	3.5	1.7	2.5	2.2	2.8	3.1	2.3	1.3	1.4	2.4	2.1	1.6
Total Nitrogen (N)	mg/L	2.5	2.5	3	3.8	1.7	2.5	no data	2.8	3.1	2.3	1.3	1.4	2.4	2.1	1.6
Dissolved Phosphorus (P)	mg/L	0.26	0.44	0.19	0.51	0.57	0.39	0.28	0.19	0.029	0.16	0.041	0.027	0.42	0.32	0.3
Total Phosphorus (P)	mg/L	0.34	0.52	0.39	0.63	0.69	0.52	0.32	0.23	0.16	0.18	0.074	0.078	0.49	0.43	0.43
Major ions and related variables																
Total Dissolved Solids	mg/L	450	460	530	910	780	990	730	1100	1000	680	860	820	720	770	870
Hardness (as CaCO3)	mg/L	150	140	160	300	260	290	280	310	290	320	520	470	340	290	260
Alkalinity (PP as CaCO3)	mg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	9.3	25	9.6	<0.5	<0.5	<0.5	6.7	6.1
Alkalinity (Total as CaCO3)	mg/L	230	290	310	350	340	520	250	400	350	270	280	350	430	410	530
Bicarbonate (HCO3)	mg/L	290	360	380	430	420	630	310	460	370	310	340	430	530	490	640
Carbonate (CO3)	mg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	11	30	12	<0.5	<0.5	<0.5	8.1	7.3
Dissolved Chloride (Cl)	mg/L	40	29	42	25	38	31	27	40	46	24	16	24	14	34	39
Dissolved Fluoride (F)	mg/L	0.21	0.26	0.26	0.24	0.22	0.26	0.21	0.25	0.24	0.18	0.14	0.18	0.22	0.24	0.29
Dissolved Sulphate (SO4)	mg/L	99	70	95	360	240	290	310	400	430	260	400	320	190	210	200
Hydroxide (OH)	mg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Dissolved Calcium (Ca)	mg/L	36	29	34	63	52	58	50	51	45	53	95	100	56	50	43
Dissolved Magnesium (Mg)	mg/L	15	15	17	34	32	35	37	45	44	45	68	54	48	41	37
Dissolved Manganese (Mn)	mg/L	<0.004	0.0048	<0.004	0.023	0.13	0.0047	0.24	0.13	0.01	0.066	0.38	0.073	0.053	0.02	0.032
Dissolved Potassium (K)	mg/L	21	25	23	15	11	15	19	23	21	19	14	12	12	14	11
Dissolved Sodium (Na)	mg/L	100	120	130	210	190	240	140	260	240	110	94	96	140	170	230

Appendix III, continued

		V6 (VER3)			V7 (VER6)			STR1			STR2		
			2014			2014			2014			2014	
		07-Jul	27-Aug	07-Oct	07-Jul	27-Aug	07-Oct	07-Jul	27-Aug	07-Oct	07-Jul	27-Aug	07-Oct
		3:20 PM	12:00 PM	12:30 PM	11:15 AM	9:30 AM	10:00 AM	2:00 PM	11:00 AM	11:30 AM	12:14 PM	10:30 PM	11:00 AM
Field Data and related variables													
Flow velocity	m/s	no flow	no flow	no flow	0.50	0.54	no flow	0.17	0.13	no flow	no flow	0.07	no flow
Water columr	cm	124	77	no reading	26	28	no reading	11	11	no reading	75	30	no reading
DO	mg/L	**2.88**	6.19	9.26	10.4	8.42	10.48	**4.5**	**1.59**	6.65	12.22	5.96	7.04
Conductivity (	uS/cm	1200	1200	1500	1100	1100	1100	730	720	800	1200	1400	1500
Conductivity (	uS/mL	1236	1212	1235	1124	1108	867.5	722	716	671.5	1212	1357	573
Temperature (Field)		23.4	18.1	9.2	21.7	16.5	7.5	19.9	16.1	8.4	22.9	15.3	6.6
pH (field)	pH	7.7	8.03	8.15	8.4	8.17	8.08	7.7	7.65	8.00	8.12	7.8	7.78
Total Suspend	mg/L	7.3	10	3.3	6	1.3	1.3	5.3	19	3.3	4	12	8
Biological measurements													
Chlorophyll a	ug/L	13	62	13	5.4	2.5	1.2	5.7	11	5.1	6.3	6.3	19
E.coli DST	#/100mL	22	58	**120**	93	**140**	7.4	35	25	0.5	41	27	19
Fecal Coliforn	CFL/100mL	52	75	87	120	84	11	24	15	1	10	14	0.5
Total Coliforn	mpn/100mL	2000	>2400	1300	>2400	>2400	1100	>2400	870	820	2400	1000	>2400
Nutrients													
Dissolved Nitr	mg/L	<0.01	<0.01	1.2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dissolved Nitr	mg/L	<0.01	0.019	0.072	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total Ammon	mg/L	0.051	0.48	0.18	<0.05	<0.05	0.063	0.061	0.1	0.075	<0.05	<0.05	<0.05
Nitrate plus N	mg/L	<0.01	0.019	1.3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total Kjeldahl	mg/L	1.9	2.9	1.9	1.5	1.3	0.77	2.6	3.8	2.7	1.4	1.2	1.2
Total Nitroger	mg/L	1.9	2.9	3.2	1.5	1.3	0.77	2.6	3.8	2.7	1.4	1.2	1.2
Dissolved Pho	mg/L	0.67	0.27	0.032	0.29	0.28	0.02	0.72	0.95	0.47	0.2	0.13	0.043
Total Phosphc	mg/L	0.74	0.39	0.069	0.31	0.3	0.046	0.8	1.2	0.56	0.24	0.29	0.22
Major ions and related variables													
Total Dissolve	mg/L	780	760	880	770	730	670	440	410	450	780	910	910
Hardness (as (	mg/L	340	310	380	400	330	320	320	310	340	520	550	550
Alkalinity (PP	mg/L	<0.5	<0.5	0.98	14	15	1.1	<0.5	<0.5	<0.5	3.5	<0.5	<0.5
Alkalinity (Tot	mg/L	450	410	410	410	430	390	320	380	430	430	490	530
Bicarbonate (I	mg/L	550	500	490	470	490	470	390	460	530	510	600	650
Carbonate (C(	mg/L	<0.5	<0.5	1.2	17	18	1.4	<0.5	<0.5	<0.5	<0.5	<0.5	4.2
Dissolved Chl	mg/L	26	38	110	26	27	27	9	10	12	42	29	44
Dissolved Fluc	mg/L	0.23	0.22	0.3	0.23	0.21	0.21	0.21	0.19	0.21	0.27	0.22	0.24
Dissolved Sulp	mg/L	220	210	220	220	200	180	73	5.7	9.7	220	270	240
Hydroxide (OI	mg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Dissolved Calc	mg/L	61	46	64	82	60	65	68	63	65	110	120	110
Dissolved Mag	mg/L	45	47	54	48	44	39	36	38	44	58	64	66
Dissolved Mar	mg/L	1.9	0.21	0.074	0.015	0.019	0.035	0.22	0.4	0.084	0.15	0.36	0.25
Dissolved Pot	mg/L	13	13	16	13	11	8.9	28	27	28	15	14	13
Dissolved Sod	mg/L	140	160	170	140	140	110	30	32	36	78	110	120

Appendix III, continued

Variable	Unit	V1 (BEA1) 2014			V2 (MIN2A) 2014			V3 (TWO2A) 2014			V4 (EE010) 2014			V5 (VER1) 2014		
		08-Jul	**28-Aug**	**08-Oct**	**08-Jul**	**28-Aug**	**08-Oct**	**08-Jul**	**28-Aug**	**08-Oct**	**08-Jul**	**28-Aug**	**08-Oct**	**08-Jul**	**27-Aug**	**07-Oct**
		3:15 PM	1:15 PM	2:00 PM	2:00 PM	12:00 PM	12:30 PM	12:30 PM	11:00am	2:00 PM	11:45 AM	10:00 AM	9:30 AM	10:00 AM	1:30 PM	1:00 PM
Metals and trace elements																
Total Aluminum (Al)	mg/L	0.022	0.047	0.049	0.33	0.039	0.2	0.015	0.031	0.048	0.032	0.025	0.042	0.31	0.17	0.23
Total Antimony (Sb)	mg/L	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006
Total Arsenic (As)	ug/L	3.7	**6**	4.4	**5.9**	**7.8**	**6.5**	2.4	2.6	2.2	2.6	1.1	0.9	4	4.1	3.9
Total Barium (Ba)	mg/L	0.031	0.037	0.036	0.059	0.043	0.043	0.055	0.019	0.024	0.039	0.054	0.049	0.063	0.061	0.046
Total Beryllium (Be)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Total Boron (B)	mg/L	0.033	0.04	0.039	0.18	0.12	0.11	0.18	0.17	0.13	0.17	0.13	0.13	0.27	0.32	0.45
Total Cadmium (Cd)	ug/L	<0.025	<0.02	<0.02	<0.025	<0.02	<0.02	<0.025	<0.02	<0.02	<0.025	<0.02	<0.02	<0.025	<0.02	<0.02
Total Chromium (Cr)	ug/L	<1.0	<1.0	5.1	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.2	<1.0	<1.0	<1.0	<1.0	<1.0
Total Cobalt (Co)	ug/L	0.53	0.45	0.47	1.10	0.50	0.69	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	0.68	0.48	0.56
Total Copper (Cu)	ug/L	1.9	0.93	1.1	2.5	0.99	2	0.51	0.5	1	0.99	0.34	0.84	1.9	1.5	1.8
Dissolved Iron (Fe)	mg/L	0.13	0.17	<0.06	0.41	0.32	<0.06	0.063	0.062	<0.06	0.1	0.15	<0.06	0.25	0.12	<0.06
Total Iron (Fe)	mg/L	0.4	0.53	0.46	0.97	0.59	0.7	0.1	0.42	0.15	0.21	0.3	0.46	0.66	0.42	0.53
Total Lead (Pb)	ug/L	<0.2	<0.2	<0.2	0.55	0.20	0.52	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.27	0.29	0.28
Total Lithium (Li)	mg/L	0.033	0.043	0.047	0.09	0.062	0.12	0.082	0.13	0.12	0.08	0.07	0.067	0.1	0.085	0.081
Total Mercury (Hg)	ug/L	<0.0050	<0.0050	<0.0050	0.0052	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.005
Total Molybdenum (Mo)	ug/L	1.1	0.83	1.1	1.3	1.1	1.4	0.25	0.36	0.72	0.59	0.31	1.5	0.72	0.81	1
Total Nickel (Ni)	ug/L	5.3	6.1	6.2	5.9	4.3	6.4	1.6	1.3	1.6	1.4	0.74	0.67	2.6	2.6	3.4
Total Selenium (Se)	ug/L	0.30	0.25	0.34	0.52	0.29	0.41	<0.2	<0.2	<0.2	0.22	<0.2	<0.2	0.22	<0.2	<0.2
Total Silicon (Si)	mg/L	0.48	1.5	0.53	5.6	3.3	3.2	2.2	6.4	2.5	4.3	1.5	3	8.2	3.2	1.7
Total Silver (Ag)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Total Strontium (Sr)	mg/L	0.25	0.27	0.27	0.68	0.53	0.53	0.57	0.63	0.54	0.54	0.58	0.6	0.59	0.56	0.46
Total Thallium (Tl)	mg/L	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Total Tin (Sn)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Total Titanium (Ti)	ug/L	1.3	<1.0	1.8	11	1.8	12	1	<1.0	1.8	<1.0	1.6	3	8.6	5.4	7.2
Total Uranium (U)	ug/L	1.00	0.73	1.30	2.20	2.00	5.20	0.23	0.66	1.20	1.00	1.40	1.50	1.30	1.20	1.70
Total Vanadium (V)	ug/L	2.3	1.5	1.5	5	2.6	3.6	1.5	0.5	1.5	2.2	0.5	1.1	4.1	4.5	3.8
Total Zinc (Zn)	ug/L	4.5	<3.0	<3.0	6.7	<3.0	4.4	5.1	<3.0	5.9	6.4	<3.0	<3.0	4.9	<3.0	7.4
Cyanide (CN)	ug/L	2.4	<2.0	<2.0	3.1	<2.0	2.4	3.3	<2.0	<2.0	2.7	<2.0	<2.0	2.4	2	2.4
Pesticides (only those with detections listed here - refer to Appendix 1 for full list analyzed)																
2,4-D	ug/L	<0.050	<0.050	<0.050										0.071	<0.050	<0.050
Bromoxynil	ug/L	<0.020	<0.020	<0.020										0.029	<0.020	<0.020
MCPA	ug/L	**0.073**	0.028	<0.020										**0.17**	<0.020	<0.020

Appendix III, completed.

		V6 (VER3) 2014			V7 (VER6) 2014			STR1 2014			STR2 2014		
		07-Jul	27-Aug	07-Oct	07-Jul	27-Aug	07-Oct	07-Jul	27-Aug	07-Oct	07-Jul	27-Aug	07-Oct
		3:20 PM	12:00 PM	12:30 PM	11:15 AM	9:30 AM	10:00 AM	2:00 PM	11:00 AM	11:30 AM	12:14 PM	10:30 PM	11:00 AM
Metals and trace elements													
Total Aluminu	mg/L	0.027	0.039	0.028	0.12	0.036	0.025	0.043	0.22	0.058	0.047	0.042	0.036
Total Antimor	mg/L	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006	<0.0006
Total Arsenic	ug/L	3.7	4.2	2	**5**	**5**	2.7	4.7	4.6	3.6	4	3.9	2.7
Total Barium (	mg/L	0.093	0.072	0.082	0.055	0.039	0.038	0.067	0.092	0.057	0.067	0.061	0.055
Total Berylliur	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Total Boron (E	mg/L	0.24	0.25	0.22	0.22	0.24	0.18	0.021	<0.020	<0.020	0.14	0.2	0.17
Total Cadmiur	ug/L	0.01	<0.02	<0.02	0.045	<0.02	<0.02	0.01	<0.02	<0.02	<0.005	<0.02	<0.02
Total Chromiu	ug/L	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Total Cobalt (	ug/L	0.67	0.32	0.37	0.43	<0.3	<0.3	0.54	0.70	0.43	0.57	0.37	0.32
Total Copper (	ug/L	0.89	0.83	0.85	3.1	2.2	1	1.3	0.97	0.75	1.1	0.8	0.67
Dissolved Iron	mg/L	0.33	0.18	<0.06	0.07	0.11	<0.06	0.11	0.46	<0.06	0.077	0.11	<0.06
Total Iron (Fe)	mg/L	0.48	0.33	0.13	0.28	0.16	0.2	0.37	1.1	0.33	0.49	0.73	1.1
Total Lead (Pt	ug/L	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.22	<0.2	<0.2	<0.2	<0.2
Total Lithium	mg/L	0.094	0.098	0.079	0.08	0.088	0.064	0.039	0.031	0.034	0.054	0.076	0.074
Total Mercury	ug/L	<0.005	<0.0050	<0.005	<0.005	<0.0050	<0.005	<0.005	<0.0050	<0.005	<0.005	<0.0050	<0.005
Total Molybde	ug/L	0.31	0.58	1.9	0.94	0.86	1.4	0.66	<0.2	0.2	1.4	0.86	0.87
Total Nickel (N	ug/L	1.9	1.7	2.2	3	2	1.2	2.4	1.9	1.6	4.1	2.4	2.4
Total Seleniur	ug/L	0.31	0.22	0.21	0.31	0.25	<0.2	0.32	0.22	0.20	0.41	0.27	0.24
Total Silicon (S	mg/L	8.1	6.7	3.6	3.9	1.8	0.93	4.2	4.4	0.45	3.1	4.9	3.2
Total Silver (A	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Total Strontiu	mg/L	0.6	0.53	0.64	0.59	0.59	0.55	0.3	0.31	0.31	0.66	0.89	0.86
Total Thallium	mg/L	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Total Tin (Sn)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Total Titaniun	ug/L	2.5	1.2	1.3	5	1.1	1	2.4	5.6	2.7	2.5	1.5	1.7
Total Uranium	ug/L	0.66	0.60	1.40	1.20	0.85	1.40	0.77	0.31	0.61	1.90	1.10	1.50
Total Vanadiu	ug/L	2.6	2	1.4	4.3	2.6	0.5	3.4	2.6	1	3.4	1.8	1.1
Total Zinc (Zn)	ug/L	4.9	3.2	4.1	4.1	<3.0	<3.0	34	24	<3.0	<3.0	<3.0	<3.0
Cyanide (CN)	ug/L	<2.0	<2.0	<2.0	<2.0	<2.0	2.3	2.6	2.3	2.4	<2.0	2.4	<2.0
Pesticides (only those with detections listed here - refer to Appendix 1 for full list analyzed)													
2,4-D	ug/L				0.064	<0.050	<0.050				<0.050	<0.050	<0.050
Bromoxynil	ug/L				<0.020	<0.020	<0.020				<0.020	<0.020	<0.020
MCPA	ug/L				**0.068**	<0.020	<0.020				0.03	<0.020	<0.020

Appendix IV. Correlation Matrix (Pearson Correlation Coefficients) for variables monitored in 2014

	DO	EC (Lab)	EC (field)	Field T	pH	TSS	Chl-a	E. coli	Total Ammonia	Nitrate plus Nitrite	TKN	TN	TPP	TDP	TP	TDS	Hardness	Alkalinity	HCO3	Cl	F	SO4
DO	1.00																					
EC (Lab)	0.29	1.00																				
EC (field)	0.18	0.72	1.00																			
Field T	-0.25	-0.31	0.24	1.00																		
pH	0.68	0.29	0.31	-0.13	1.00																	
TSS	-0.18	0.12	0.00	-0.32	0.14	1.00																
Chl-a	0.11	0.34	0.19	-0.31	0.31	0.61	1.00															
E. coli	0.01	-0.33	-0.19	0.27	0.09	0.17	0.03	1.00														
Total Ammonia	-0.20	0.11	0.21	0.30	-0.10	-0.09	0.29	0.23	1.00													
Nitrate plus Nitrite	0.38	0.84	0.39	-0.85	-0.23	-0.48	-0.26	0.26	-0.11	1.00												
TKN	-0.37	-0.23	-0.05	0.16	0.10	0.50	0.37	0.14	0.20	-0.44	1.00											
TN	-0.32	-0.13	0.00	0.11	0.10	0.43	0.34	0.18	0.34	0.47	0.95	1.00										
TPP	-0.41	-0.02	-0.27	-0.32	-0.24	0.69	0.29	-0.19	0.04	-0.31	0.46	0.39	1.00									
TDP	-0.74	-0.49	-0.21	0.39	-0.42	0.19	-0.24	0.06	-0.02	-0.56	0.52	0.43	0.35	1.00								
TP	-0.76	-0.45	-0.25	0.28	-0.43	0.33	-0.15	0.01	-0.01	-0.54	0.57	0.47	0.55	0.98	1.00							
TDS	0.30	0.98	0.80	-0.16	0.31	0.05	0.28	-0.33	0.09	0.69	-0.26	-0.19	-0.13	-0.49	-0.47	1.00						
Hardness	0.11	0.40	0.17	-0.13	-0.31	-0.27	-0.14	-0.45	-0.08	0.78	-0.56	-0.51	-0.13	-0.35	-0.35	0.43	1.00					
Alkalinity	-0.06	0.52	0.19	-0.41	-0.15	0.13	-0.11	-0.36	-0.02	0.26	-0.29	-0.28	0.26	-0.01	0.05	0.45	0.42	1.00				
HCO3	-0.13	0.47	0.13	-0.40	-0.23	0.11	-0.15	-0.34	0.03	0.21	-0.29	-0.28	0.30	0.04	0.10	0.39	0.41	0.99	1.00			
Cl	0.37	0.47	0.25	-0.28	0.24	-0.05	0.19	0.10	0.19	0.94	-0.12	0.13	-0.06	-0.47	-0.43	0.37	-0.01	0.14	0.11	1.00		
F	0.18	0.37	0.20	-0.21	0.21	0.24	0.05	0.15	0.11	0.92	0.08	0.21	0.17	-0.06	-0.02	0.27	-0.24	0.45	0.43	0.65	1.00	
SO4	0.34	0.80	0.77	0.03	0.37	-0.01	0.37	-0.25	0.08	0.00	-0.19	-0.17	-0.29	-0.53	-0.54	0.88	0.36	0.02	-0.04	0.19	-0.06	1.00
Ca	0.11	0.28	0.05	-0.12	-0.37	-0.23	-0.20	-0.38	-0.23	0.72	-0.56	-0.54	-0.06	-0.28	-0.26	0.30	0.96	0.37	0.38	-0.08	-0.24	0.24
Mg	0.09	0.49	0.30	-0.15	-0.22	-0.27	-0.06	-0.48	0.03	0.43	-0.50	-0.43	-0.19	-0.40	-0.40	0.53	0.95	0.44	0.41	0.07	-0.22	0.46
Mn	-0.50	-0.06	0.06	0.28	-0.49	-0.06	-0.10	-0.24	-0.14	-0.22	-0.05	-0.08	0.07	0.34	0.32	-0.03	0.14	0.11	0.14	-0.12	-0.13	-0.04
K	-0.28	-0.52	-0.42	0.04	-0.07	0.25	0.03	0.15	-0.29	0.21	0.68	0.63	0.26	0.39	0.41	-0.55	-0.38	-0.41	-0.41	-0.17	-0.03	-0.44
Na	0.23	0.76	0.71	-0.09	0.54	0.27	0.38	-0.02	0.16	0.39	0.10	0.14	0.00	-0.24	-0.22	0.76	-0.25	0.26	0.20	0.41	0.52	0.63
Al	-0.24	0.10	0.15	0.10	0.02	0.37	-0.05	0.06	0.09	-0.26	0.38	0.36	0.34	0.41	0.45	0.09	-0.14	0.31	0.33	-0.24	0.19	-0.03
As	-0.22	-0.20	-0.02	0.24	-0.01	0.26	-0.12	0.29	0.15	-0.45	0.25	0.19	0.32	0.62	0.63	-0.21	-0.43	0.14	0.17	-0.18	0.29	-0.35
Ba	-0.55	-0.15	-0.08	0.20	-0.62	-0.06	-0.22	-0.21	0.30	0.64	0.05	0.15	0.18	0.47	0.46	-0.18	0.35	0.27	0.32	0.00	-0.02	-0.30
B	-0.13	0.41	0.41	-0.02	-0.02	-0.14	-0.17	-0.26	0.45	-0.10	-0.27	-0.21	-0.05	-0.05	-0.06	0.42	0.18	0.59	0.57	0.11	0.23	0.17
Co	-0.21	0.05	0.29	0.40	0.00	0.21	-0.05	0.04	-0.16	-0.24	0.51	0.46	0.07	0.53	0.50	0.09	-0.21	-0.11	-0.11	-0.35	-0.08	0.26
Cu	0.17	-0.03	0.08	0.24	0.26	0.05	-0.13	0.30	0.05	-0.22	0.06	0.05	-0.08	0.21	0.17	-0.01	-0.22	0.17	0.14	-0.12	0.21	-0.09
Dissolved Fe	-0.64	-0.11	-0.11	-0.06	-0.48	0.54	0.27	-0.03	0.00	0.89	0.54	0.57	0.68	0.74	0.78	-0.17	-0.20	0.11	0.18	-0.33	-0.08	-0.22
Total Fe	-0.45	0.07	-0.18	-0.05	-0.43	0.42	-0.05	-0.03	-0.02	-0.33	0.23	0.17	0.71	0.42	0.53	0.03	0.17	0.38	0.45	-0.23	0.08	-0.15
Pb	0.50	0.70	0.62	-0.08	0.46	0.26	0.78	0.51	0.55	1.00	0.34	0.40	-0.21	-0.29	-0.28	0.68	0.10	0.19	0.20	0.07	0.39	0.73
Li	0.15	0.80	0.78	-0.01	0.45	0.13	0.33	-0.20	0.16	-0.60	0.00	0.02	-0.18	-0.30	-0.31	0.85	0.11	0.36	0.29	0.21	0.22	0.76
Mo	0.49	0.25	0.02	-0.33	0.19	0.10	0.07	0.18	0.03	0.96	-0.22	-0.02	0.06	-0.28	-0.25	0.14	0.04	0.17	0.17	0.55	0.45	-0.02
Ni	0.13	-0.11	-0.10	0.09	0.19	0.39	0.03	0.48	0.03	0.08	0.29	0.27	0.33	0.24	0.29	-0.15	-0.50	-0.04	0.00	0.11	0.51	-0.24
Se	0.27	0.30	0.38	0.27	0.16	0.16	0.13	-0.06	-0.01	-0.03	0.14	0.11	0.04	0.10	0.10	0.33	-0.04	-0.01	-0.01	-0.08	0.33	0.46
Si	-0.47	0.28	0.47	0.43	-0.19	0.04	0.03	-0.12	0.26	-0.65	0.21	0.22	0.01	0.32	0.29	0.33	0.21	0.28	0.28	-0.08	0.02	0.24
Sr	0.14	0.75	0.53	-0.02	-0.04	-0.21	-0.04	-0.32	0.26	0.59	-0.51	-0.43	-0.15	-0.45	-0.44	0.78	0.75	0.49	0.46	0.23	0.06	0.67
Ti	-0.10	0.25	0.27	0.07	0.23	0.42	-0.03	0.17	-0.03	-0.39	0.37	0.34	0.22	0.37	0.38	0.24	-0.16	0.35	0.36	-0.23	0.26	0.10
U	0.41	0.48	0.27	-0.30	0.38	0.27	0.12	-0.06	-0.12	0.32	-0.10	-0.08	0.11	-0.10	-0.07	0.43	0.06	0.37	0.38	0.13	0.30	0.28
V	-0.11	-0.02	0.18	0.44	0.07	0.14	-0.16	0.14	0.17	-0.38	0.19	0.16	0.10	0.48	0.45	0.00	-0.14	0.23	0.23	-0.17	0.26	-0.09
Zn	-0.53	-0.59	-0.71	0.02	-0.56	0.08	-0.24	-0.33	-0.33	-0.21	0.37	0.26	0.39	0.69	0.68	-0.65	0.04	-0.16	-0.14	-0.42	-0.34	-0.61

Appendix IV, completed.

	Ca	Mg	Mn	K	Na	Al	As	Ba	B	Co	Cu	Diss. Fe	Fe	Pb	Li	Mo	Ni	Se	Si	Sr	Ti	U	V	Zn	CN
DO																									
EC (Lab)																									
EC (field)																									
Field T																									
pH																									
TSS																									
Chl-a																									
E. coli																									
Total Ammonia																									
Nitrate plus Nitrite																									
TKN																									
TN																									
TPP																									
TDP																									
TP																									
TDS																									
Hardness																									
Alkalinity																									
HCO3																									
Cl																									
F																									
SO4																									
Ca	1.00																								
Mg	0.82	1.00																							
Mn	0.11	0.16	1.00																						
K	-0.32	-0.41	-0.05	1.00																					
Na	-0.36	-0.10	-0.16	-0.35	1.00																				
Al	-0.13	-0.13	-0.21	-0.12	0.26	1.00																			
As	-0.30	-0.52	-0.09	0.02	0.16	0.38	1.00																		
Ba	0.32	0.34	0.55	-0.05	-0.41	0.21	0.02	1.00																	
B	0.02	0.35	0.07	-0.64	0.39	0.43	-0.10	0.32	1.00																
Co	-0.16	-0.26	0.10	-0.01	0.23	0.73	0.39	0.12	0.01	1.00															
Cu	-0.15	-0.28	-0.27	-0.25	0.22	0.59	0.51	-0.07	0.21	0.49	1.00														
Dissolved Fe	-0.16	-0.21	0.33	0.00	-0.01	0.59	0.44	0.52	0.10	0.69	0.07	1.00													
Total Fe	0.28	0.04	0.11	0.01	-0.05	0.55	0.37	0.28	-0.01	0.44	0.10	0.79	1.00												
Pb	0.42	-0.29	-0.52	-0.08	0.55	0.49	0.24	-0.29	-0.40	0.73	0.84	0.21	0.25	1.00											
Li	-0.07	0.30	0.02	-0.42	0.82	0.19	-0.11	-0.20	0.46	0.19	0.12	-0.16	-0.12	0.66	1.00										
Mo	0.15	-0.08	-0.36	-0.35	0.14	0.19	0.15	0.01	-0.08	0.16	0.32	0.22	0.17	0.75	-0.11	1.00									
Ni	-0.33	-0.65	-0.21	0.11	0.23	0.34	0.71	-0.20	-0.34	0.38	0.46	0.24	0.36	0.84	-0.17	0.41	1.00								
Se	0.10	-0.21	0.00	-0.15	0.40	0.38	0.46	-0.12	-0.28	0.69	0.48	0.16	0.28	0.91	0.19	0.42	0.67	1.00							
Si	0.11	0.31	0.46	-0.19	0.21	0.32	0.09	0.47	0.32	0.31	0.05	0.36	0.29	0.08	0.51	-0.19	-0.19	0.02	1.00						
Sr	0.67	0.77	0.10	-0.65	0.31	0.00	-0.24	0.13	0.42	-0.04	-0.06	-0.15	0.17	0.57	0.56	0.12	-0.30	0.12	0.42	1.00					
Ti	-0.14	-0.18	-0.20	-0.09	0.41	0.92	0.45	0.07	0.26	0.74	0.60	0.54	0.51	0.87	0.36	0.21	0.50	0.54	0.32	0.01	1.00				
U	0.11	-0.01	-0.24	-0.34	0.43	0.36	0.35	-0.17	-0.07	0.33	0.35	0.18	0.27	0.70	0.32	0.54	0.52	0.59	-0.07	0.19	0.63	1.00			
V	-0.10	-0.18	-0.07	-0.20	0.18	0.73	0.58	0.28	0.35	0.65	0.79	0.29	0.29	0.61	0.11	0.19	0.44	0.65	0.34	0.01	0.72	0.33	1.00		
Zn	0.31	-0.17	0.02	0.78	-0.68	0.03	0.21	0.31	-0.41	0.08	-0.15	0.16	0.30	-0.55	-0.64	-0.15	-0.17	-0.04	-0.02	-0.63	-0.07	-0.25	0.11	1.00	

For more information on this report, please contact:
North Saskatchewan Watershed Alliance
#202 – 9440 49th St. NW
Edmonton, AB T6B 2M9