# Water Quality in Alberta's Irrigation Districts 2011 to 2015

# 2014 Progress Report

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Editors

Water Quality Branch

Irrigation and Farm Water Division

Alberta Agriculture and Forestry

2015

**Report citation**
Charest, J., Olson, B., Kalischuk, A., and Gross, D. (eds.). 2015. Water Quality in Alberta's Irrigation Districts 2011 to 2015: 2014 Progress Report. Alberta Agriculture and Forestry, Lethbridge, Alberta, Canada. 215 pp.

**Chapter citation example**
Villeneuve, J. and Charest, J. 2014. Irrigation Return Load Impacts on Rivers. Pages 81-115 *in* Charest, J., Olson, B., Kalischuk, A., and Gross, D. (eds.), Water Quality in Alberta's Irrigation Districts 2011 to 2015: 2014 Progress Report. Alberta Agriculture and Forestry, Lethbridge, Alberta, Canada.

**Published by**
Irrigation and Farm Water Division
Alberta Agriculture and Forestry
Lethbridge, Alberta, Canada



Printed in Canada

**Copies of this report are available from**
Water Quality Branch
Alberta Agriculture and Forestry
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# Water Quality in Alberta's Irrigation Districts Project

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# Acknowledgements

We are very grateful to the Alberta Irrigation Council and the Alberta Irrigation Projects Association for providing financial support. Also, thanks to the Eastern Irrigation District for leadership and administrative support. Thanks to Agriculture and Agri-Food Canada (AAFC) for pesticide analysis, Environment Canada (EC) for veterinary pharmaceutical analysis, and Alberta Health Services (AHS) for pathogen analysis.

This project required support from numerous individuals, including Alberta Agriculture and Forestry staff Christian Blott, Janna Casson, Brian Coffey, Brian Cook, Michael Ellefson, Paul Graveland, Adele Harding, Bonnie Hofer, Mark Kadijk, Madison Kobryn, Gyan Mankee, Gerald Ontkean, Troy Ormann, Ravinder Pannu, Murray Peters, Wally Sawchuk, Lawrence Schinkel, Lisa Tymensen, Deb Werk, and Bob Winter; as well as from AAFC staff; Monique Dawson, Kyo Farrington, Ryan Kong, Tanner Lohr, Denise Nilsson, Scott Spengler, and Tara Vucurevich; and AHS staff Shannon Braithwaite, Lorraine Ingham, and Norman Neumann. We are grateful for the collaboration with the Taber Irrigation District and support form Chris Gallagher, Brenda Pyrch, and Fred Williams. We appreciate the collaboration with AAFC and EC staff on the larger veterinary pharmaceutical project, in particular Allan Cessna (AAFC), John Headley (EC), and Tim McAllister (AAFC).

We are also grateful to the landowners who gave permission to enter on their land so we could access some of the sampling sites.

# Executive Summary

## Introduction

More than 65% of Canada's irrigation occurs in Alberta's 13 irrigation districts. The districts encompass approximately 8,000 km of district- and government-owned irrigation infrastructure and more than 55 reservoirs serving 555,220 ha of irrigated agricultural land.

Irrigation is essential for high agricultural production and crop diversity in southern Alberta. The irrigation conveyance network supplies water to thousands of rural homes and more than 30 communities for household potable water, municipal pools, parks, and industrial use including food processing plants and factories. The conveyance network also supplies water for several other uses including livestock production, wildlife habitat, and recreational activities such as fishing, boating, and camping on irrigation reservoirs.

Good quality irrigation water is needed for all uses. High yielding and safe food production requires low concentrations of herbicides and pathogens. Low nutrient concentrations in water help prevent the growth of aquatic weeds and algae that would otherwise impede water conveyance. Good quality water is also important to minimize treatment costs for rural communities.

A five-year study (2011 to 2015) is being conducted to assess the quality of irrigation water within Alberta's irrigation districts. This report summarizes activities and findings of the 2014 sampling season, which was the fourth year of the study. New to the study in 2014 was a case study to better understand the effects of landscape and canal characteristics on water quality along the conveyance system, and two synoptic surveys on the Oldman River to study the cumulative effects of irrigation returns on the river water quality.

## Objectives

The objectives of monitoring were to assess the:

- quality of source water used for irrigation and livestock watering,
- quality of irrigation water for recreational use and for the protection of aquatic life,
- changes in water quality as water travels through the irrigation infrastructure,
- differences in water quality among the irrigation districts, and the
- cumulative impact of irrigation returns on rivers.

## Methods

In 2014, water quality sampling methods remained essentially unchanged from 2013. A total of 90 sites were grab-sampled four times between June and September (June 10 to 12, July 7 to 10, August 6 to 8, and September 2 to 4). Each sample was analyzed for more than 160 water quality parameters including nutrients, salinity, physical parameters, metals, fecal indicator bacteria, and pesticides. In 2014, two new pesticides, clodinafop-propargyl and propiconazole, were added to the analytical suite. The herbicide glyphosate (Roundup®) and two other related compounds were analyzed for a reduced number of sites, and only during the first and last sampling events because of the expensive analytical cost.

In 2012, a qualitative analysis of fecal pathogen was initiated and added to the study. The analysis included Salmonella, Campylobacter, and Escherichia coli (E. coli) O157:H7. In 2014, a quantitative assessment of these pathogens was completed. A total of 21 sites were monitored twice, once in July and again in August.

In 2013, Agriculture and Agri-Food Canada (AAFC) approached Alberta Agriculture and Forestry to participate in an assessment for the presence of veterinary pharmaceuticals in southern Alberta surface water. Veterinary antimicrobials are used therapeutically to treat disease and sub-therapeutically to prevent disease and promote growth in livestock production. During the past decade, the use of veterinary antimicrobials has received increased attention because of growing bacterial resistance to antimicrobials used in human medicine and the effect that this may have on the treatment of infectious diseases. In 2014, the monitoring of veterinary pharmaceuticals continued and 24 secondary and irrigation return sites of eight irrigation districts (MVID, UID, LNID, TID, SMRID, WID, BRID, and EID) were sampled. Samples were collected for each of the four sampling events. Each sample was analyzed for seven livestock pharmaceuticals (chlortetracycline, erythromycin, lincomycin, monensin, sulfamethazine, tylosin, and tetracycline) by the National Hydrology Research Centre of Environment Canada in Saskatoon, Saskatchewan.

Sampling sites were categorized by the following types:

- **Alberta Environmental and Parks - AEP** (n = 3): government-owned infrastructure where water is diverted from a river.
- **Primary** (n = 14): main canals where source water enters the district.
- **Secondary** (n = 32): lateral canals that branch off from a main canal or a lateral canal that is immediately downstream from a reservoir.
- **Return** (n = 41): at the end of the irrigation district infrastructure after which water is no longer used for irrigation. There are two types of returns:
  - Watershed returns (n = 19): natural channels that collect natural drainage, and in some cases, municipal discharge.
  - Infrastructure returns (n = 22): constructed canals that are generally less influenced by surface runoff than watershed returns.

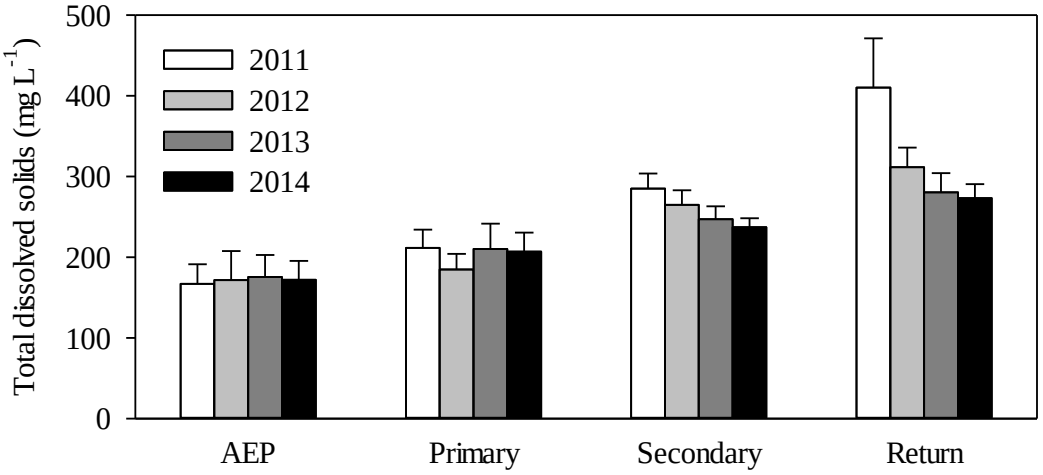
## Irrigation water quality results

### Nutrients

The average concentrations of total phosphorus (TP) and total dissolved phosphorus (TDP) among all sites (n=357) in 2014 were 0.062 and 0.039 mg $L^{-1}$, respectively. The average concentration of TP in 2014 was lower than in 2011 but higher than in 2012 and 2013. Total dissolved phosphorus concentrations represented more than half of TP at most sites except for the AEP sites where 37% of the TP was in dissolved forms. The proportion of samples that had TDP concentrations less than the method detection limit of 0.005 mg $L^{-1}$ decreased from 22% in 2013 to 12% in 2014, supporting a general increase in TDP concentration since 2012. The average concentration of total nitrogen (TN) among all sites (n=357) was 0.50 mg $L^{-1}$ in 2014, which was higher than in 2013 (0.49 mg $L^{-1}$) but less than in 2011 (0.59 mg $L^{-1}$) or 2012 (0.54 mg $L^{-1}$). There was an increase in average concentrations of N from primary to secondary to return sites in 2014, but the increases were generally less compared to previous years.

### Salinity

In 2014, total dissolved solids (TDS) concentration ranged from 89 to 981 mg $L^{-1}$ and averaged 247 mg $L^{-1}$. The average concentration of TDS in 2014 was less as than the three previous years. A decreasing trend with time was especially noticeable in secondary and return sites. Average TDS concentration increased from the AEP or primary sites to the return sites, but not as much as in previous years. There were lower TDS concentrations in the more westerly districts (MVID, AID, UID, MID, LNID) compared to the other districts.




**Average total dissolved solids concentrations for different site types from 2011 to 2014. Error bars indicate the 90% confidence intervals.**

| Average values of selected water quality parameters measured in 2014. | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site type | MVID | AID | UID | MID | RID | LNID | TID | SMRID | RCID | WID | BRID | EID |
| **Total Phosphorus (mg $L^{-1}$)** | | | | | | | | | | | | |
| AEP | - | - | - | 0.016 | - | - | - | - | - | 0.023 | 0.013 | - |
| Primary | 0.017 | - | 0.004 | 0.016 | 0.020 | 0.028 | 0.043 | 0.045 | 0.355 | 0.013 | 0.009 | 0.019 |
| Secondary | - | - | 0.019 | 0.116 | - | 0.037 | 0.053 | 0.061 | - | 0.032 | 0.037 | 0.042 |
| Return | 0.020 | 0.023 | 0.083 | 0.104 | 0.186 | 0.095 | 0.062 | 0.099 | - | 0.077 | 0.068 | 0.074 |
| **Total Nitrogen (mg $L^{-1}$)** | | | | | | | | | | | | |
| AEP | - | - | - | 0.163 | - | - | - | - | - | 0.350 | 0.685 | - |
| Primary | 0.293 | - | 0.173 | 0.278 | 0.288 | 0.265 | 0.303 | 0.444 | 1.695 | 0.288 | 0.318 | 0.538 |
| Secondary | - | - | 0.288 | 0.315 | - | 0.360 | 0.637 | 0.610 | - | 0.338 | 0.679 | 0.466 |
| Return | 0.295 | 0.380 | 0.340 | 0.583 | 0.520 | 0.496 | 0.663 | 0.674 | - | 0.448 | 0.633 | 0.473 |
| **Total Suspended Solids (mg $L^{-1}$)** | | | | | | | | | | | | |
| AEP | | | | 16.5 | | | | | | 16.0 | 11.8 | |
| Primary | 3.4 | | 10.1 | 4.5 | 7.5 | 19.8 | 4.3 | 8.9 | 7.3 | 6.1 | 2.3 | 12.5 |
| Secondary | | | 2.4 | 18.0 | | 7.8 | 5.0 | 10.8 | | 8.9 | 6.0 | 10.6 |
| Return | 6.3 | 4.1 | 75.5 | 60.0 | 28.0 | 52.6 | 6.6 | 14.8 | | 6.9 | 6.1 | 20.4 |
| **Total Dissolved Solids (mg $L^{-1}$)** | | | | | | | | | | | | |
| AEP | - | - | - | 108 | - | - | - | - | - | 212 | 197 | - |
| Primary | 144 | - | 102 | 121 | 139 | 157 | 179 | 176 | 510 | 240 | 328 | 201 |
| Secondary | - | - | 123 | 184 | - | 197 | 232 | 189 | - | 256 | 357 | 230 |
| Return | 149 | 147 | 136 | 349 | 341 | 207 | 262 | 215 | - | 354 | 419 | 279 |
| **Fecal Coliforms (% guideline exceedance)*** | | | | | | | | | | | | |
| AEP | - | - | - | 0 | - | - | - | - | - | 50 | 25 | - |
| Primary | 0 | - | 0 | 0 | 0 | 50 | 25 | 0 | 25 | 0 | 0 | 25 |
| Secondary | - | - | 0 | 25 | - | 15 | 9 | 0 | - | 19 | 0 | 0 |
| Return | 25 | 100 | 55 | 100 | 75 | 60 | 0 | 43 | - | 63 | 42 | 35 |
| **Number of Samples** | | | | | | | | | | | | |
| AEP | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 |
| Primary | 4 | 0 | 4 | 4 | 4 | 4 | 4 | 11 | 4 | 8 | 4 | 4 |
| Secondary | 0 | 0 | 4 | 4 | 0 | 20 | 11 | 20 | 0 | 16 | 20 | 32 |
| Return | 4 | 4 | 11 | 4 | 8 | 16 | 8 | 28 | 0 | 8 | 24 | 48 |

*Fecal coliforms are presented as the % of samples that exceed the water quality guidelines of 100 CFU 100 $mL^{-1}$ for irrigation.

The irrigation guideline for TDS ranges from 500 mg $L^{-1}$ for strawberries, raspberries, beans, and carrots to 3,500 mg $L^{-1}$ for other crops including oat, rye, wheat, sugar beet, and barley. The irrigation guideline of 500 mg $L^{-1}$ was exceeded in 3.1% (11/357) of the samples in 2014, signifying minimal concern.

## Metals

All 25 metals analyzed were detected in 2014. Beryllium, tin, and thallium were detected in only three to nine samples (0.9 to 2.6% detection frequency). The detection frequency of mercury, on the other hand, increased from 0.6% in 2013 to 14.6% in 2014. However, this increase in detection frequency does not reflect an increase in mercury concentration, but rather a decrease

in the laboratory detection limit, which changed from 0.1 µg $L^{-1}$ in 2011, 2012, and 2013 to 0.005 µg $L^{-1}$ in 2014.

Irrigation and/or livestock watering guidelines exist for 19 of the 25 metals analyzed. The highest concentrations measured for most of the metals were well below irrigation guidelines in 2014. However, chromium, copper, and boron exceeded irrigation guidelines in one to seven of 351 samples (0.3 to 2% detection frequency). The metals that exceeded irrigation guidelines were most likely from geological sources as they were typically well correlated with total suspended solids (TSS). The livestock water guidelines were not exceeded in 2014.

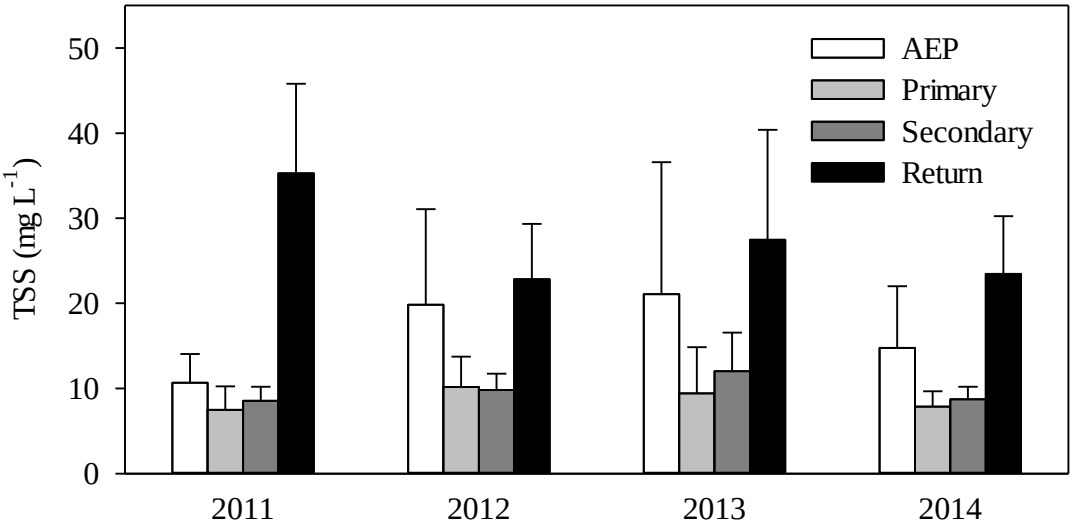
Protection of aquatic life guidelines exist for 16 of the analyzed metals, and nine of these were exceeded at least once in 2014. Frequency of guideline exceedance was the highest for aluminum (60%), iron (27%), and chromium (6%). The protection of aquatic life guidelines were less frequently exceeded in 2014 as compared to 2013.

**Physical parameters and pH**

The average sample temperature was 18.6°C in 2014 as compared to 19.4°C in 2013, 17.7°C in 2012, and 19.9°C in 2011. As in the previous years (2011–2013), on average, water temperature was cooler at the AEP and primary sites compared to the secondary and return sites. This trend probably reflects the size of the canals and the travel time required for the water to warm.

Fifteen degree celsius is a critical temperature for the development and control of zebra and quagga mussels that are potential invasive species that would be detrimental to the irrigation industry if they become established. Zebra and quagga mussels can spawn at 12ºC and 9ºC, respectively. During the first sampling event from June 10 to 12, 2014, 74% of the samples had water temperatures greater than 15°C. The proportion increased to 96 and 97% in early July and August, respectively, but decreased to 41% in early September.

Total suspended solids ranged from 1 to 423 mg $L^{-1}$ in 2014. The average concentration was 15.5 mg $L^{-1}$, which was lower than previous years. The highest average TSS values were at the return sites and there was a decrease in concentration from the AEP to the primary sites. The reduction in TSS concentration could be explained by the sedimentation in Chestermere, McGregor, Travers, and St. Mary reservoirs between the AEP and primary sites. Concentrations of TSS were highest in early July for the AEP, primary, and secondary sites, and this could be explained by the precipitation event at the end of June 2014.




**Average concentration of total suspended solids (TSS) for the different sampling site types from 2011 to 2014. Error bars are 90% confidence intervals.**

The pH of irrigation water was alkaline and ranged from 7.9 to 9.8 in 2014. As in 2011 to 2013, the 2014 average pH value increased from AEP to secondary sites and then slightly decreased at the return sites. The protection of aquatic life guideline for pH (6.5 to 9.0) was exceeded in 7.6% of the samples in 2014 as compared to 5.9% in 2013.

Sample temperature ranged from 9.6 to 28.1°C in 2013. The average sample temperature in 2013 was 19.4°C, which was higher than in 2012 (17.7°C) and similar to 2011 (19.9°C). As in 2011 and 2012, water temperature was cooler at the AEP and primary sites compared to the secondary and return sites, and this probably reflects the size of the canals and the travel time. Water temperature increased from early June to early August and then decreased at the end of August.

**Biological parameters**

In 2014, the median concentration of generic *E. coli* was 44 CFU 100 $mL^{-1}$. Similar to 2013, overall median *E. coli* concentrations increased from primary to return sites within each sampling period, and this was consistent within each irrigation district. The irrigation guideline for *E. coli* (100 CFU 100 $mL^{-1}$) was exceeded in 25% (90/356) of the water samples. Specifically, the guideline was exceeded in 25% (3/12) of AEP, 9% (5/55) of primary, 6% (8/127) of secondary, and 46% (74/162) of return site samples. It should be noted that although a large proportion of return sites exceeded the irrigation water quality guideline for *E. coli*, water in returns or at the end of the irrigation water conveyance networks is generally not applied to crops.

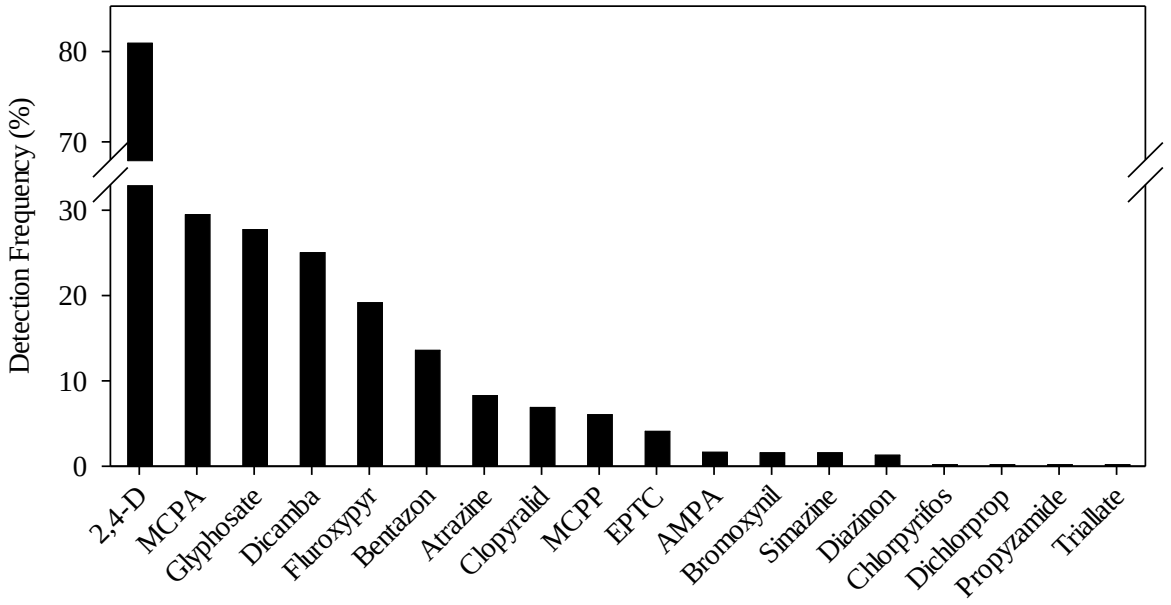
*Campylobacter* spp. was not detected at any of the sites in 2014, although in 2013, detection occurred in five water samples collected at three return sites and one secondary site. *Escherichia coli* O157:H7 was not detected in any of the water samples during 2014 or 2013. Similar to 2013, only one of the 40 samples was positive for *Salmonella enterica* subspecies *enterica* in 2014. Specifically, *Salmonella* serovar Typhimurium was detected from an irrigation return site at a concentration of 23 MPN 300 $mL^{-1}$. *Salmonella* serovar Typhimurium has been among the top three serovars most commonly reported as causing human salmonellosis in Canada during the past several years. This serovar may be isolated from a variety of animal sources (e.g., cattle, hogs, poultry, and wild birds); however, without advanced molecular subtyping, it was impossible to know the source of the serovar in this particular sample.

Risk interpretation of fecal pathogens is complicated, given there are no water quality guidelines. Fecal pathogens will likely be present in irrigation water. But, the risk of foodborne illness from Alberta's irrigation water is very low because more than 99% of the crops grown under irrigation are used to feed livestock or are processed prior to consumption, and processing generally destroys pathogens. Further, there are many steps from field-to-plate that will minimize exposure and health risks.

**Pesticides**

Of the 109 pesticides analyzed in 2014, 18 were detected. At least one pesticide compound was detected in 310 of the 358 samples (86.6%) analyzed. The pesticides that were detected included 15 herbicides, two insecticides (diazinon and chlorpyrifos), and one fungicide (propiconazole). No other type of pesticide analyzed (acaricide, nematicide, bactericide, or growth regulator) was detected. The pesticides most frequently detected were 2,4-D (81%), MCPA (30%), glyphosate (28%), dicamba (25%), fluroxypyr (19%), and bentazon (14%). All other pesticides and the metabolite AMPA were detected in 8% or less of all samples. The type of pesticides detected, their detection frequency, and concentrations were generally consistent with previous studies in Alberta.

For pesticides detected every year (2011 to 2014), such as 2,4-D, dicamba, and MCPA, detection frequencies were similar from 2012 to 2014; whereas, detection frequencies were slightly higher in 2011. A number of other pesticides (fluroxypyr, bentazon, atrazine, clopyralid, EPTC, and bromoxynil) had higher detection frequencies in 2014 compared to 2013. For all pesticides detected in 2014, the average detected concentrations were lower in 2014 compared to previous years, but maximum detected concentrations were higher.



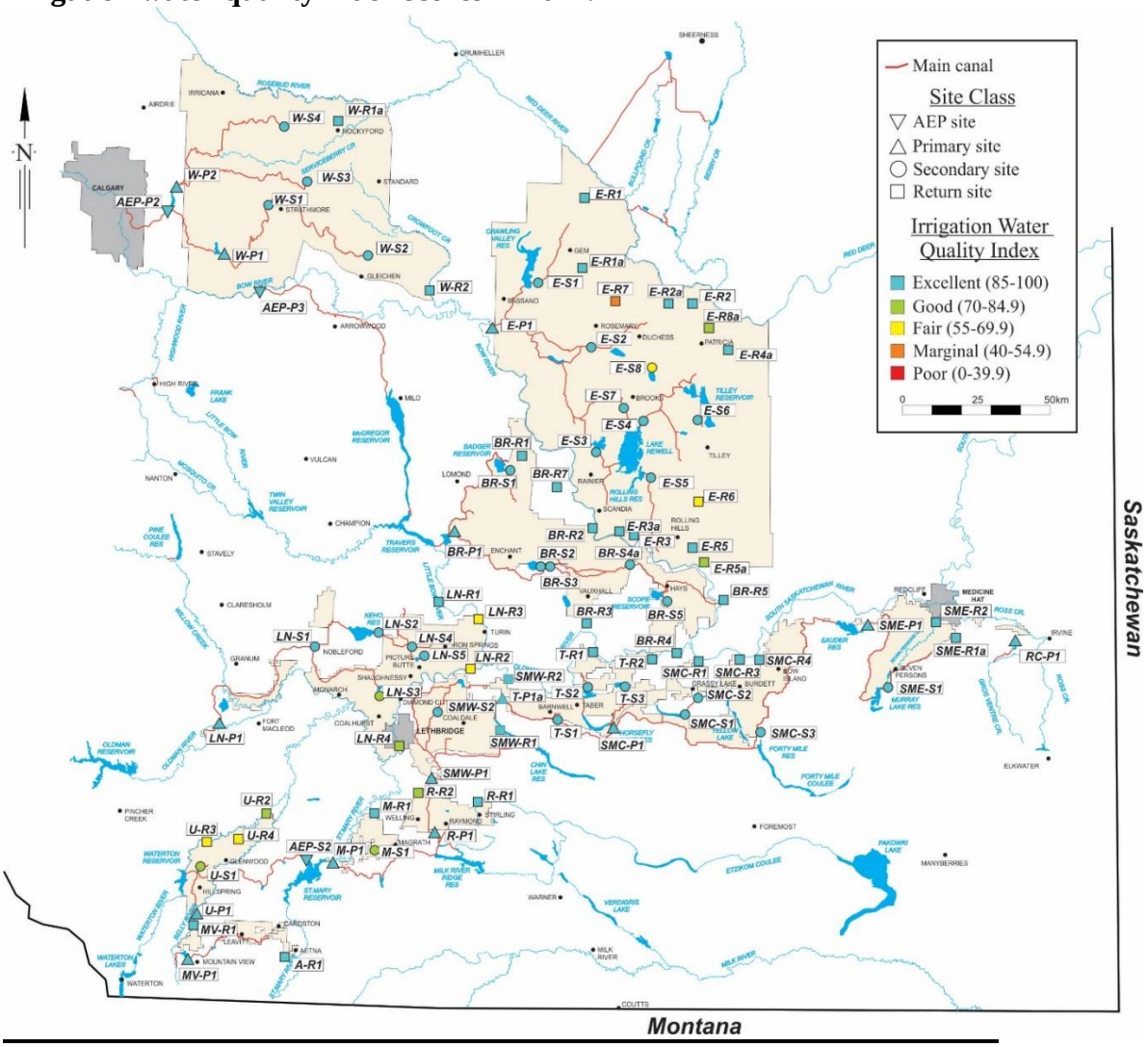

**Pesticide detection frequencies in 2014.**

Pesticide guidelines for livestock watering were not surpassed in 2014. One sample exceeded the protection of aquatic life guideline for MCPA. The irrigation water quality guidelines were surpassed in 25% of the samples for dicamba and 16% of the samples for MCPA. Nine of the 18 pesticides detected in 2014 do not have water quality guidelines (AMPA, bentazon, chlorpyrifos, clopyralid, diazinon, dichlorprop, EPTC, fluroxypyr, and propiconazole). A general increase in pesticide detections and concentrations was observed as the water moved through the irrigation infrastructure. These results were generally consistent with previous Alberta studies.

## Veterinary pharmaceuticals

The detection frequency of the seven veterinary pharmaceuticals analyzed ranged from 1 % (sulfamethazine) to 100 % (chlortetracycline and tetracycline). In order of average detected concentrations, veterinary pharmaceuticals ranked as tetracycline (72.0 ng $L^{-1}$) > chlortetracycline > tylosin > monensin > erythromycin > lincomycin > sulfamethazine (1.5 ng $L^{-1}$).

**Irrigation water quality index scores in 2014.**




**Parameters and guidelines used to calculate the annual irrigation water quality indices.**

| Variable | | Objective[z] | Variable | | Objective[z] |
|---|---|---|---|---|---|
| **Salinity** | SAR | 5.0 | **Metals** | Aluminum | 5.0 mg $L^{-1}$ |
| | Cl | 178 mg $L^{-1}$ | | Arsenic | 0.1 mg $L^{-1}$ |
| | TDS | 500 mg $L^{-1}$ | | Beryllium | 0.1 mg $L^{-1}$ |
| | | | | Boron | 0.5 mg $L^{-1}$ |
| **Biological** | Fecal coliforms | 100 CFU mg $L^{-1}$ | | Cadmium | 5.1 µg $L^{-1}$ |
| | | | | Chromium | 4.9 µg $L^{-1}$ |
| **Pesticides** | Atrazine | 10 µg $L^{-1}$ | | Cobalt | 0.05 mg $L^{-1}$ |
| | Bromacil | 0.2 µg $L^{-1}$ | | Copper | 0.2 mg $L^{-1}$ |
| | Bromoxynil | 0.33 µg $L^{-1}$ | | Iron | 5.0 mg $L^{-1}$ |
| | Diclofop-methyl | 0.18 µg $L^{-1}$ | | Lead | 0.2 mg $L^{-1}$ |
| | Dicamba | 0.006 µg $L^{-1}$ | | Lithium | 2.5 mg $L^{-1}$ |
| | MCPA | 0.025 µg $L^{-1}$ | | Manganese | 0.2 mg $L^{-1}$ |
| | Metolachlor | 28 µg $L^{-1}$ | | Molybdenum | 0.01 mg $L^{-1}$ |
| | Simazine | 0.5 µg $L^{-1}$ | | Nickel | 0.2 mg $L^{-1}$ |
| | | | | Selenium | 0.02 mg $L^{-1}$ |
| | | | | Uranium | 0.01 mg $L^{-1}$ |
| | | | | Vanadium | 0.1 mg $L^{-1}$ |
| | | | | Zinc | 5.0 mg $L^{-1}$ |

[z] Objectives are based on the Environmental Quality Guidelines for Alberta Surface Waters.

**Irrigation water quality index scores and rankings[z] (blue to red) for each sampling site from 2011 to 2014.**

| Irrigation District | Site | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|
| MVID | MV-P1 | 100.0 | 100.0 | 100.0 | 100.0 |
| | MV-R1 | 100.0 | 100.0 | 100.0 | 100.0 |
| AID | A-R1 | 96.8 | 100.0 | 100.0 | 95.7 |
| UID | U-P1 | 97.3 | 100.0 | 58.9 | 100.0 |
| | U-S1 | 55.2 | 100.0 | 80.8 | 81.9 |
| | U-R2 | 52.7 | 94.5 | 89.6 | 73.7 |
| | U-R3 | 62.9 | 91.7 | 77.9 | 55.8 |
| | U-R4 | -[y] | 100.0 | 70.2 | 66.0 |
| MID | M-P1 | 93.6 | 100.0 | 100.0 | 97.9 |
| | M-S1 | 96.6 | 97.1 | 81.8 | 82.2 |
| | M-R1 | 97.4 | 97.8 | 100.0 | 87.2 |
| RID | R-P1 | 96.8 | 100.0 | 100.0 | 95.5 |
| | R-R1 | 87.7 | 90.2 | 95.5 | 95.8 |
| | R-R2 | 91.6 | 97.9 | 100.0 | 78.8 |
| LNID | LN-P1 | 100 | 100.0 | 95.9 | 100.0 |
| | LN-S1 | 97.5 | 100.0 | 97.9 | 100.0 |
| | LN-S2 | 100.0 | 100.0 | 100.0 | 100.0 |
| | LN-S3 | 97.9 | 92.2 | 71.9 | 79.4 |
| | LN-S4 | 97.8 | 97.3 | 100.0 | 95.6 |
| | LN-S5 | 93.9 | 93.9 | 77.3 | 91.8 |
| | LN-R1 | 91.6 | 92.6 | 89.0 | 93.3 |
| | LN-R2 | 86.6 | 86.4 | 72.8 | 67.8 |
| | LN-R3 | 96.5 | 100.0 | 83.6 | 60.0 |
| | LN-R4 | - | 83.4 | 64.9 | 79.9 |
| TID | T-P1a | 97.5 | 97.9 | 100.0 | 97.7 |
| | T-S1 | 97.9 | 97.9 | 97.0 | 97.5 |
| | T-S2 | 91.9 | 96.1 | 93.8 | 87.8 |
| | T-S3 | 86.1 | 89.7 | 92.2 | 89.5 |
| | T-R1 | 91.2 | 94.1 | 96.2 | 93.0 |
| | T-R2 | 86.1 | 88.5 | 92.5 | 91.0 |
| SMRID | SMW-P1 | 95.4 | 100.0 | 100.0 | 97.9 |
| | SMW-S2 | 95.5 | 100.0 | 97.9 | 97.9 |
| | SMW-R1 | 93.4 | 79.4 | 95.7 | 96.0 |
| | SMW-R2 | 90.6 | 94.5 | 94.8 | 94.5 |
| | SMC-P1 | 97.6 | 97.8 | 100.0 | 97.1 |
| | SMC-S1 | 100.0 | 100.0 | 100.0 | 97.9 |
| | SMC-S2 | 100.0 | 100.0 | 100.0 | 97.9 |
| | SMC-S3 | 97.6 | 97.9 | 97.9 | 97.8 |
| | SMC-R1 | 100 | 100.0 | 100.0 | 100.0 |
| | SMC-R3 | 97.9 | 97.9 | 100.0 | 100.0 |
| | SMC-R4 | 97.6 | 100.0 | 97.8 | 97.8 |
| | SME-P1 | 92.5 | 100.0 | 97.9 | 97.5 |
| | SME-S1 | 100.0 | 100.0 | 100.0 | 100.0 |
| | SME-R1a | 97.8 | 100.0 | 100.0 | 100.0 |
| | SME-R2 | 91.4 | 100.0 | 97.9 | 100.0 |
| RCID | RC-P1 | - | - | 95.5 | 97.2 |
| WID | W-P1 | 94.9 | 97.6 | 97.3 | 100.0 |
| | W-P2 | 89.5 | 95.4 | 96.1 | 95.3 |
| | W-S1 | 90.9 | 94.0 | 97.0 | 100.0 |
| | W-S2 | 95.7 | 97.7 | 95.6 | 100.0 |
| | W-S3 | 92 | 94.8 | 93.6 | 100.0 |
| | W-S4 | 94.8 | 95.6 | 93.9 | 100.0 |
| | W-R1a | 97.5 | 97.4 | 94.7 | 100.0 |
| | W-R2 | 93.5 | 92.4 | 95.5 | 95.9 |
| BRID | BR-P1 | 100.0 | 100.0 | 100.0 | 100.0 |
| | BR-S1 | 97.5 | 100.0 | 100.0 | 94.4 |
| | BR-S2 | 92.9 | 97.5 | 97.5 | 100.0 |
| | BR-S3 | 100.0 | 100.0 | 100.0 | 95.3 |
| | BR-S4a | 100.0 | 100.0 | 94.6 | 93.7 |
| | BR-S5 | 100.0 | 100.0 | 100.0 | 97.7 |
| | BR-R1 | 100.0 | 100.0 | 100.0 | 100.0 |
| | BR-R2 | 96.7 | 100.0 | 93.3 | 93.5 |
| | BR-R3 | 96.9 | 97.0 | 94.6 | 97.0 |
| | BR-R4 | 97.9 | 95.7 | 95.4 | 97.5 |
| | BR-R5 | 100.0 | 97.5 | 100.0 | 94.1 |
| | BR-R7 | | 97.4 | 94.9 | 100.0 |
| EID | E-P1 | 100.0 | 100.0 | 100.0 | 100.0 |
| | E-S1 | 95.2 | 96.4 | 100.0 | 100.0 |
| | E-S2 | 100.0 | 100.0 | 100.0 | 100.0 |
| | E-S3 | 94.4 | 96.9 | 95.4 | 96.7 |
| | E-S4 | 48.4 | 100.0 | 89.0 | 100.0 |
| | E-S5 | 100.0 | 100.0 | 100.0 | 100.0 |
| | E-S6 | 97.6 | 100.0 | 100.0 | 100.0 |
| | E-S7 | 95.5 | 97.1 | 79.2 | 96.1 |
| | E-S8 | 69.2 | 70.4 | 63.5 | 68.6 |
| | E-R1 | - | 57.1 | 90.0 | 97.4 |
| | E-R1a | 84.4 | 57.5 | 97.9 | 95.7 |
| | E-R2 | - | 89.9 | 45.5 | 85.9 |
| | E-R2a | 58.1 | 84.9 | 97.8 | 51.2 |
| | E-R3 | | 78.3 | 91.6 | 89.8 |
| | E-R3a | 81.7 | 85.7 | 91.6 | 93.5 |
| | E-R4a | - | 77.0 | 79.7 | 87.8 |
| | E-R5 | - | 100.0 | 92.2 | 91.4 |
| | E-R5a | 69.6 | 86.6 | 81.2 | 73.2 |
| | E-R6 | 51.9 | 74.6 | 83.0 | 62.5 |
| | E-R7 | 49.8 | 87.3 | 97.9 | 52.3 |
| | E-R8a | 89.3 | 70.2 | 75.7 | 71.1 |
| AEP canals | AEP-P2 | 96.3 | 93.9 | 100.0 | 95.4 |
| | AEP-P3 | 100.0 | 90.7 | 100.0 | 100 |
| | AEP-S2 | 88.3 | 97.7 | 97.9 | 100 |
| Average | All sites | 91.2 | 94.3 | 92.6 | 91.9 |

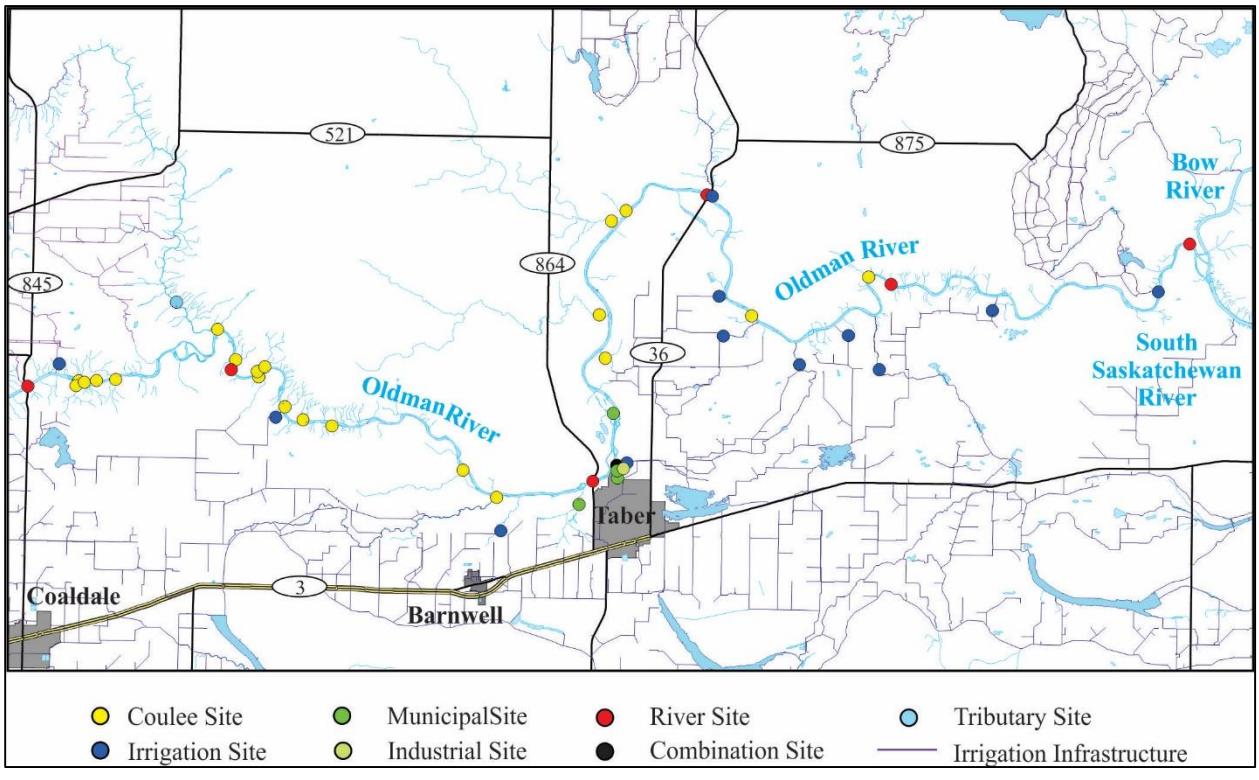
[z] Blue = excellent (85 to 100), green = good (70 to 84.9), yellow = fair (55 to 69.9), orange = marginal (40 to 54.9), and red = poor (0 to 39.9).

[y] Site not sample in 2011and/or 2012.

**Contribution of Irrigation Returns to Rivers**

Irrigation districts currently return approximately 20% of diverted water back to the rivers. The quality of return water is usually not as good as source water and this leads to questions regarding the potential effects of irrigation returns on rivers in southern Alberta.

Two synoptic surveys were carried out on a 122-km stretch of the Oldman River in 2014: one during active runoff (June 18) and one during a dry period (August 14). The surveys captured periods when irrigation returns were likely to have the greatest effects on the river. A total of 46 synoptic survey sampling sites were selected. At six sites, the Oldman River was sampled to provide a more detailed description of water quality changes in the river. The 40 potential contributing sources to the river included 21 natural coulees; 12 irrigation returns in the LNID, SMRID, and BRID; four municipal discharges; one industrial discharge; one tributary (Little Bow River); and one site that contained a combination of irrigation, municipal and industrial inputs. Each sample was analyzed for nutrients, salinity, coliform bacteria, pesticides, and physical parameters. Six water quality parameters (TN, TP, TDP, TSS, TDS and 2,4 D) were used for the synoptic survey assessments.




**Synoptic Survey sites on the Oldman River.**

In a synoptic survey, water samples are collected from a single "parcel" of water as it moves down the river. All contributions to the river are also sampled synchronously with the parcel of water. This method can be used to assess the effects of contributions on water quality and how water quality changes within a reach of a river.

Flow from irrigation returns was the dominant contribution during both surveys, especially during the dry-season survey when flow from other contributing sources was reduced. During the runoff synoptic survey, irrigation returns contributed 43% of the total flow inputs to the Oldman River within the study reach. The Little Bow River and coulee runoff were the next largest inputs at 37% and 17%, respectively. During the dry-season synoptic survey, irrigation returns contributed 64% and the Little Bow River contributed about 35% of total flow contributions to the river. Coulee, municipal and industrial had a combined flow contribution of less than 1%. The proportion of irrigation return flow into the river in relation to the river flow was 1% during the runoff synoptic survey and 11% during the dry-season survey. The difference was mainly the result of the lower river flow during the dry-season survey.

As expected, the concentrations of most parameters in the Oldman River were greater during the runoff survey than during the dry-season survey. Generally, parameter concentrations varied little among the six river sites during both surveys with either a slight decrease from upstream to downstream or no consistent trends, despite higher concentrations of most parameters from the contributing sources.

The river ratio is a way to compare the load of a particular contributing source with the load in the river. It is calculated using the following equation:

$$River\ ratio\ (\%) = \frac{\sum\ contribution\ source\ loads}{downstream\ river\ load} \times 100$$

River ratio calculations showed that all contributing sources varied from 1 (TSS) to 74% (2,4-D) of the total load of the river during the runoff synoptic survey. Irrigation, followed by coulee and tributary contributed to the greatest loads for most parameters. The coulees contributed greatest loads for TP and TSS. The pesticide 2,4-D was not detected in the tributary during the runoff survey.

Loads from all contributions varied from 23 (TDS) to 112% (TP) relative to the river loads during the dry-season synoptic survey. Irrigation contributed the largest load for most parameters followed by the tributary. The only exception was for TSS, in which the Little Bow River tributary contributed the largest load to the river.

As river water moved from upstream to downstream, it was hypothesized that loading would be cumulative and changes in concentrations and loads would be proportional to the contribution source inputs. However, this was not observed. For example, despite a cumulative TSS contribution from all inputs corresponding to 112% of the downstream river load during the dry-season synoptic survey, the TSS load was reduced by 0.9% from the upstream to the downstream river sites.

**River ratios for runoff and dry-season synoptic surveys.**

| Site type | Flow | TN | TDP | TP | TSS | TDS | 2,4-D |
|---|---|---|---|---|---|---|---|
| | ---------- (%)---------- | | | | | | |
| | | | *Runoff synoptic survey* | | | | |
| All contributions | 2.70 | 3.27 | 21.9 | 1.59 | 1.12 | 6.43 | 73.6 |
| Coulee | 0.47 | 1.21 | 7.74 | 0.62 | 0.66 | 1.62 | 21.2 |
| Tributary | 0.99 | 0.77 | 3.47 | 0.40 | 0.38 | 2.05 | 0.00 |
| Irrigation | 1.17 | 1.21 | 10.2 | 0.55 | 0.05 | 2.47 | 45.5 |
| Municipal | 0.07 | 0.07 | 0.40 | 0.03 | 0.025 | 0.29 | 6.83 |
| Industrial | 0.002 | 0.006 | 0.09 | 0.001 | 0.00003 | 0.004 | 0.14 |
| | | | *Dry-season synoptic survey* | | | | |
| All contributions | 16.7 | 52.9 | 78.5 | 112.0 | 111.4 | 22.3 | na[z] |
| Coulee | 0.01 | 0.03 | 0.10 | 0.11 | 0.09 | 0.02 | na |
| Tributary | 5.90 | 8.98 | 14.8 | 34.5 | 80.2 | 7.43 | na |
| Irrigation | 10.7 | 43.3 | 63.0 | 76.7 | 30.9 | 14.5 | na |
| Municipal | 0.11 | 0.53 | 0.60 | 0.65 | 0.19 | 0.33 | na |
| Industrial | 0.00004 | 0.006 | 0.0002 | 0.0001 | 0.000004 | 0.0004 | na |

[z] na = not applicable, because there was no detection of 2,4-D at downstream river site.

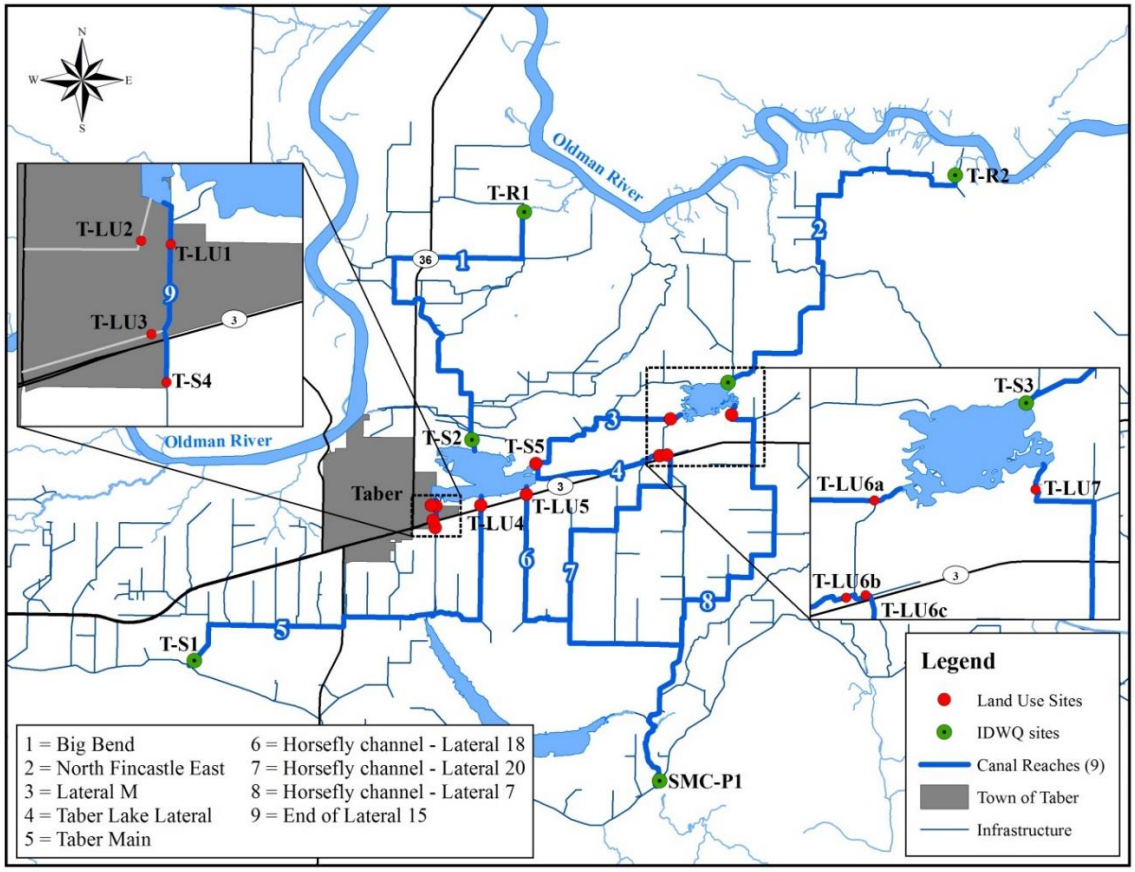
During both synoptic surveys, the Oldman River loads were not influenced by any contributing sources, including irrigation returns. During the runoff synoptic survey, the river flow was several orders of magnitude larger than all contribution source volumes so the effect of these inputs was negligible. During the dry-season synoptic survey, the dynamic physical, chemical, and biological processes of the river had more effect on water quality than the contributing sources. While the cumulative effects of contributions to the river were non-measurable, the buffering capacity of natural river processes remains unknown.

**Factors Affecting Irrigation Water Quality**

Our monitoring study has shown that water quality typically degrades as water flows through the irrigation distribution system. One of the study objectives was to assess relationships between landscape/canal characteristics and irrigation water quality. A literature review revealed that, to date, little work has been done to evaluate relationships between land-use and irrigation water quality. As such, a case study was designed to examine irrigation water quality and the influence of:

- irrigation reservoirs,
- municipal stormwater, and
- canal and landscape characteristics in selected irrigation canal segments.

A total of 17 water quality sampling sites were located throughout the Taber Irrigation District (TID) in an upstream to downstream monitoring design. Six sites were part of the existing study, nine of the new sites were added to assess water quality changes along nine canal segments, and two sites were added to sample municipal stormwater contributions. The sampling sites at each reservoir inlet and outlet were used to assess the influence of the reservoirs on water quality. Sites were monitored for nutrients, pesticides, salinity, and physical parameters during 16 sampling events from March to November 2014.




**Land-use water quality sampling sites and studied canal segments in 2014.**

Landscape parameters were developed using a Geographic Information System (GIS). Data entered into the GIS included details from a landscape survey that included the locations and flow potential characteristics of all potential flow contributions from drain inlets, as well as the agricultural characteristics along the canals. Topographic landscape characteristics were derived from a digital elevation model created from a Light Detection and Ranging (LiDAR) dataset, while irrigation conveyance characteristics were derived from an irrigation canal geodatabase. Canal and landscape parameters included canal length, type and flow capacity, number and size of drainage inlets, surrounding slopes, crop types, presence of irrigation pivots, and road density within the immediate area.

Results showed the reservoirs had a positive effect on water quality. Most water quality parameters decreased in concentration from upstream to downstream of Taber Lake and Fincastle reservoirs. The reduction can be attributed to sedimentation, dilution, and chemical and biological processes that occur in the reservoirs. The reduction was especially noticeable during periods when poorer water quality flowed into the reservoirs including during the irrigation district spring flushing event and during runoff events. During the irrigation season when the quality of water was better, a slight increase in salinity, nutrient and pesticide concentrations was measured downstream of the reservoirs. This suggests that the reservoirs have a limited buffering capacity and can also release some of the accumulated contaminants.

For most water quality parameters, the concentrations at the two stormwater sampling sites (T-LU2 and T-LU3) were generally greater than the concentrations in the irrigation canals. Furthermore, the number of different pesticides detected at the stormwater sites relative to the irrigation canals was much higher. Despite the elevated concentrations, relatively small and intermittent flows of stormwater limited the seasonal loading to Taber Lake Reservoir. However, the high concentrations and diversity of pesticides as well as high concentrations of nutrients and salts in the stormwater are undesirable.

An increase in concentration for water quality parameters was generally observed in water as it moved from upstream to downstream sites for each canal segment. The changes in water quality concentrations varied widely among the parameters, sampling events, and canal segments. The largest changes in water quality in the canal segments were observed during the initial flush of irrigation water through the canals, followed by pre-irrigation and runoff events. During the irrigation season, the water quality was generally the best and more consistent in time and space. The changes in concentration were only statistically significant for a few parameters and canal segments.

Correlation analysis was performed to examine the change in water quality in the canal segments as influenced by landscape characteristics. The strongest correlations observed were between water quality and canal characteristics, suggesting that the canal characteristic parameters may

have had more of an effect on water quality than the surrounding landscape over the entire season. More degradation of water quality were observed in earth canals as compared to lined canals. A second year of data will be collected in 2015, and these data will help to establish the relationship between the change in irrigation water quality and landscape/canal characteristics.

**2014 Summary**

Water quality was assessed using environmental quality guidelines for Alberta surface waters to calculate water quality indices. The indices provide a practical reporting method to assess the overall water quality among the sites and the years.

Water quality indices for irrigation, livestock watering, protection of aquatic life, and recreation were assessed. The average score for irrigation (91.9) was excellent in 2014. Average irrigation water quality index scores were 91.2, 94.3, and 92.6 in 2011, 2012, and 2013, respectively. Of the 90 irrigation district monitoring sites, 82% had an excellent rating, 9% had a good rating, 7% had a fair rating, and 2% had a marginal rating for irrigation water quality in 2014. Lower scores were observed at return sites, which are at the end of the distribution system after which water is no longer used for irrigation. Irrigation guideline exceedances for pesticides and coliforms remained the main cause of reduced water quality index scores.

None of the livestock water quality guidelines were surpassed in 2014 and the index score rated 100. The average index score for the protection of aquatic life was 96.1, which was excellent and better than previous years. The recreation index, which is solely based on an *E. coli* guideline, was 86.2, which was still considered excellent and comparable to the 2013 results.

**Future Work**

Water sampling will continue at the same sites and follow the same methods for the final year of the project in 2015. The collaboration with Alberta Health Services and the Public Health Agency of Canada will continue for the pathogen sampling as well as the collaboration with AAFC for the pesticide and the veterinary pharmaceutical analyses.

Dry-season synoptic surveys are planned on the lower reach of the Bow and Oldman rivers in 2015.

The evaluation of the relationship between landscape/canal characteristics and irrigation water quality will be continued in TID in 2015 following essentially the same methods used in 2014. One new sampling site may be added and additional data loggers will be installed to more accurately measure flow at all of the sites.

A final report will be produced and will include a trend analysis to statically assess the changes in irrigation water quality from 2006 to 2015.

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# 1 Introduction

Jollin Charest and Don Gross
Alberta Agriculture and Forestry

## 1.1 Background

More than 65% of Canada's irrigation occurs in Alberta's 13 irrigation districts. The districts encompass approximately 8,000 km of district- and government-owned irrigation infrastructure and more than 55 on-stream and off-stream reservoirs that serve about 555,220 ha of irrigated agricultural land (ARD 2013). Irrigation is the largest water user in the province, accounting for approximately 63% of water consumption (AMEC Earth and Environment 2007). Water for the irrigation districts mainly comes from five river systems: Belly River, Waterton River, St.Mary River, Oldman River, and Bow River.

Irrigation is essential for agricultural diversity and high production yields in southern Alberta. Irrigated agriculture provides as much as 30% of all regional employment and directly contributes to the long-term targets of $10 billon in primary and $20 billon of value-added production (AIPA 2012). The open canals, buried pipelines, and control structures that make up the district's conveyance network, not only supply water for agricultural production, they also supply water to thousands of rural residents and more than 30 municipalities for household potable water, municipal pools, parks, and industrial use including food processing plants and factories. The irrigation conveyance system also supplies water to other users, including water for livestock production. Water stored in irrigation reservoirs provide habitat for wildlife and opportunities for recreational activities such as fishing, boating, and camping.

Good quality irrigation water is needed for all uses. High yielding and safe food production requires low concentrations of herbicides and pathogens. Low nutrient concentrations in water help prevent the growth of aquatic weeds and algae that would otherwise impede water conveyance. Good quality water is also important to minimize treatment costs for rural communities. Water quality deterioration can occur in a number of ways including overland runoff from agricultural, industrial, and municipal activities. Assuring a continued supply of good quality water is an important aspect to maintain a healthy aquatic environment and to ensure sustainable rural development. The water quality data from this study are a valuable source of information for all users of irrigation water.

The quality of irrigation water in Alberta has been previously monitored by researchers including Bolseng (1991), Cross (1997), Greenlee et al. (2000), Saffran (2005), Little et al. (2010), and Palliser Environmental Services Ltd. (2011). The extent of monitoring varied among these

studies and ranged from a one-time sampling of return sites in select irrigation districts (Bolseng 1991) to the first major comprehensive study throughout the irrigation districts (Little et al. 2010). Palliser Environmental Services Ltd. (2011) focused on only one irrigation district; whereas, irrigation water quality reported by Saffran (2005) was part of a larger study on surface water quality within the Oldman Watershed. Cross (1997) carried out a review of irrigation district water quality based on several data sources from 1977 to 1996.

This report summarizes the fourth year of activities and findings of a comprehensive five-year study (2011 to 2015) that assesses the quality of irrigation water within the Alberta irrigation districts. This project is a continuation of the Assessment of Water Quality in Alberta's Irrigation District study carried out in 2006 and 2007 by Little et al. (2010).

### 1.2 Development in 2014

In 2014, all 90 sampling sites remained the same as in 2013. The list of analyzed parameters essentially remained the same except for the addition of two pesticides and one veterinary pharmaceutical and the removal of fecal coliform bacteria. Clodinafop-propargyl, an herbicide, and propiconazole, a fungicide, were added to the analytical suite for a total of 106 pesticides analyzed in 2014. Tetracycline was added to the six other veterinary pharmaceuticals analyzed by Environment Canada in 2013. The fecal coliform bacteria was not included in the analytical list in 2014 because of the similarity of the results with the generic *Escherichia coli* (*E. coli*) data. Both parameters were highly correlated (99.6%) and their average relative percent difference was only 6%. Furthermore, the updated irrigation water quality guideline for fecal coliform was replaced by *E. coli*, which is the most common fecal indicator bacteria.

A few additional changes occurred in the laboratory analysis in 2014. The method detection limit for mercury was change from 0.1 to 0.005 µg $L^{-1}$ by Exova® Lab. The method detection limit for the pharmaceutical analyses changed from 5 to 2.5 ng $L^{-1}$ for all seven parameters in 2014.

In an effort to determine the cumulative effects of irrigation returns on river water quality, two synoptic surveys were carried out on a 122-km stretch of the Oldman River in 2014: one during active runoff (June 18) and one during a dry period (August 14). These surveys were originally scheduled for 2013, but atypical flows in the Oldman River forced a postponement to 2014. A synoptic survey is the assessment of the change in quality of a single “parcel” of water as it moves down the river in relation to all contributions to the river that are also sampled synchronously with the parcel of water.

A land use and water quality relationship study was initiated in 2014. A total of 17 water quality sampling sites were located throughout the Taber Irrigation District in an upstream to

downstream monitoring design to assess water quality change along nine canal segments. Landscape characteristics including canal length, type and flow capacity, number and size of drain inlet, surrounding slopes, crop types, presence of irrigation systems, and road density were compared with the change in water quality using correlation analysis. Influence of reservoirs and municipal stormwater on irrigation water quality was also studied.

An assessment of selected waterborne fecal pathogens was added in 2012. Water was monitored in 2012, 2013, and 2014 for the presence *Salmonella*, *Campylobacter*, and *E. coli* O157:H7, and these are the most important bacteria responsible for foodborne illness in Canada (PHAC 2013). Although there is no direct evidence of foodborne illness caused by irrigation water in Alberta, these pathogens have been implicated in irrigation water outbreaks elsewhere (Lynch et al., 2009). As in 2013, 21 sites were sampled and analyzed within 10 irrigation districts in 2014. In 2013, samples from the 21 sites were also analyzed for shiga-toxin producing *E. coli* (STEC). The bacteria were identified using a general method for the detection of shiga-toxin (ST) producing genes. The preliminary results from 2013 indicated that ST genes are abundant in irrigation water; however, detection of the ST genes does not provide any serotype information regarding STEC. There are hundreds of different STEC serotypes, and not all are equally pathogenic. In fact, there are many serotypes that have never been associated with human disease (Karmali et al. 2003). Without knowing which serotypes were isolated, the utility of the information is severely limited since interpretation of the results is difficult and potentially misleading. Unfortunately, isolation and serotyping methods for STEC are very costly and time consuming. Therefore, analysis of samples for this pathogen was not continued by Alberta Agriculture and Rural Development (ARD) in 2014.

New in 2014 was the quantitative analysis to provide a concentration of the pathogen bacteria in positive samples. In previous years only qualitative assessment (i.e., presence or absence) was done. Also new in 2014, collaboration with the Public Health Agency of Canada (PHAC) FoodNet program was established. The FoodNet program provides in-depth investigation of food-borne and waterborne diseases through sentinel site surveillance. The sentinel sites were selected based on specific criteria and were established by creating partnerships with public health units and provincial laboratories along with a working network of local water, agriculture, and retail food sectors, as well as provincial and federal institutions responsible for public health. There are currently three sentinel sites in the system: British Columbia (Fraser Health Authority), Ontario (Region of Waterloo Public Health), and new in 2014, Alberta (Calgary and Central Alberta). The collaboration with the PHAC, the ProvLab, and ARD has allowed for the establishment of the Calgary FoodNet sentinel sites. The PHAC was able to take advantage of the sampling ARD was doing in the irrigation districts, as well as the services provided by the ProvLab, for the new sentinel site in Alberta. Results for the samples collected for FoodNet Project are not presented in this report and will be reported by PHAC. More details regarding

this gastrointestinal disease surveillance program and reporting of findings can be found online at http://www.phac-aspc.gc.ca/foodnetcanada/.

In 2013, Agriculture and Agri-Food Canada initiated a study to assess the presence of veterinary pharmaceuticals in surface water. The sampling of irrigation water in the current study offered an opportunity to do a preliminary assessment of veterinary pharmaceuticals in rural Alberta surface waters. In 2014, 24 sites (nine secondary and 15 return sites from eight irrigation districts) were sampled four times as per all other parameters. This was different then in 2013 when 15 sites were only sampled in early June and at the end of August. These samples were analyzed by the National Hydrology Research Center of Environment Canada in Saskatoon, Saskatchewan. Veterinary antimicrobials are used in animal production, therapeutically to treat disease and sub-therapeutically to prevent disease and promote growth. During the last decade, use of veterinary antimicrobials has received increased attention because of growing bacterial resistance to antimicrobials used in human medicine (Chee-Sanford et al. 2001) and the impact that this may have on the treatment of infectious diseases (Goss et al. 2013). Most antimicrobials are not metabolized by the animal or its microbial population with the residues excreted in feces or urine either as the parent compound or its metabolites. There is very limited information about the effects of antimicrobials or their metabolites on the environment and human health. Contamination of surface and ground water with antimicrobials used in veterinary medicine can be from point and non-point sources. Point sources include livestock feeding operations where manure is stored either as a solid or liquid prior to land application. Non-point sources of antimicrobial residues include crop and pasture land after application of manure from livestock feeding operations. Only one previous study assessed for the presence of veterinary pharmaceuticals in Alberta surface water (Forrest et al. 2011).

Finally, new water quality indices were calculated in 2014. In previous years, Canadian Water Quality Guidelines were used to calculate the indices. But updated guidelines were published by Alberta Environment and Sustainable Resource Development in 2014 and these were used to calculate the water quality indices. To maintain the comparison with previous years, the indices of 2011 to 2013 were recalculated with the newer Environmental Quality Guidelines for Alberta Surface Waters (ESRD 2014).

### 1.3 Objectives

The objectives for 2014 were to assess the:

- quality of source water used for irrigation and livestock watering,
- quality of irrigation water for recreational use and for the protection of aquatic life,
- changes in water quality as water travels through the irrigation infrastructure,
- differences in water quality among the irrigation districts,

- cumulative effect of irrigation returns on rivers, and
- relationship between land use and irrigation water quality.

### 1.4 Report Overview

This fourth progress report focuses on the study design and method updates; the 2014 water quality results; and provides a comparison to the 2011, 2012, and 2013 water quality results. In addition to the introduction chapter, there are four chapters and four appendices.

**Chapter 2 — Field and Laboratory Methods.** In this chapter, general methods for the study are described including sampling site locations and type, sampling schedule, sampling protocol, water quality parameters, analytical methods, and water quality guidelines.

**Chapter 3 — Water Quality in the Irrigation Districts.** This chapter summarizes the results obtained from the analysis of the water samples collected from June to September 2014. Results are presented by site type and irrigation district. Water quality indices for irrigation, livestock watering, protection of aquatic life, and recreational use are presented. Some comparisons are made to the 2011, 2012, and 2013 data.

**Chapter 4 — Irrigation Return Load Impacts on Rivers.** This chapter describes the synoptic surveys completed in 2014 for a reach on the Oldman River.

**Chapter 5 — Investigation of Land Use Effects on Irrigation Water Quality.** This chapter describes the study design, methods, and results for the 2014 assessment of the relationship between land use and water quality.

**Appendix A — Water Quality Sampling Sites and Irrigation Districts Maps.** Maps of the irrigation districts infrastructure and location of sampling sites is provided along with detailed descriptions and maps for the new sampling sites of the land use study in 2014.

**Appendix B — Weather.** Temperature and precipitation data from five weather stations in southern Alberta for 2014 are summarized and compared to 30-year average values.

**Appendix C — Quality Assurance/Quality Control and Quality Assurance/Surveillance Plan.** This appendix summarizes the quality assurance/quality control protocol used for the project and the quality control results for 2014.

**Appendix D — Sampling Sites Water Quality.** Water quality data for selected parameters are presented for each sampling site in 2014.

## 1.5 Future Work

In 2015, water sampling for nutrients, salinity, metals, pathogens, pesticides, and veterinary pharmaceutical will continue for the final year of this project using the same sites and protocols as in 2014.

Additional synoptic surveys are planned in 2015 on the Bow River and the Oldman River. The surveys will be conducted during periods of low river flows.

The land use study will continue for a second year with nearly the same design and protocol used in 2014, except for one sampling site that will be relocated to better assess the flow connectivity outside of the irrigation season.

A final report will be prepared for the five-year study (2001–2015) presenting the overall findings on water quality in Alberta's irrigation districts. Data from the 2006 and 2007 study by Little et al. (2010) will be included for trend analysis.

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# 2 Field and Laboratory Methods

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## 2.1 Sampling Sites

Sampling sites were selected using a similar process reported by Little et al. (2010). The sampling sites were categorized into four types: primary, secondary, return, and Alberta Environmental Protection (AEP) sites. The AEP sites represent water that is diverted from the rivers for irrigation use. Primary sites are typically on main canals where source water enters an irrigation district. Secondary sites are typically on lateral canals that branch-off a main canal or are immediately downstream of a reservoir. Return sites are typically at the end of the irrigation district infrastructure conveyance system after which the water is no longer used for irrigation and is returned to the natural drainage system.

As in 2013, a total of 90 sites were sampled in 2014 (Figure 2.1 and Table 2.1). In addition, 11 new sampling sites were added in 2014 for the Land Use Study and these sites are described Chapter 5.

The AEP sampling sites were located on Government of Alberta owned canals outside the irrigation districts. These structures continue to be under the jurisdiction of Alberta Environment and Sustainable Resource Development (ESRD). These sites were sampled to assess the quality of source water diverted from main-stem rivers upstream from the primary site and provide an opportunity to evaluate the effects of reservoirs on water quality, as they were located upstream from reservoirs.

Return sites comprise of two types: watershed and infrastructure returns (Table 2.2). The watershed returns are natural channels, which also collect natural drainage flow and occasionally ditch water or municipal effluent. Most of the water flow in the watershed returns generally originates from within the irrigation district during the irrigation season. If irrigation did not occur, many of the watershed returns are dry during the summer. Infrastructure returns are constructed canals at the end of the districts infrastructure. These returns are generally less influenced by surface runoff than watershed returns.

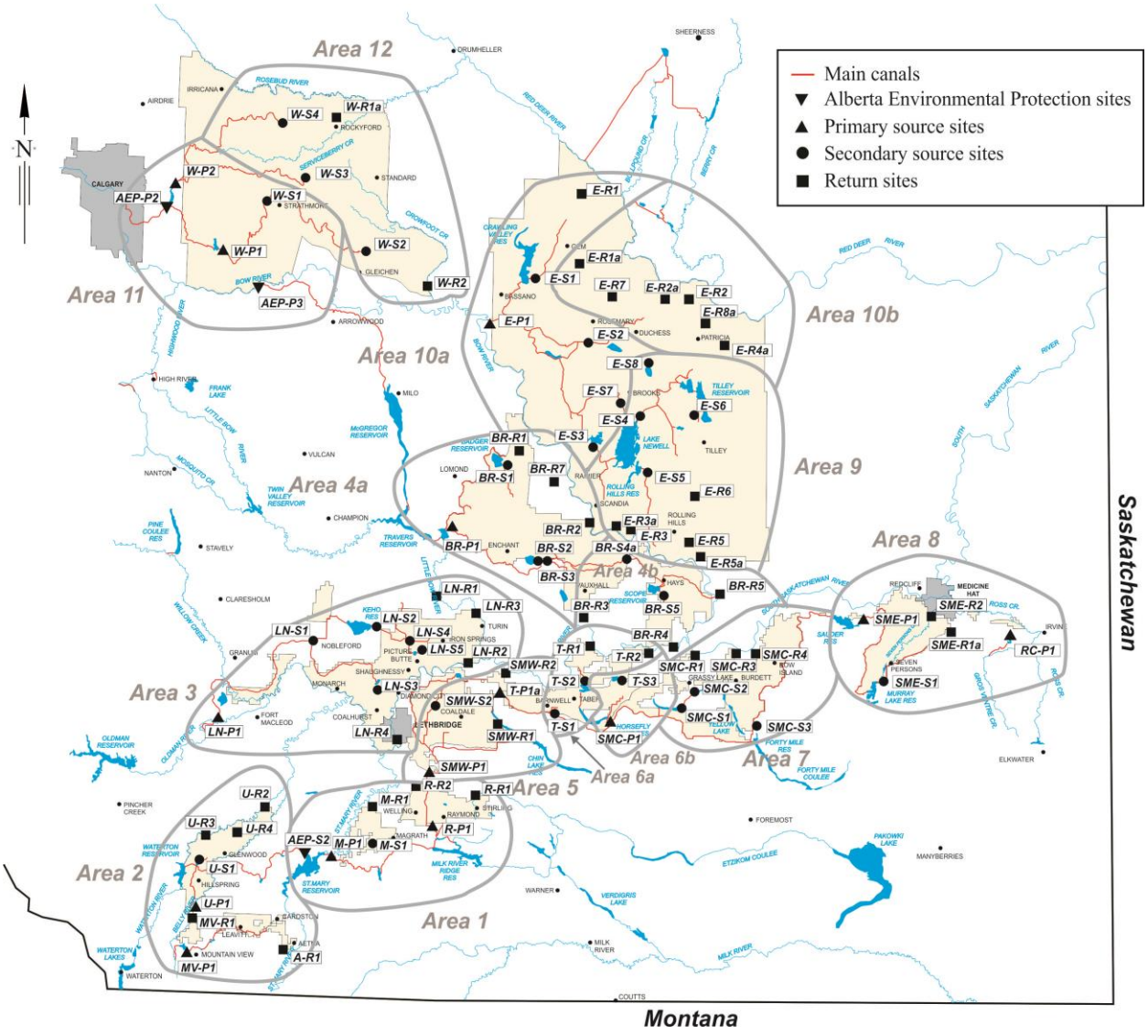


**Figure 2.1. Location of water quality sampling sites and sampling areas in 2014.**

Sampling site names were created by using their location in either an irrigation district (abbreviated to the first letter of the district in most cases), or outside of the district (AEP = Alberta Environmental Protection). The St. Mary River Irrigation District was divided into western, central, and eastern portions (SMW, SMC, and SME). Next, a hyphen and then the site type (P = Primary, S = Secondary, R = Return,) was added to the site name. Numbers at the end are used to differentiate sites of the same type within the same district and they do not necessarily follow numerically the flow direction or site type. Finally, the letter ‘a’ at the end of some site names indicates a site that was moved from its original location. In some cases, the site with an ‘a’ is comparable to the former site without the ‘a’.

**Table 2.1. Sampling sites, grouped by irrigation district, and associated water quality analysis in 2014.**

| Irrigation district | Site | G[z] | P | VP | FN | Sampling area |
|---|---|---|---|---|---|---|
| MVID | MV-P1 | x | | | | 2 |
| | MV-R1 | x | x | x[y] | | 2 |
| AID | A-R1 | x | x | | | 2 |
| UID | U-P1 | | | | | 2 |
| | U-S1 | | | | | 2 |
| | U-R2 | x | x | x[y] | | 2 |
| | U-R3 | x | x | x | | 2 |
| | U-R4 | x | x | | | 2 |
| MID | M-P1 | | | | | 1 |
| | M-S1 | | x | | | 1 |
| | M-R1 | x | | | | 1 |
| RID | R-P1 | | | | | 1 |
| | R-R1 | x | | | | 1 |
| | R-R2 | x | | | | 1 |
| LNID | LN-P1 | x | | | | 3 |
| | LN-S1 | | | | | 3 |
| | LN-S2 | | | | | 3 |
| | LN-S3 | | | x[y] | | 3 |
| | LN-S4 | x | | | | 3 |
| | LN-S5 | | | x | | 3 |
| | LN-R1 | x | | x[y] | | 3 |
| | LN-R2 | x | x | x | | 3 |
| | LN-R3 | x | x | x | | 3 |
| | LN-R4 | x | | | | 3 |
| TID | T-P1a | x | x | | | 5 |
| | T-S1 | | | | | 6a |
| | T-S2 | | | x | | 6a |
| | T-S3 | x | x | x | | 6b |
| | T-R1 | x | x | | | 6a |
| | T-R2 | x | | x[y] | | 6a |
| SMRID | SMW-P1 | | | | | 5 |
| | SMW-S2 | x | | | | 5 |
| | SMW-R1 | x | | x | | 5 |
| | SMW-R2 | x | | x | | 5 |
| | SMC-P1 | | | | | 6b |
| | SMC-S1 | | | | | 7 |
| | SMC-S2 | x | | | | 7 |
| | SMC-S3 | x | | | | 7 |
| | SMC-R1 | x | x | | | 7 |
| | SMC-R3 | x | | | | 7 |
| | SMC-R4 | x | x | x | | 8 |
| | SME-P1 | x | | | | 8 |
| | SME-S1 | | | | | 8 |
| | SME-R1a | x | x | | | 8 |
| | SME-R2 | x | | x | | 8 |
| RCID | RC-P1 | | | | | 8 |
| WID | W-P1 | x | | | x | 11 |
| | W-P2 | x | | | x | 11 |
| | W-S1 | | x | x | x | 11 |
| | W-S2 | | x | x[y] | x | 12 |
| | W-S3 | | | | x | 12 |
| | W-S4 | | x | | x | 12 |
| | W-R1a | x | x | | x | 12 |
| | W-R2 | x | | x | x | 12 |
| BRID | BR-P1 | x | | | | 4a |
| | BR-S1 | | | | | 4a |
| | BR-S2 | x | | x | | 4a |
| | BR-S3 | | | | | 4a |
| | BR-S4a | | | | | 4b |
| | BR-S5 | x | | x[y] | | 4b |
| | BR-R1 | x | x | | | 4a |
| | BR-R2 | x | | | | 4a |
| | BR-R3 | x | | x | | 4b |
| | BR-R4 | x | | | | 4b |
| | BR-R5 | x | | | | 4b |
| | BR-R7 | x | | | | 4a |
| EID | E-P1 | x | | | | 10a |
| | E-S1 | | | | | 10a |
| | E-S2 | | | | | 10a |
| | E-S3 | | | | | 10a |
| | E-S4 | | | | | 9 |
| | E-S5 | | | | | 9 |
| | E-S6 | | | | | 9 |
| | E-S7 | x | | x[y] | | 10a |
| | E-S8[x] | | | | | 10a |
| | E-R1 | x | x | | | 10a |
| | E-R1a | x | | | | 10b |
| | E-R2 | x | x | x[y] | | 10b |
| | E-R2a | x | | | | 10b |
| | E-R3 | x | | | | 9 |
| | E-R3a | x | | x | | 9 |
| | E-R4a | x | | | | 10b |
| | E-R5 | x | | | | 9 |
| | E-R5a | x | | | | 9 |
| | E-R6 | x | | | | 9 |
| | E-R7 | x | | | | 10b |
| | E-R8a | x | | | | 10b |
| AEP sites | AEP-P2 | x | | | x | 11 |
| | AEP-P3 | | | | x | 11 |
| | AEP-S2 | | | | | 1 |

[z] All sites were sampled for nutrients, salinity parameters, metals, bacteria, and pesticides. In addition, selected sites were sampled for glyphosate, glufosinate and AMPA (G), pathogens (P), veterinary pharmaceuticals (VP) and FoodNet (FN) pathogen samples collected for the Public Health Agency of Canada in 2014.

[y] Additional veterinary pharmaceuticals sites were sampled in 2014.

**Table 2.2. Irrigation return sites (n=41) sampled in 2014.**

| Watershed return (n=19) | | Infrastructure return (n=22) | |
|---|---|---|---|
| M-R1 | BR-R2 | MV-R1 | SME-R1a |
| R-R1 | BR-R3 | A-R1 | SMW-R2 |
| R-R2 | BR-R4 | U-R2 | W-R1a |
| LN-R1 | BR-R7 | U-R3 | BR-R1 |
| LN-R2 | E-R1a | U-R4 | BR-R5 |
| SME-R2 | E-R2a | LN-R3 | E-R1 |
| SMW-R1 | E-R3a | LN-R4 | E-R2 |
| W-R2 | E-R5a | T-R1 | E-R3 |
| | E-R6 | T-R2 | E-R4a |
| | E-R7 | SMC-R1 | E-R5 |
| | E-R8a | SMC-R3 | |
| | | SMC-R4 | |

Of the 13 irrigation districts, 12 were sampled in 2014: Mountain View (MVID), Aetna (AID), United (UID), Magrath (MID), Raymond (RID), Lethbridge Northern (LNID), Taber (TID), St. Mary River (SMRID), Ross Creek (RCID), Western (WID), Bow River (BRID), and Eastern (EID). Even though there are no sampling sites in the Leavitt Irrigation District (LID), source water quality upstream of the LID was monitored.

All sampling sites were marked with a sign and their Global Positioning System coordinates were recorded. Descriptions of the sampling sites and irrigation districts have been previously reported by Charest et al. (2012, 2013, and 2014).

## 2.2 Water Sampling

### 2.2.1 Main Parameter Suite Samples

All sites were grab sampled four times during the 2014 irrigation season for the analysis of nutrients, salinity, and physical parameters as wells as for metals, bacteria, and pesticides . Sampling was carried out from early June to the beginning of September. The four sampling events in 2014 were separated by four weeks (Table 2.3). Three to four consecutive days were required to sample all sites in each sampling event. The sites were grouped into 15 sampling areas (Figure 2.1 and Table 2.1). In 2014, the sampling Area 6 was divided into Area 6a and 6b (Figure 2.1) to accommodate the Land Use Study (Chapter 5). For three of the four sampling events, the sampling sites were sampled on Tuesday, Wednesday, or Thursday of the same week.

In July, four days were required to accommodate laboratory processing times of microbiology analysis associated with the Land Use Study (Table 2.3).

A quality assurance and quality control (QA/QC) field and laboratory protocol was followed. As required, QA/QC samples were collected at randomly selected sites during each sampling time. Methods and results of QA/QC are detailed in Appendix C.

**Table 2.3. Sampling dates in 2014 for most parameters except for pathogens[z].**

| | Sampling area | | |
|---|---|---|---|
| Sampling event | 6a, 6b, 9, 11,12 | 1, 2, 3, 4a, 4b | 5, 7, 8, 10a, 10b |
| 1 | June 10 | June 11 | June 12 |
| 2[y] | July 7 | July 8 | July 9, 10 |
| 3 | August 8 | August 6 | August 7 |
| 4 | September 2 | September 3 | September 4 |

[z] See Table 2.6 for pathogen sampling information.
[y] During the second sampling event four consecutive days were used for sampling. Monday: Areas 6a, 6b, 11, and 12; Tuesday: Areas 1, 2, 3, 4a, and 4b; Wednesday: Areas 5, 7 and 8 and Thursday: Areas 9, 10a and 10b.

Grab samples were collected using a 1-L polyethylene bottle, which was pre-washed with double distilled water, attached to a telescopic pole. The bottle was filled by pointing the bottle opening upstream to the flow, as far into the middle of the channel as possible, and about mid-depth to avoid sampling the water surface or disturbing the bottom sediment. The sampling bottle was triple rinsed with water from the canal, and the rinse water emptied downstream of the sample site. A new sampling bottle was used at each site to fill all laboratory sample bottles.

At each site, the sampling bottle was used to fill several laboratory bottles, and samples in the laboratory bottles were analyzed for one or more parameters (Table 2.4). Most of the laboratory bottles were triple rinsed and then filled with irrigation water. Once the bottles were filled, acid preservatives were added to nutrient, total nitrogen (TN), and metal bottles. All bottles were labeled with site name, date, time, and parameter type. Latex gloves and appropriate safety equipment were used to fill all bottles and handle the acid preservatives. Samples were placed in coolers with ice while in the field.

Sample bottles for routine, nutrient, TN, metals, and *Escherichia (E. coli)* were packed in coolers with ice and shipped to Exova Group Limited (Exova) in Calgary, Alberta, to arrive before 9:00 a.m. the following morning via courier, or by driving to Calgary immediately after sampling was completed in Areas 9, 10a, 10b, 11, and 12. The 1-L pesticides bottles and 1-L pharmaceutical bottles were kept in a refrigerator at 4ºC. The pesticide samples were analyzed by Agriculture and Agri-Food Canada (AAFC) in Lethbridge and the pharmaceutical samples were shipped to the National Hydrology Research Centre (NHRC) in Saskatoon, Saskatchewan. Most QA/QC

duplicate samples and blank samples were refrigerated until analyzed by the Alberta Agriculture and Forestry (AF) laboratory.

The number of sample associated for each project component is presented in Table 2.5. The details on number of sample collected is described in different chapters; comprehensive including pesticides and pharmaceuticals, and pathogens sampling - Chapter 3, Oldman River synoptic survey sampling – Chapter 4, land use study sampling - Chapter5, and QA/QC sampling - Appendic C)

**Table 2.4. Laboratory bottles used for water sampling in 2014.**

| Parameter type | Bottle type | Tripled rinsed | Preservative |
|---|---|---|---|
| Routine (Exova) [z] | 500 mL polyethylene | yes | none |
| Nutrient (Exova) [y] | 250 mL polyethylene | yes | 2 mL 9 M sulphuric acid [x] |
| TN (Exova) [w] | 250 mL polyethylene | yes | 2 mL 6 M hydrochloric acid [x] |
| Metals (Exova) | 250 mL polyethylene | yes | 2 mL 8 M nitric acid [x] |
| *E. coli* (Exova) | 300 mL polyethylene | no | 0.2 g sodium thiosulphate [v] |
| Pathogen [u]: | | | |
| Pathogen (ProvLab) | 1 L polyethylene | no | four tablets – 40 mg total [v] |
| *E. coli* (Exova) | 300 mL polyethylene | no | 0.2 g sodium thiosulphate [v] |
| VTEC (PHAC) [t] | 500 mL polyethylene | yes | none |
| Pesticides (AAFC) [s] | 1 L amber glass[t] | no | none |
| Pesticides (AI) [r] | 125 mL polyethylene | yes | none |
| Pharmaceuticals (NHRC) | 1 L amber glass | no | none |

[z] Routine analysis included $NO_2$-N, $NO_3$-N, Ca, Mg, Na, K, $CaCO_3$, OH, $CO_3$, $HCO_3$, Cl, $SO_4$, pH, EC, TDS, and TSS.
[y] Nutrient analysis included $NH_3$-N, TDP, TP, and DRP.
[x] Acid solutions were prepared by diluting concentrated acids with water.
[w] TN = total nitrogen.
[v] Preservative was in the bottle prior to filling with sample water.
[u] Pathogen samples were collected at selected sites (Table 2.1) and on different days than shown in Table 2.3 (July 14, July 21, August 18, and August 25).
[t] VTEC (Verocytotoxigenic *E. coli*) samples were collected in sampling Areas 11 and 12 during regular sampling and Area B during pathogen sampling (Table 2.1).
[s] The inside of the screw-cap was lined with aluminum foil.
[r] Pesticides from Alberta Innovates were collected at selected sites (Table 2.1).
AAFC = Agriculture and Agri-Food Canada, Lethbridge, Alberta.
AI = Alberta Innovates – Technology Futures, Vegreville, Alberta.
NHRC= National Hydrology Research Centre, Saskatoon, Saskatchewan.
ProvLab = Provincial Laboratory, Edmonton, Alberta.
PHAC = Public Health Agency of Canada, Guelph, Ontario.

Sampling sheets were used to record all relevant field data and observations from each sampling site. These included weather conditions, date and time of sample, requisition number, water temperature, stage of water where a staff gauge was present, visual turbidity, and other observations relevant to water quality.

**Table 2.5. Number of samples associated with different project components.**

| Project component | Expected samples | Missed samples | Quality control samples [z] | Samples utilized for the analysis |
|---|---|---|---|---|
| Comprehensive (Exova) | 425 [y] | 3 [x] | 65 | 357 |
| Pesticides (AAFC) | 372 | 2 [x] | 12 | 358 |
| Pesticides (Ab Innovates) | 119 | 1 [x] | 3 | 115 |
| Pharmaceuticals | 97 | 0 | 1 | 96 |
| Pathogens | 42 | 2 [w] | | 40 |
| Oldman River Synoptics | 55 | 0 [v] | | 55 |
| Land use | 252 [u] | 25 [t] | 2 [s] | 225 [r] |

[z] Includes blanks, duplicates, check standard and other quality control samples not to be included in the data analysis

[y] These includes 15 samples that were used for both the comprehensive and land use project components (Land use analysis was done with 266 samples) .

[x] One sample was missed due to an access issue and, two samples were lost by the courier during shipping to Exova lab, and one pesticide bottle broke.

[w] Samples lost in the courier.

[v] Some sites were not flowing and were not sampled.

[u] Samples collected exclusively for the land use study. These include 15 preliminary samples. For these, all parameters except pesticides were analyzed using a different lab (Alberta Agriculture and Rural Department in Lethbridge) instead of Exova.

[t] Five samples to Exova were lost by courier, and 20 samples could not be collected because there was no flow.

[s] Preliminary samples from T-LU6 and T-LU8 were collected once.

[r] 15 of these samples were from upstream sites with poor flow connectivity of their associated downstream sites and were removed from some analysis.

### 2.2.2 Fecal Pathogen and Generic *E. coli* Samples

The same sub-set of 21 sample sites (Figure 2.2) used in 2013 (Charest et al. 2014) were also sampled in 2014 for the quantification of generic *E. coli* and pathogen analyses of *Salmonella, E. coli* O157:H7, and *Campylobacter* (Tables 2.1 and 2.6). Due to the limited capacity of the Provincial Laboratory for Public Health of Alberta Health Services (ProvLab – Edmonton site) and cost to process samples, there were a limited number of sites that could be sampled. The rational for the site selection is described in Charest et al. (2014).

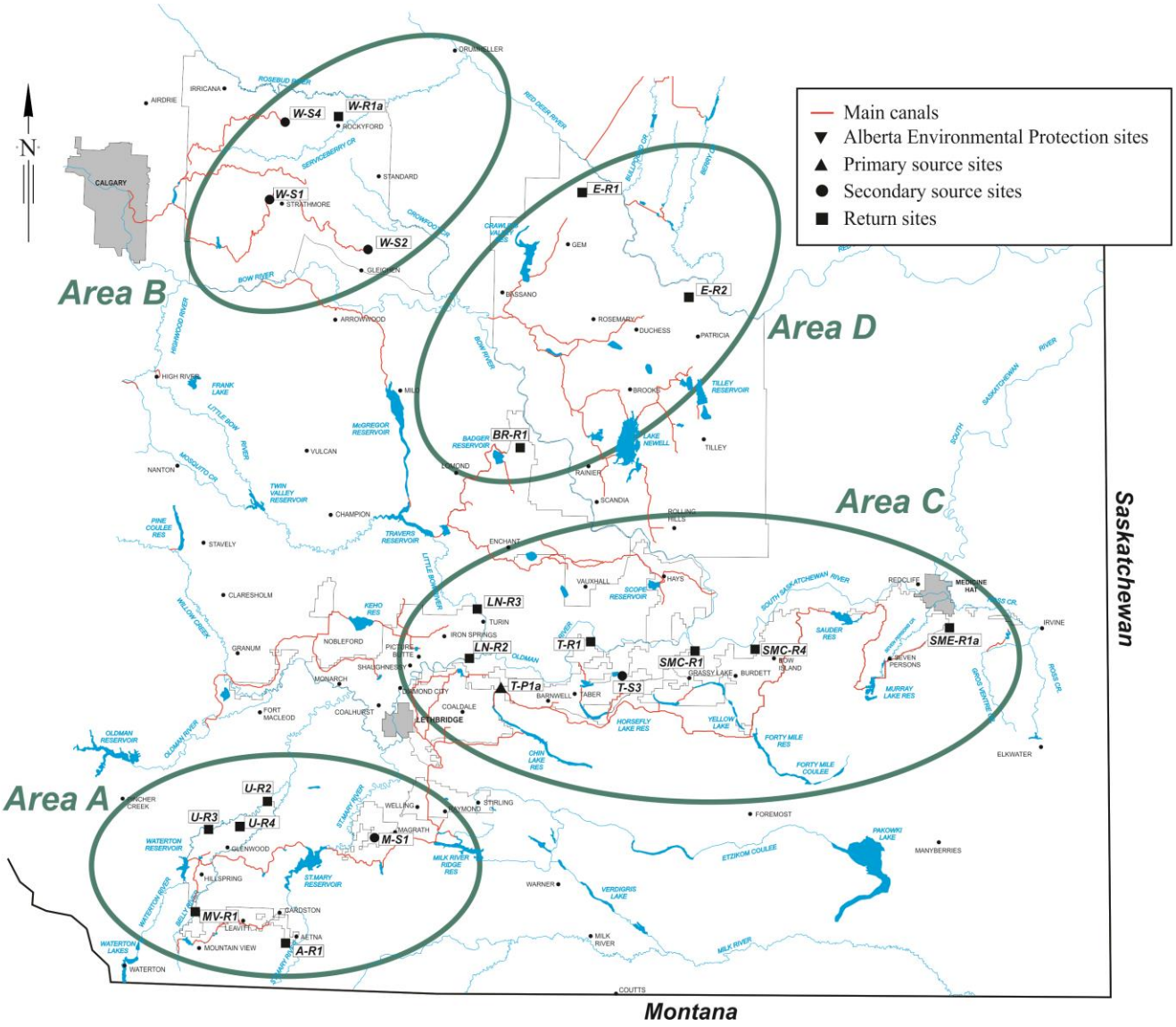


**Figure 2.2. Location of the pathogen sampling sites and sampling areas in 2014.**

The pathogen sampling sites were divided into four areas (Figure 2.2 and Table 2.6) and each site was sampled twice, once in July and once in August. Note that August samples from sites LN-R2 and LN-R3 were lost due to a courier error. Areas A and B were sampled on the same days and Areas C and D were sampled on the same days (Table 2.6). Water was collected following the grab sampling protocol previously described using a 1-L polyethylene bottle attached to a telescopic pole. The 1 L bottle was used to fill the pathogen bottle (1 L) and the generic *E. coli* bottle (300 mL) (Table 2.4). For the sites in Area B, a Foodnet bottle (500 mL) was also filled as well. Once collected and placed into the appropriate bottle, water samples were stored with ice packs in a cooler while in the field.

The 300-mL bottles were shipped to Exova Group Limited (Exova) in Calgary, Alberta for the quantification of generic *E. coli* and the 1-L bottles were shipped to the ProvLab in Edmonton, Alberta for pathogen analyses. Courier services were used to ship the samples from Areas A and C to their assigned destination for arrival by 9:00 a.m. the following morning. Samples from Areas B and D were delivered to the Exova Group Limited in Calgary immediately after sampling was completed. Field sheets were completed for the samples (including the date and time a sample was collected, site observations, etc.) and a requisition form was completed for any samples shipped to the ProvLab.

**Table 2.6 Pathogen sampling dates, areas, and sites in 2014.**

| July 14 and August 18 | | July 21 and August 25 | |
|---|---|---|---|
| Area A | Area B | Area C | Area D |
| A-R1 | W-S1 | LN-R2[z] | BR-R1 |
| M-S1 | W-S2 | LN-R3[z] | E-R1 |
| MV-R1 | W-S4 | SMC-R1 | E-R2 |
| U-R2 | W-R1a | SMC-R4 | |
| U-R3 | | SME-R1a | |
| U-R4 | | T-P1a | |
| | | T-R1 | |
| | | T-S3 | |

[z] LN-R2 and LN-R3 samples from August 25 were lost by the courier.

The FoodNet (PHAC 2015) samples were collected at the ten sites Area's 11 and 12 (Figure 2.1) on the four sampling dates in conjunction with the main suite of IDWQ parameters (Table 2.3) , as well as the four sites in Area B (Figure 2.2) during the pathogen sampling dates (Table 2.6). A 500-mL bottle was used to collect a sample for the analysis Verocytotoxigenic *E. coli* (VTEC) specifically for the FoodNet project (Table 2.4). The 500-mL VTEC bottle was sent to the Public Health Agency of Canada (PHAC) laboratory in Guelph, Ontario for analysis. As part of the collaboration with the PHAC, the pathogen and generic *E. coli* analysis results from the FoodNet samples were shared with PHAC.

### 2.2.3 Glyphosate, Glufosinate and AMPA Samples

A total of 58 sites, including all irrigation returns and a few other selected sites, were sampled for glyphosate, glufosinate and aminomethylphosphonic (AMPA) analysis 2014 (Table 2.1), similar to 2012 and 2013. The samples were collected only during the first (June 10 to 12) and last (September 2 to 4) sampling events to limit analytical cost. The pesticide bottles for these three parameters were triple rinsed before filling (Table 2.4) and then placed on ice while in the field and transferred to a refrigerator at 4°C until shipped the following Monday morning. These

samples were shipped on ice via courier for analysis to Alberta Innovates-Technology Futures (AI) in Vegreville, Alberta.

### 2.2.4 Veterinary Pharmaceutical Samples

In collaboration with Dr. Francis Larney of AAFC, 24 sites in eight irrigation districts were selected for veterinary pharmaceuticals analysis in 2014 (Table 2.1).These sites included the 15 sites that were sampled in 2013 (Charest et al. 2014). Secondary and return sites were chosen based on the fecal coliform results from previous sampling years, location relative to intensive livestock operations and the 2013 results. Pharmaceutical samples were collected during the four sampling events in 2014 (Table 2.3). Samples were collected in 1-L amber glass bottles and stored at 4$^{o}$C prior to extraction and analysis. Samples were analyzed for monesin, lincomycin, erythromycin, tylosin, sulfamethazine, chlortetracycline, and tetracycline. Laboratory analysis was carried out at the National Hydrology Research Centre (NHRC), Saskatoon, Saskatchewan.Samples were transported on ice in coolers to the NHRC.

## 2.3 Laboratory Water Quality Analyses

Water samples were analyzed by Exova for nutrients, salinity, physical, and biological parameters (Table 2.7), and for metals (Table 2.8). Glyphosate, glufosinate, and AMPA were analyzed by AI. All other pesticides were analyzed by AAFC in Lethbridge (Tables 2.9 to 2.11). The pharmaceutical samples (Table 2.12) were analyzed at the NHRC in Saskatoon and the pathogen samples by Alberta Heath Services Provincial Laboratory in Edmonton.

Analytical methods, method detection limits, and water quality guideline values for irrigation, livestock water, protection of aquatic life, and recreation for the water quality parameters analyzed by Exova, AI and AAFC are presented in Tables 2.7 to 2.11. Limit of quantification of the veterinary pharmaceutical analyzed by the NHRC is presented in Table 2.12. No water quality guideline exists for veterinary pharmaceuticals. Previously in the study the Canadian Environmental Quality Guidelines (CCME 1999, 2005) were used to calculate Water Quality Indices (Chapter 3). In 2014, the Alberta government released the Environmental Quality Guidelines for Alberta Surface Waters (ESRD 2014), and these guidelines are more up to date than the CCME guidelines. Therefore, the ESRD (2014) guidelines were used in this progress report.

**Table 2.7. Nutrients, salinity, physical, and biological parameters analyzed, analytical methods, method detection limits (MDL), and water quality guideline types and values.**

| Parameter | Abbr. | Unit | Method | MDL | Guideline type[z] | Guideline |
|---|---|---|---|---|---|---|
| | | | *Nutrients* | | | |
| Ammonia nitrogen | $NH_3$-N | mg $L^{-1}$ | APHA 4500-NH3 G. Automated phenate | 0.05 | PAL[y] | 0.018 -190[x] |
| Nitrate nitrogen | $NO_3$-N | mg $L^{-1}$ | APHA 4110 B. Ion chromatography | 0.01 | PAL | 3.0 |
| Nitrite nitrogen | $NO_2$-N | mg $L^{-1}$ | APHA 4110 B. Ion chromatography | 0.005 | PAL | 0.02-0.60 |
| | | | | | Livestock | 10 |
| Total nitrogen | TN | mg $L^{-1}$ | Combustion with chemiluminescense detection | 0.06 | | |
| Dissolved reactive phosphorus | DRP | mg $L^{-1}$ | APHA 4500-P E. Ascorbic acid | 0.005 | | |
| Total phosphorus | TP | mg $L^{-1}$ | APHA 4500-P B.5 Persulfate digestion. APHA 4500-P E. Ascorbic acid | 0.005 | | |
| Total dissolved phosphorous | TDP | mg $L^{-1}$ | APHA 4500-P B.5 Persulfate digestion. APHA 4500-P E. Ascorbic acid | 0.005 | | |
| | | | *Salinity* | | | |
| Conductivity | EC | dS $m^{-1}$ | APHA 2320 B. Titration | 0.001 | | |
| Calcium, dissolved | Ca | mg $L^{-1}$ | APHA 3120 B. ICP (OES) | 0.2 | Livestock | 1000 |
| Magnesium, dissolved | Mg | mg $L^{-1}$ | APHA 3120 B. ICP (OES) | 0.2 | | |
| Sodium, dissolved | Na | mg $L^{-1}$ | APHA 3120 B. ICP (OES) | 0.4 | | |
| Potassium, dissolved | K | mg $L^{-1}$ | APHA 3120 B. ICP (OES) | 0.4 | | |
| Sodium adsorption ratio | SAR | mg $L^{-1}$ | Calculated | | Irrigation | 5 |
| Hardness (as $CaCO_3$) | Hard | mg $L^{-1}$ | APHA 4110 B. Ion chromatography | 1 | | |
| Total alkalinity (as $CaCO_3$) | Alk | mg $L^{-1}$ | APHA 2320 B. Titration | 5 | PAL | 20 |
| Hydroxide (as $CaCO_3$) | OH | mg $L^{-1}$ | APHA 2320 B. Titration | 5 | | |
| Carbonate (as $CaCO_3$) | $CO_3$ | mg $L^{-1}$ | APHA 2320 B. Titration | 6 | | |
| Bicarbonate (as $CaCO_3$) | $HCO_3$ | mg $L^{-1}$ | APHA 2320 B. Titration | 5 | | |
| Sulphate | $SO_4$ | mg $L^{-1}$ | APHA 4110 B. Ion chromatography | 0.9 | Livestock | 1000 |
| Chloride | Cl | mg $L^{-1}$ | APHA 4110 B. Ion chromatography | 0.4 | PAL | 120 |
| | | | | | Irrigation | 100-710 |
| Ion balance | Ion | % | Calculated | | | |
| Total dissolved solids | TDS | mg $L^{-1}$ | APHA 1030 F. Checking for correctness | 1 | Irrigation | 500-3500 |
| | | | | | Livestock | 3000 |
| | | | *Physical and biological* | | | |
| pH | pH | | APHA 4500-H+B. Electrometric | | PAL | 6.5-9.0 |
| Temperature | Temp | °C | *In situ* | 0.1 | | |
| Total suspended solids | TSS | mg $L^{-1}$ | APHA 2540 D. Total suspended solids Dried at 103-105°C | 1 | | |
| *Escherichia coli* | Ecoli | CFU 100 $mL^{-1}$ | APHA 9222 G Membrane filtration partition procedure | 1 | Irrigation | 100 |
| | | | | 1 | Recreation | 126[w] |

[z] Environmental Quality Guidelines for Alberta Surface Waters (ESRD 2014).
[y] PAL = Protection of aquatic life.
[x] Ammonia guideline varies based on pH and temperature (CCME 1999).
[w] Guidelines for Canadian recreational water quality from Health Canada (2012).

**Table 2.8. Metals analyzed (totals), method detection limits (MDL)[z], and water quality guidelines.**

| | | | Guidelines[y] | | |
|---|---|---|---|---|---|
| | | MDL | Protection of aquatic life | Irrigation | Livestock water |
| Parameter | Abbr. | ---------- ($\mu g\ L^{-1}$) ---------- | | | |
| Aluminum | Al | 20 | 50 or calculated if pH < 6.5<br>100 or calculated if pH ≥ 6.5 | 5000 | 5000 |
| Antimony | Sb | 0.2 | - | - | - |
| Arsenic | As | 0.2 | 5 | 160 | 25 |
| Barium | Ba | 1 | - | - | - |
| Beryllium | Be | 0.1 | - | 100 | 100 |
| Boron | B | 2 | 1500 | 500-6000 | 5000 |
| Cadmium | Cd | 0.01 | 0.04- 0.37[x] | 8.2 | 80 |
| Chromium | Cr | 0.5 | 1 | 4.9 | 50 |
| Cobalt | Co | 0.1 | 2.5 | 50 | 1000 |
| Copper | Cu | 1 | 0.9-62 [x] | 200-1000 | 500-5000 |
| Iron | Fe | 50 | 300 | 5000 | - |
| Lead | Pb | 0.1 | 1-7 [x] | 200 | 100 |
| Lithium | Li | 1 | - | 2500 | - |
| Manganese | Mn | 5 | - | 200 | - |
| Mercury | Hg | 0.005 [w] | 0.005 | - | 3 |
| Molybdenum | Mo | 1 | 73 | 10 | 500 |
| Nickel | Ni | 0.5 | 4-170[x] | 200 | 1000 |
| Selenium | Se | 0.2 | 1 | 20-50 | 50 |
| Silver | Ag | 0.01 | 0.1 | - | - |
| Thallium | Tl | 0.05 | 0.8 | - | - |
| Tin | Sn | 1 | - | - | - |
| Titanium | Ti | 0.5 | - | - | - |
| Uranium | U | 0.5 | 15 | 10 | 200 |
| Vanadium | V | 0.1 | - | 100 | 100 |
| Zinc | Zn | 1 | 30 | 1000-5000 | 50000 |

[z] Analytical method for metals was APHA 3125B/USEPA 200.8 (ICP/MS), except for mercury, which was analyzed using the cold-vapor atomic absorption spectrometry for mercury in sediment (USEPA 245.7 method).

[y] Environmental Quality Guidelines for Alberta Surface Waters (ESRD 2014).

[x] Hardness dependent guideline.

[w] New analytical method and MDL for mercury in 2014.

**Table 2.9. Herbicides analyzed, method detection limits (MDL), and water quality guidelines.**

| Herbicide [y] | Abbr. | MDL | Guidelines [z] | | |
|---|---|---|---|---|---|
| | | | Protection of aquatic life | Irrigation | Livestock water |
| | | | ---------- (µg $L^{-1}$) ---------- | | |
| *2,4-D | 2,4D | 0.025 | 4 | - | 100 |
| *2,4-DB | 2,4DB | 0.025 | 25 | - | 100 |
| *2,4-DCP | 2,4DCP | 0.140 | 25 | - | 100 |
| Alachlor | ALAC | 0.025 [w] | - | - | - |
| Allidochlor | ALLI | 0.025 | - | - | - |
| Aminomethylphosphonic acid [x] | AMPA | 0.1 [w] | - | - | - |
| *Atrazine | ATRA | 0.025 | 1.8 | 10 | 5 |
| Benfluralin | BENF | 0.025 | - | - | - |
| Bentazon | BENT | 0.025 | - | - | - |
| Benzoylprop-Ethyl | BENZ | 0.025 | - | - | - |
| *Bromacil | BROC | 0.025 | 5 | 0.2 | 1100 |
| *Bromoxynil | BROX | 0.024 [w] | 5 | 0.44 | 11 |
| Butachlor | BUTA | 0.079 | - | - | - |
| Butralin | BUTR | 0.025 | - | - | - |
| Butylate | BUTY | 0.026 | - | - | - |
| Chlorthiamid | CHTM | 0.026 | - | - | - |
| Clodinafop-propargyl [v] | CLOD | 0.150 | - | - | - |
| Clomazone | CLOM | 0.025 | - | - | - |
| *Clopyralid | CLOP | 0.025 | - | - | - |
| Cycloate | CYCL | 0.025 [w] | - | - | - |
| Desmetryne | DESM | 0.026 | - | - | - |
| *Dicamba | DICM | 0.024 | 10 | 0.008 | 122 |
| Dichlobenil | DICB | 0.025 | - | - | - |
| *Dichlorprop | DCPR | 0.025 [w] | 4 | - | - |
| *Diclofop | DICF | 0.026 | 6.1 | 0.24 | 9 |
| Dimethachlor | DIMC | 0.026 | - | - | - |
| Diphenamid | DIPH | 0.026 [w] | - | - | - |
| EPTC | EPTC | 0.025 | - | - | - |
| *Ethalfluralin | ETFL | 0.120 | - | - | - |
| Ethofumesate | ETHO | 0.025 | - | - | - |
| *Fenoxapropl | FENO | 0.368 | - | - | - |
| Flamprop-Isopropyl | FLAI | 0.025 [w] | - | - | - |
| Flamprop-Methyl | FLAM | 0.025 | - | - | - |
| Fluroxypyr | FLUR | 0.025 | - | - | - |
| Glyphosate [x] | GLYP | 0.1 [w] | 65 | - | 280 |
| Glufosinate [x] | GLYF | 1.000 | | | |
| *Imazethapyr | IMAZ | 0.115 | - | - | - |
| *MCPA | MCPA | 0.025 | 2.6 | 0.04 | 25 |
| *Mecoprop | MCPP | 0.025 | 13 | - | 100 |
| Metolachlor | METO | 0.025 | 7.8 | 28 | 50 |
| *Picloram | PICL | 0.025 | 29 | - | 190 |
| Prometon | PROM | 0.025 | - | - | - |
| Propham | PROP | 0.026 | - | - | - |
| Propyzamide | PROA | 0.025 | - | - | - |
| *Quinclorac | QUIN | 0.026 | | - | 100 |
| Simazine | SIMA | 0.025 | 10 | 0.5 | 10 |
| Terbacil | TEBC | 0.092 | - | - | - |
| Terbutryne | TRBY | 0.025 | - | - | - |
| *Triallate | TRAL | 0.025 | 0.24 | - | 230 |
| Triclopyr | TRIC | 0.025 | - | - | - |
| *Trifluralin | TRFL | 0.026 | 0.2 | - | 45 |

[z] Environmental Quality Guidelines for Alberta Surface Waters (ESRD 2014).
[y] Herbicides with an asterisk were analyzed by Little et al. (2010) during the 2006-2007 study.
[x] Parameter analyzed by Alberta Innovates. All other parameters were analyzed by Agriculture and Agri-Food Canada.
[w] Mean detection limit value did not change from 2013.
[v] New herbicide added to the main pesticide suite in 2014.

**Table 2.10. Insecticides analyzed, method detection limits (MDL), and water quality guidelines.**

| Insecticide [y] | Abbr. | MDL | Guidelines [z] Protection of aquatic life | Irrigation | Livestock water |
|---|---|---|---|---|---|
| | | ---------- (µg $L^{-1}$) ---------- | | | |
| *Aldrin | ALDR | 0.025 | ~~0.004~~ [x] | - | - |
| Bifenthrin | BIFE | 0.025 | - | - | - |
| Bromophos-Ethyl | BRO-E | 0.026 | - | - | - |
| Chlordane (*cis*-Chlordane) | CCHL | 0.025 | ~~0.006~~ | - | ~~7~~ |
| Chlordane (*trans*-Chlordane) | TCHL | 0.025 | ~~0.006~~ | - | ~~7~~ |
| Chlormephos | CHMP | 0.026 | - | - | - |
| *Chlorpyrifos | CHPY | 0.025 | 0.002 | - | 24 |
| Chlorpyrifos-Methyl | CHLM | 0.050 | - | - | - |
| Chlorthal-Dimethyl | CHLD | 0.025 | - | - | - |
| DDD (*op'*-DDD) | opDDD | 0.025 | - | - | - |
| DDD (*pp'*-DDD) | ppDDD | 0.025 | - | - | - |
| *DDE (*op'*-DDE) | opDDE | 0.050 | - | - | - |
| *DDE (*pp'*-DDE) | ppDDE | 0.025 | - | - | - |
| DDT (*op'*-DDT) | opDDT | 0.025 | ~~0.001~~ | - | ~~30~~ |
| DDT (*pp'*-DDT) | ppDDT | 0.059 | ~~0.001~~ | - | ~~30~~ |
| Diazinon | DIAZ | 0.025 | - | - | - |
| Dichlorvos | DICV | 0.068 | - | - | - |
| *Dieldrin | DIEL | 0.025 | ~~0.004~~ | - | - |
| *Dimethoate | DIME | 0.967 | 6.2 | - | 3 |
| Dioxathion | DIOX | 0.145 | - | - | - |
| Endosulfan | ENDO | 0.085 | 0.003 | - | - |
| Endrin | ENDR | 0.025 | ~~0.0023~~ | - | ~~0.2~~ |
| Ethion | ETHI | 0.045 | - | - | - |
| Etrimphos | ETRI | 0.026 | - | - | - |
| Fenchlorphos | FENC | 0.025 | - | - | - |
| Fenthion | FENT | 0.026 | - | - | - |
| Fonofos | FONO | 0.026 | - | - | - |
| HCH (α-HCH) [w] | a-HCH | 0.025 | 0.01 [v] | - | |
| HCH (β-HCH) [w] | b-HCH | 0.025 | 0.01 [v] | - | |
| HCH (δ-HCH) [w] | d-HCH | 0.154 | 0.01 [v] | - | |
| *HCH (γ-HCH) [w] (Lindane) | LIND | 0.025 | 0.01 [v] | - | 4 |
| *Heptachlor | HEPT | 0.025 | ~~0.01~~ | - | ~~3~~ |
| *Heptachlor Epoxide (*trans*-Heptachlor Epoxide) | HEPE | 0.071 | ~~0.01~~ | - | ~~3~~ |
| Isofenphos | ISOF | 0.051 | - | - | - |
| *Methoxychlor | METC | 0.025 | - | - | - |
| Mirex | MIRE | 0.025 | - | - | - |
| Permethrin (*cis*-Permethrin) | CPER | 0.024 | 0.004 [w] | - | - |
| Permethrin (*trans*-Permethrin) | TPER | 0.025 | 0.004 [w] | - | - |
| Phorate | PHOR | 0.041 | - | - | - |
| Pirimicarb | PICA | 0.026 | - | - | - |
| Pirimiphos-Ethyl | PIRE | 0.059 | - | - | - |
| Pirimiphos-Methyl | PIRM | 0.025 | - | - | - |
| Sulfotep | SULF | 0.026 | - | - | - |
| Sulprophos | SULP | 0.025 | - | - | - |
| Terbufos | TEBF | 0.044 | - | - | - |

[z] Environmental Quality Guidelines for Alberta Surface Waters (ESRD 2014).

[y] Insecticides with an asterisk were analyzed by Little et al. (2010) during the 2006-2007 study.

[x] Strikethrough guideline values are no longer recommended (ESRD 2014)

[w] Hexachlorocyclohexane (HCH) is also known as benzene hexachloride (BHC).

[v] Guideline applies to the sum of all isomers.

**Table 2.11. Other pesticides (non- herbicide or insecticide) analyzed, method detection limits (MDL), and guideline values.**

| | | | | Guidelines | | |
|---|---|---|---|---|---|---|
| Pesticide | Abbr. | MDL (µg $L^{-1}$) | Pesticide type | Protection of aquatic life | Irrigation | Livestock water |
| | | | | ---------- (µg $L^{-1}$) ---------- | | |
| Benalaxyl | BENA | 0.025 | Fungicide | - | - | - |
| Bromoprophylate | BROP | 0.053 | Acaricide | - | - | - |
| Bupirimate | BUPI | 0.025 | Fungicide | - | - | - |
| Chloroneb | CHRN | 0.025 | Fungicide | - | - | - |
| Diclofenthion | DICL | 0.030 | Nematicide | - | - | - |
| Etradiazole | ETRA | 0.036 | Fungicide | - | - | - |
| Flumentralin | FLUM | 0.052 | Growth reg. | - | - | - |
| Nitrapyrin | NITR | 0.033 | Bactericide | - | - | - |
| Procymidone | PROC | 0.037 | Fungicide | - | - | - |
| Propiconazole [z] | PROI | 0.074 | Fungicide | - | - | - |
| Quintozene | QUIT | 0.040 | Fungicide | - | - | - |
| Tetradifon | TEFO | 0.022 | Acaricide | - | - | - |
| Tetrasul | TESU | 0.025 | Acaricide | - | - | - |

[z] New fungicide added to the main pesticide suite in 2014.

The analyzed parameters and methods were generally the same for 2013 and 2014. The AAFC pesticide analytical method was adapted from Bruns et al. (1991) and Hill et al. (2002). Additional method details were reported in Charest et al. (2012). Specific method detection limit (MDL) for each pesticide changed slightly annually (Tables 2.9 to 2.11). One new herbicide (Clodinafop-propargyl) and one new fungicide (Propiconazole) were added in 2014.

The analysis of glyphosate, AMPA, and glufosinate was based on work by Tsunoda (1993) and Alferness and Iwata (1994). In this method, glyphosate, AMPA, and glufosinate are derivatized with trifluoroacetic anhydride (TFA) and heptafluorobutanol (HFB). The TFA reacts with the amine functional groups to form the corresponding trifluoroaectyl derivatives while the HFB reacts with the phosphoric and acetic acid functional groups to form the corresponding heptafluorobutal esters. Analysis was by gas chromatography–mass spectrometry (GC-MS) using a Varian Ion Trap with phenanthrene-d10 as an internal standard.

### 2.3.1 Pathogens and Indicator Bacteria

Generic *E. coli* were analyzed by Exova using a membrane filtration method. Results were expressed in colony forming units (CFU) 100 $mL^{-1}$. Water samples were not analyzed for fecal coliforms in 2014 since these data were highly correlated with generic *E. coli* in previous years (Charest et al. 2012, 2013, and 2014).

The generic *E. coli* data obtained from samples included in the pathogen analyses were analyzed separately from the data associated with samples from the main irrigation water quality study, which included analysis of numerous chemical and biological parameters, and were not used to calculate water quality indices because the sampling dates were different and included a limited number of sites.

Pathogen samples were analyzed using culture- and molecular-based methods to determine the presence or absence of *Campylobacter, E. coli* O157:H7, and *Salmonella.* A new quantitative assessment of, *Campylobacter,* and *Salmonella* was performed in 2014. Samples positive for *Campylobacter* or *Salmonella* were further tested to identify the species.

#### 2.3.1.1 *Campylobacter*

To isolate *Campylobacter* spp., 400 mL of water sample was centrifuged (RC-5B centrifuge;Sorvall) at 14,000 x *g* for 20 min. The supernatant was decanted and the pellet re-suspended in 4 mL of Bolton broth (CM0983; Oxoid) with Bolton broth supplement (LC22-05; Dalynn Biologicals) and with a final concentration of 25 mg $L^{-1}$ sulphamethoxazole ([SMX] S7507; Sigma-Aldrich). Three millilitres of the re-supended pellet were aliquoted into three wells of a 96-deep-well, round-bottom plate (780261; Griener BioOne) with a loose fitting hard shell lid (656171; Griener Bio One), according to a miniaturized format for the most probable number (MPN) assay described by Chenu et al. (2013). The three wells were then serially diluted from $10^0$ to $10^{-3}$ using the BB with supplement and SMX media, and incubated at 37ºC under microaerophilic conditions (RE681005; Mitsubishi Gas Chemical Company). After about 42 h of incubation, the initial 96 well enrichment plate was diluted 1:3 into a 0.2-mL v-bottom 96-well plate (651160; Griener BioOne) with a hard shell lid and containing the same media as above, but with the addition of 150 µg $mL^{-1}$ 2,3,5-triphenyltetrazolium solution ([TTC] T8877; Sigma-Aldrich). The second plate was incubated for an additional 22 to 24 h under the same conditions as the initial enrichment plate. An aliquot of all wells in the second enrichment plate was transferred to two separate 96-well plates (652290; Greiner Bio-One with film 676001; Griener Bio-One). One 96-well plate was used for archival of the culture to a final concentration of 10% skim milk (232100, BD Diagnostics) with 15% glycerol (G5516: Sigma-Aldrich), and the second 96-well plate was heated at 95ºC for 10 min to lyse bacterial cells for qPCR (Taqman, Life Technologies) analysis. The qPCR assay included a 16S primer set for detection of *Campylobacter* species (de Boer et al. 2013) and an internal amplification control ([IAC] Deer et al. 2010). The qPCR results, based on a logarithmic amplification curve and a Ct value of $\leq$30, were used to determine presence or absence of *Campylobacter* in the culture well, and generate a MPN for the sample according to Standard Methods of Water and Wastewater, 2013. All qPCR 16S positive wells were streaked onto *Campylobacter* Blood Free ([CBF] PC20; Daylnn Biologicals) agar plates for the isolation of *Campylobacter* (37ºC, microaerophilic conditions, 48 h) for verification. 16S positive wells, as well as suspect *Camylobacter* colonies from CBF plates

(lysed at 95ºC for 10 min), were run by multiplex endpoint PCR (Yamazki-Matsune et al. 2007) to identify putative *Campylobacter* species (*C. jejuni, coli, lari, fetus, upsaliensis*) in addition to organisms belonging to the *Campylobacter* genus (*16S*).

For each sampling period, ongoing precision and recovery (OPR) samples and matrix spikes (MS) were included and processed through the MPN via the same protocol as the samples. Specifically, the OPR consisted of three x 399 mL of autoclaved raw water (from the previous sampling week) with serial dilutions of 1 mL of *C. jejuni* (ATCC 29428), which were concomitantly spread for enumeration on blood agar plates ([BAP] PS58; Dalynn Biologicals) and incubated for 42 h at 37ºC under microaerophillic conditions. Matrix spikes were performed similar to OPR with the exception that 1 mL of the *C. jejuni* serial dilution was added to 399 mL of one of the samples received. One MS sample was chosen randomly for each week of sampling.

#### 2.3.1.2 *Escherichia coli O157*

To isolate *Escherichia coli* O157 (*E. coli*), 100 mL of each water sample were filtered through a sterile 0.45-µm membrane filter (EZHAWG474; EDM Millipore) and the filter placed in modified Tryptic Soy Broth with EHEC supplement (BT86-220, VE20-05; Dalynn Biologicals), then incubated overnight at 35°C. One millilitre of the overnight enrichment broth was processed by immunomagnetic separation (IMS) using anti-O157 antibody-coated Dynabeads (71004; Life Technologies Inc.) as per the manufacturer's instructions. Fifty microlitres of the final Dynabead suspension were plated onto an O157 CHROMagar plate (214984; BD Diagnostics) and incubated for 24 h at 35°C. All mauve colonies were further subcultured on BAP for Vitek identification (Vitek GN ID card 21341 on Vitek 2-Compact; Biomerieux). Slide agglutination with O157 antisera (229701; BD Diagnostics) was performed on all Vitek identified '*E. coli*' isolates. A positive slide agglutination test confirmed that *E. coli* O157 was present in the sample. A positive control of *E. coli* O157:H7 (ATCC 35150) and a filter blank was included each week that samples were processed.

#### 2.3.1.3 *Salmonella*

To isolate *Salmonella* spp., 400 mL of the water sample was centrifuged (RC-5B centrifuge;Sorvall) at 14,000 x *g* for 20 min. The supernatant was discarded and the pellet was re-suspended in 4 mL of Tryptic Soy Broth (211825, BD Diagnostics). As in the *Campylobacter* MPN protocol described above, three x 1 mL serial dilution were performed and incubated at 37ºC for 24 h (i.e., $10^0$ to $10^{-3}$ dilutions). All wells of the TSB enrichment plate were then diluted 1:3 into a second, 96-well plate with RV broth (CM0669; Oxoid) containing 10 mg $L^{-1}$

novobiocin supplement (SR0181; Oxoid) in 0.2-mL, v-bottom 96-well plate covered with a loose fitting lid, and incubated at 42ºC for 16 to 18 h. Contents of the RV selection plate were transferred to two additional 96-well plates: one plate for archival of the culture in skim milk/glycerol (as in the *Campylobacter* protocol) and the other plate for qPCR analysis after heating at 95ºC for 10 min. Extracts of DNA were diluted 1:100 prior to qPCR for *Salmonella* target - invasin A (*invA*) utilizing the primers and probe of Daum et al. (2002) and IAC (as per *Campylobacter* protocol). Wells were deemed positive for *Salmonella* spp. with Ct $\leq$30 and used to generate an MPN. When a qPCR well resulted in a Ct $\leq$36, 10 µL of skim milk/glycerol archive was subcultured to a xylose lysine deoxycholate (XLD) agar plate (PX75, Dalynn Biologicals) and incubated aerobically at 37ºC overnight. Isolated black colonies were subcultured to BAP and processed on the Vitek 2-Compact (Biomerieux) using gram-negative Vitek ID cards (21341; Biomerieux). All Vitek '*Salmonella* group' identifications were sent for molecular serotypying following the 'Check&Trace' *Salmonella* user manual at Calgary ProvLab (the principle of the assay is detailed in Wattiau et al. 2008). *Salmonella* OPR and MS were set up as in the *Campylobacter* protocol using *Salmonella meleagridis* (ProvLab laboratory strain) and processed the same as samples.

### 2.3.2 Veterinary Pharmaceuticals

A liquid chromatography tandem mass spectrometry (LC-MS-MS) analytical method was used for detection and quantification of six veterinary pharmaceuticals. Samples were analyzed within 48 h after sampling by solid-phase extraction (SPE). The eluate from the SPE cartridges was concentrated (1 mL) and the extract analyzed by LC-MS-MS. The limits of quantification (LOQ) for each analyte are included in Table 2.12. Concentrations falling between 50 and 100 % of LOQ were assigned values of 50 % LOQ for statistical purposes (i.e. 1.25 ng $L^{-1}$). Concentrations < 50 % of LOQ were considered 'non-detectable' and were omitted from averaging analyses.

Solid-phase extraction was carried out using conditions as reported in 2013 progress report (Charest et al. 2014) with the following modifications. McIlvaine-EDTA buffer (50 mL per litre sample) was used instead of 0.2 M citric acid buffer. McIlvaine-EDTA buffer (pH 4.0) was prepared by dissolving anhydrous dibasic sodium phosphate (28.4 g) in distilled water (1 L) (phosphate solution). Citric acid monohydrate (21.0 g) was dissolved in distilled water (separate 1 L) to which phosphate solution (625 mL) was added and mixed thoroughly. Disodium EDTA (ethylenediaminetetraacetic acid) dehydrate (60.5 g) was added to the resulting 1.625 L solution. SPE was carried out using a Strata strong anion exchange (SAX) cartridge (55-µm particle size, 500 mg sorbent, Phenomenex, Torrance, California, United States) stacked on top of an Oasis hydrophilic-liphophilic balance (HLB) cartridge (60-µm particle size, 225 mg sorbent, Waters, Milford, Massachusetts, United States) instead of a combination of Oasis weak cation exchange

(WCX) cartridge stacked on top of an Oasis hydrophilic-lipophilic balance (HLB) cartridge. The SAX cartridge was eluted with methanol (10 mL).

**Table 2.12. Veterinary pharmaceuticals selected for analysis.**

| Veterinary pharmaceutical | Class | Limit of quantification (ng $L^{-1}$) |
|---|---|---|
| Monensin sodium | Ionophore | 2.5 |
| Lincomycin | Lincosaminide | 2.5 |
| Erythromycin | Macrolide | 2.5 |
| Tylosin | Macrolide | 2.5 |
| Sulfamethazine | Sulfonamide | 2.5 |
| *Iso*-chlortetracycline [z] | Tetracycline | 2.5 |
| Tetracycline | Tetracycline | 2.5 |

[z] Chlortetracycline irreversibly isomerizes to *iso*-chlortetracycline in water (Cessna et al. 2011) thus *iso*-chlortetracycline was monitored instead of chlortetracycline.

All concentrated extracts were analyzed using a high pressure liquid chromatograph (Waters 2965 Alliance Separation Module, Waters Canada) interfaced with a tandem mass spectrometer (Micromass Quattro Ultima, Waters Canada). The conditions for LC/MS/MS analysis were adapted from Cessna et al. (2011). The water samples were analyzed in sets of eight along with a control sample and a fortified sample.

Liquid chromatographic separation of analytes was achieved using a 50-mm by 2.1-mm i.d. stainless steel column (Kinetex biphenyl, 2.6-µm diameter particle packing, Phenomenex, Torrance, California, United States), a mobile phase flow rate of 0.2 mL $min^{-1}$ and an injection volume of 20 µL. Two mobile phases were used: mobile Phase A was 100 % de-ionized water containing 0.1 % formic acid (v/v) and mobile Phase B was 90 % acetonitrile and 10 % de-ionized water containing 0.1 % formic acid (v/v). Gradient elution (Table 2.13) was used to achieve separation of analytes prior to detection in tandem mass spectrometer. Retention times of all analytes are listed in Table 2.14. Mass spectrometer parameters were optimized for all analytes by infusion of individual standard analyte solutions. Precursor and product ion transitions used for confirmation and quantification are listed in Table 2.14. The sum of two product ion transitions for each analyte was used for quantification and data analysis was carried out using MassLynx software (v 4.1, Waters, Milford, Massachusetts, United States).

Mass spectrometer parameters were optimized for all analytes by infusion of individual standard analyte solutions. Precursor and product ion transitions used for confirmation and quantification are listed in Table 2.14. The sum of two product ion transitions for each analyte was used for

quantification and data analysis was carried out using MassLynx software (v 4.1, Waters, Milford, Massachusetts, USA).

**Table 2.13. Liquid chromatography mobile phase gradient elution timetable.**

| Time (min.) | Mobile Phase A (%) | Mobile Phase B (%) | Flow rate (mL $min^{-1}$) | Curve |
|---|---|---|---|---|
| 0.00 | 85.0 | 15.0 | 0.2 | 1 |
| 2.00 | 85.0 | 15.0 | 0.2 | 11 |
| 20.00 | 0.0 | 100.0 | 0.2 | 6 |
| 20.10 | 85.0 | 15.0 | 0.2 | 1 |
| 25.00 | 85.0 | 15.0 | 0.2 | 1 |

**Table 2.14. Precursor ion-product ion (multiple reaction monitoring-MRM transitions) for lincomycin, tetracycline, *iso*-chlortetracycline, sulfamethazine, $13C_6$-sulfamethazine, erythromycin, $^{13}C_2$-erythromycin, tylosin, and monensin.**

| Pharmaceuticals | Parent ion to product ion transitions (m/z) | Cone voltage (v) | Collision energy (ev) | Retention time (min) |
|---|---|---|---|---|
| Lincomycin | 407.2 > 126.0 | 40.00 | 28.00 | 1.08 |
| | 407.2 > 359.3 | 40.00 | 18.00 | |
| Tetracycline | 445.0 > 410.0 | 20.00 | 20.00 | 1.58 |
| | 445.0 > 427.0 | 20.00 | 10.00 | |
| *Iso*-Chlortetracycline | 478.9 > 443.9 | 16.00 | 22.00 | 1.79 |
| | 478.9 > 461.9 | 16.00 | 22.00 | |
| Sulfamethazine | 279.2 > 155.7 | 35.00 | 18.00 | 1.95 |
| | 279.2 > 185.7 | 30.00 | 16.00 | |
| $^{13}C_6$-Sulfamethazine | 285.0 > 186.0 | 35.00 | 16.00 | 1.96 |
| | 285.0 > 162.0 | 35.00 | 18.00 | |
| Erythromycin | 734.5 > 157.9 | 30.00 | 30.00 | 9.72 |
| | 734.5 > 576.2 | 30.00 | 30.00 | |
| $^{13}C_2$-Erythromycin | 736.5 > 159.9 | 30.00 | 30.00 | 9.73 |
| | 736.5 > 578.2 | 30.00 | 30.00 | |
| Tylosin | 916.6 > 174.0 | 70.00 | 38.00 | 11.09 |
| | 916.6 > 772.4 | 70.00 | 32.00 | |
| Monensin | 693.5 > 461.2 | 85.00 | 40.00 | 18.95 |
| | 693.5 > 675.4 | 85.00 | 40.00 | |

Individual stock solutions of analytical standards were prepared in acetonitrile (100 mg $L^{-1}$). A working solution mixture of all analytes was made from the stock solutions in de-ionised water (1 mg $L^{-1}$) and calibration standards were prepared. A six-point calibration curve (2, 5, 10, 25, 50and 100 ng $L^{-1}$) was established for each analyte.

Control water samples (from Swift Current Creek, Swift Current, Saskatchewan, Canada) were fortified with 10 µL or 50 µL of an aqueous solution of a mixture of *iso*-chlortetracycline, sulfamethazine, tylosin, monensin, lincomycin, erythromycin, and tetracycline, each at 1 mg $L^{-1}$ (equivalent to 20 ng $L^{-1}$ or 100 ng $L^{-1}$). The fortified water was thoroughly mixed and subjected to SPE under the same conditions as described earlier.

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# 3 Water Quality in the Irrigation Districts

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## 3.1 Introduction

This chapter summarizes the results from the analyses of water samples collected in 2014. First, the water quality parameters (i.e., nutrients, salinity and hardness, metals, biological, physical, pesticides and veterinary pharmaceuticals) are presented by comparing results among the irrigation districts, including some comparisons with the 2011, 2012 and 2013 results, which were previously reported by Charest et al. (2012, 2013 and 2014). Then this is followed by a calculation of water quality indices for irrigation, livestock water, protection of aquatic life, and recreation using appropriate surface water quality guidelines.

Interpretation of water quality results is complex because there are often many data points from a large number of samples and variables. Water quality indices are practical reporting tools for comparing results among sites or years, or to depict spatial or temporal trends, as indices combine all data into one simple, numeric or narrative statement. Water quality indices have been used in a number of studies; however, results are most often not comparable unless the same variables, guidelines, and ratings are used. In 2011, 2012 and 2013, Canadian Water Quality Guidelines were used to calculate the indices. In 2014, provincial water quality guideline were updated and used to calculate the indices. To be able to compare the 2014 water quality indices results with those of the previous years, the indices of 2011 to 2013 were recalculated with the revised Environmental Quality Guidelines for Alberta Surface Waters (ESRD 2014).

## 3.2 Methods

### 3.2.1 Sampling

Detailed descriptions of the sites, sampling procedures, and sample analyses are presented in Chapter 2. In brief, a total of 462 samples were collected from 90 sites in 2014. This included 40 samples collected specifically for the analysis of pathogens. Of the other 422 samples, 65 samples were for the quality assurance/quality control (QA/QC) surveillance plan (Appendix C). The remaining 357 samples were used for water quality assessment in the irrigation districts (Table 3.1).

Three samples were missed in 2014. On September 2, the samples from SMC-P1 and T-S3 did not reach the Exova lab for analysis due to complications with the courier service and on September 3, site U-R4 could not be accessed due to rain and poor road conditions. Some analyses were not performed due to missed bottles. On September 3, at site LN-R2, the *E. coli* bottle was missed, and on September 4, at site E-S2, the pesticide bottle broke and therefore the sample was lost. Samples for metals analysis were missed on August 5 for T-S1, T-S2, T-S3, T-R1, T-R2, and SMC-P1. During pathogen sampling, on August 25, samples from sites LN-R2 and LN-R3 arrived one day late to the lab due to a problem with the courier and were not analyzed because they did not meet the holding time.

There were a total of 358 samples analyzed for pesticides by Agriculture and Agri-Food Canada (AAFC), and 115 samples analyzed for aminomethyl phosphonic acid (AMPA), glyphosate, and glufosinate-ammonium by Alberta Innovates (AI). A total of 109 pesticides were analyzed in 2014, including one new herbicide (clodinafop-propargyl) and one new fungicide (propiconazole).

**Table 3.1. The number of Alberta Environmental Protection (AEP), primary, secondary, and return sites sampled in the irrigation districts in 2014.**

| Site type[z] | MVID | AID | UID | MID | RID | LNID | TID | SMRID | RCID | WID | BRID | EID | Totals |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AEP | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 | 12 |
| Primary | 4 | 0 | 4 | 4 | 4 | 4 | 4 | 11 | 4 | 8 | 4 | 4 | 55 |
| Secondary | 4 | 4 | 11 | 4 | 8 | 16 | 8 | 28 | 1 | 8 | 24 | 48[y] | 163 |
| Return | 0 | 0 | 4 | 4 | 0 | 20[y] | 11 | 20 | 0 | 16 | 20 | 32 | 127 |
| Totals | 8 | 4 | 19 | 16 | 12 | 40 | 23 | 59 | 5 | 36 | 52 | 84 | 357 |

[z] All 90 sites were sampled four times in 2014 (June 10 to 12, July 7 to 10, August 5 to 7, and September 2 to 4) except for three missed samples from sites, SMC-P1 and T-S3 (September 2), and U-R4 (September 4).

[y] One pesticide (E-S2 on September 4 ) sample and one *E. coli* (LN-R2 on September 3) sample were missed.

### 3.2.2 Analysis and Water Quality Indices

The water quality analysis results were compiled in a Microsoft Office Excel 2010® file. Descriptive statistics were used to analyze results. Graphs were made using Sigma Plot 12.5®. For most parameters, except for pesticides and veterinary pharmaceuticals, values less than the analytical minimum detection limits (MDL) were replaced by half of the detection limit. Pesticide and veterinary pharmaceuticals values less than detection limits were considered absent because they do not occur naturally.

Four water quality indices were calculated for irrigation, livestock watering, protection of aquatic life, and recreation water quality indices using the Canadian Council of Ministers of the Environment (CCME) Water Quality Index Calculator 2.0 Beta (CCME 2011). The Environmental Quality Guidelines for Protection of Agricultural Water Uses and for the

Protection of Aquatic Life (CCME 1999a, CCME 2005) were used in the calculator in previous years (Charest et al. 2012, 2013, 2014). Some guidelines were updated and published in the Environmental Quality Guidelines for Alberta Surface Waters (ESRD 2014). These guidelines were used to calculate the 2014 indices and to recalculate the 2011 to 2013 indices in order to make comparisons among years. Only measured parameters with applicable guidelines were used in the indices. The parameters and guidelines used for the irrigation, livestock watering, and protection of aquatic life water quality indices are listed in Tables 3.2 and 3.3. Since the mercury guideline was lower than the lab MDL (0.0001mg $L^{-1}$ in 2011 to 2013) all concentrations less than 0.0001mg $L^{-1}$ were considered as missing data in the index calculation. The only parameter used for the recreation water quality index was *E. coli* with a guideline value of 200 CFU 100 $mL^{-1}$ (Health Canada 2012). This guideline was preferred than the one published by ESRD 2014 because it does not require multiple samples collected within a month.

Index values were calculated using Equations 3.1 to 3.5. The index values ranged from zero (poorest quality) to 100 (best quality), and this range was divided into five rank classes (Table 3.4).

$$WQI = 100 - \left(\frac{\sqrt{F1^2+F2^2+F3^2)}}{1.732}\right) \qquad \textbf{Equation 3.1}$$

Where:
*WQI* is the water quality index value
*F*1 (scope) is the number of guidelines that are not met

$$F1 = \left(\frac{Number\ of\ variables\ exeeding\ guideline}{Total\ number\ of\ variables}\right) \times 100 \qquad \textbf{Equation 3.2}$$

*F*2 (frequency) is the frequency with which the guidelines are not met

$$F2 = \left(\frac{Number\ of\ samples\ exceeding\ guidelines}{Total\ number\ of\ samples}\right) \times 100 \qquad \textbf{Equation 3.3}$$

*F*3 (amplitude) is the amount by which the guidelines are not met

$$F3 = median\left(\frac{Exceeded\ guideline_i - Guideline_j}{Exceeded\ guideline_i}\right) \times 100 \qquad \textbf{Equation 3.4}$$

When less than five parameters were used, as for the salinity and biological irrigation sub-indices and the recreation index, the scope factor (*F*1) was removed from the WQI calculation (Equation 3.5), because it would have weighted too much on the index (Wright et al. 1999).

$$WQI = 100 - \left(\frac{\sqrt{F2^2+F3^2)}}{1.414}\right) \qquad \textbf{Equation 3.5}$$

**Table 3.2. Parameters and guidelines used to calculate the irrigation and livestock watering water quality indices[z].**

| Irrigation | | | | Livestock watering | | | |
|---|---|---|---|---|---|---|---|
| Type | Parameter | Guideline | Unit | Type | Parameter | Guideline | Unit |
| Salinity | SAR | 5 | | Salinity | Ca | 1,000 | mg $L^{-1}$ |
| | Cl | 178 | mg $L^{-1}$ | | TDS | 3,000 | mg $L^{-1}$ |
| | TDS | 500 | mg $L^{-1}$ | | $SO_4$ | 1,000 | mg $L^{-1}$ |
| Biological | *E. coli* | 100 | CFU 100 $mL^{-1}$ | Nutrients | $NO_2$-N | 10 | mg $L^{-1}$ |
| Metals | Al | 5 | mg $L^{-1}$ | | $NO_2$-N+ $NO_3$-N | 100 | mg $L^{-1}$ |
| | As | 0.16 | mg $L^{-1}$ | Metals | Al | 5 | mg $L^{-1}$ |
| | Be | 0.1 | mg $L^{-1}$ | | As | 0.025 | mg $L^{-1}$ |
| | B | 0.5 | mg $L^{-1}$ | | Be | 0.1 | mg $L^{-1}$ |
| | Cd | 8.2 | μg $L^{-1}$ | | B | 5 | mg $L^{-1}$ |
| | Cr | 4.9 | μg $L^{-1}$ | | Cd | 0.08 | mg $L^{-1}$ |
| | Co | 0.05 | mg $L^{-1}$ | | Cr | 0.05 | mg $L^{-1}$ |
| | Cu | 0.2 | mg $L^{-1}$ | | Co | 1 | mg $L^{-1}$ |
| | Fe | 5 | mg $L^{-1}$ | | Cu | 0.5 | mg $L^{-1}$ |
| | Pb | 0.2 | mg $L^{-1}$ | | Pb | 0.1 | mg $L^{-1}$ |
| | Li | 2.5 | mg $L^{-1}$ | | Hg | 3 | μg $L^{-1}$ |
| | Mn | 0.2 | mg $L^{-1}$ | | Mo | 0.5 | mg $L^{-1}$ |
| | Mo | 0.01 | mg $L^{-1}$ | | Ni | 1 | mg $L^{-1}$ |
| | Ni | 0.2 | mg $L^{-1}$ | | Se | 0.05 | mg $L^{-1}$ |
| | Se | 0.02 | mg $L^{-1}$ | | U | 0.2 | mg $L^{-1}$ |
| | U | 0.01 | mg $L^{-1}$ | | V | 0.1 | mg $L^{-1}$ |
| | V | 0.1 | mg $L^{-1}$ | | Zn | 50 | mg $L^{-1}$ |
| | Zn | 5 | mg $L^{-1}$ | Pesticides | Atrazine | 5 | μg $L^{-1}$ |
| Pesticides | Atrazine | 10 | μg $L^{-1}$ | | Bromacil | 1,100 | μg $L^{-1}$ |
| | Bromacil | 0.2 | μg $L^{-1}$ | | Bromoxynil | 11 | μg $L^{-1}$ |
| | Bromoxynil | 0.44 | μg $L^{-1}$ | | Chlorpyrifos | 24 | μg $L^{-1}$ |
| | Dicamba | 0.008 | μg $L^{-1}$ | | Diclofop-methyl | 9 | μg $L^{-1}$ |
| | Diclofop-methyl | 0.24 | μg $L^{-1}$ | | Dicamba | 122 | μg $L^{-1}$ |
| | MCPA | 0.04 | μg $L^{-1}$ | | Dimethoate | 3 | μg $L^{-1}$ |
| | Metolachlor | 28 | μg $L^{-1}$ | | Glyphosate | 280 | μg $L^{-1}$ |
| | Simazine | 0.5 | μg $L^{-1}$ | | Lindane (γ-HCH) | 4 | μg $L^{-1}$ |
| | | | | | MCPA | 25 | μg $L^{-1}$ |
| | | | | | Metolachlor | 50 | μg $L^{-1}$ |
| | | | | | Phenoxy herbicide (2,4-D + 2,4-DB + 2,4-DCP +dichlorprop + MCPA + MCPP + quinclorac) | 100 | μg $L^{-1}$ |
| | | | | | Picloram | 190 | μg $L^{-1}$ |
| | | | | | Simazine | 10 | μg $L^{-1}$ |
| | | | | | Triallate | 230 | μg $L^{-1}$ |
| | | | | | Trifluarin | 45 | μg $L^{-1}$ |

[z] All guidelines are from the Environmental Quality Guidelines for Alberta Surface Waters (ESRD 2014).

**Table 3.3. Parameters and guidelines used to calculate the protection of aquatic life water quality index.**

| Type | Parameter | Guideline[z] | Unit | Type | Parameter | Guideline[z] | Unit |
|---|---|---|---|---|---|---|---|
| Physical | pH | 6.5 - 9.0 | | Pesticides | Atrazine | 1.8 | $\mu g\ L^{-1}$ |
| | | | | | Bromacil | 5 | $\mu g\ L^{-1}$ |
| Salinity | Cl | 120 | $mg\ L^{-1}$ | | Bromoxynil | 5 | $\mu g\ L^{-1}$ |
| | Alkalinity | < 20 | $mg\ L^{-1}$ | | Chlorpyrifos | 0.002 | $\mu g\ L^{-1}$ |
| | $SO_4$ | 429 | $mg\ L^{-1}$ | | Diazinon | 0.17 | $\mu g\ L^{-1}$ |
| | | | | | Dicamba | 10 | $\mu g\ L^{-1}$ |
| Nutrients | $NH_3$-N | Calculated [y] | $mg\ L^{-1}$ | | Diclofop | 6.1 | $\mu g\ L^{-1}$ |
| | $NO_3$-N | 3.0 | $mg\ L^{-1}$ | | Dimethoate | 6.2 | $\mu g\ L^{-1}$ |
| | $NO_2$-N | 0.06 | $mg\ L^{-1}$ | | Endosulfan | 0.003 | $\mu g\ L^{-1}$ |
| | | | | | Glyphosate | 65 | $\mu g\ L^{-1}$ |
| Metals | Al | 0.01 | $mg\ L^{-1}$ | | HCH (α,β, γ, δ) | 0.01 | $\mu g\ L^{-1}$ |
| | As | 0.005 | $mg\ L^{-1}$ | | MCPA | 2.6 | $\mu g\ L^{-1}$ |
| | B | 1.5 | $mg\ L^{-1}$ | | MCPP | 13 | $\mu g\ L^{-1}$ |
| | Cd [x] | 0.04 - 0.037 | $\mu g\ L^{-1}$ | | Metolachlor | 7.8 | $\mu g\ L^{-1}$ |
| | Cr | 0.001 | $mg\ L^{-1}$ | | Methoxychlor | 0.03 | $\mu g\ L^{-1}$ |
| | Co | 0.0025 | $mg\ L^{-}$ | | Mirex | 0.001 | $\mu g\ L^{-1}$ |
| | Cu [x] | 0.007 | $mg\ L^{-1}$ | | Permethrin (cis+trans) | 0.004 | $\mu g\ L^{-1}$ |
| | Fe | 0.3 | $mg\ L^{-1}$ | | 2,4-D | 4 | $\mu g\ L^{-1}$ |
| | Pb [x] | 0.001 - 0.007 | $mg\ L^{-1}$ | | 2,4-DB | 25 | $\mu g\ L^{-1}$ |
| | Hg | 0.005 | $\mu g\ L^{-1}$ | | Picloram | 29 | $\mu g\ L^{-1}$ |
| | Mo | 0.073 | $mg\ L^{-1}$ | | Simazine | 10 | $\mu g\ L^{-1}$ |
| | Ni [x] | 0.004 - 0.17 | $mg\ L^{-1}$ | | Triallate | 0.24 | $\mu g\ L^{-1}$ |
| | Se | 0.001 | $mg\ L^{-1}$ | | Trifluarin | 0.2 | $\mu g\ L^{-1}$ |
| | Ag | 0.1 | $\mu g\ L^{-1}$ | | | | |
| | Tl | 0.8 | $\mu g\ L^{-1}$ | | | | |
| | U | 0.015 | $mg\ L^{-1}$ | | | | |
| | Zn | 0.03 | $mg\ L^{-1}$ | | | | |

[z] Environmental Quality Guidelines for Alberta Surface Waters (ESRD 2014).
[y] Calculated based on water temperature and pH.
[x] Indicates guidelines that are hardness dependent and calculated using the Index Calculator (CCME2011).

**Table 3.4. Description of water quality index ranking.**

| Index range | Narrative description | Index rank | Colour coding |
|---|---|---|---|
| 85 – 100 | Water is of very high quality; all variables are usually within guidelines. | excellent | blue |
| 70 – 84.9 | Rare exceedance of water quality guideline by some variables; usually by a relatively small amount. | good | green |
| 55 – 69.9 | Occasional exceedance of water quality guidelines by several variables; usually by a moderate amount. | fair | yellow |
| 40 – 54.9 | Frequent exceedance of water quality guidelines by many variables, and by a relatively large amount. | marginal | orange |
| 0 – 39.9 | Very frequent exceedance of water quality guidelines by many variables, and by a rather large amount. | poor | red |

### 3.3 Results and Discussion

#### 3.3.1 Nutrients

The average concentrations of total phosphorus (TP) and total dissolved phosphorus (TDP) among all sites were 0.062 and 0.039 mg $L^{-1}$, respectively, in 2014. The average concentration of TP was lower than in 2011 (0.072 mg $L^{-1}$) but higher than in 2012 (0.058 mg $L^{-1}$) and 2013 (0.48 mg $L^{-1}$) (Figure 3.1). In 2014, TP was higher than in 2013 and 2012 at most site types except the AEP sites. Similar to 2013, TP concentrations in 2014 at the primary sites were higher than that of the secondary sites (Figure 3.2). However, from 2011 to 2014, TP concentrations increased from the secondary to the return sites. The higher TP concentrations at the primary sites can be attributed to the nearly two-fold increase in TP concentration at the RCID primary site from 2013 (0.18 mg $L^{-1}$) to 2014 (0.35 mg $L^{-1}$) (Table 3.5).

Total dissolved phosphorus in 2014 represented more than half of TP at primary (71%), secondary (53%) and at return (65%) sites. For the AEP sites, however, particulate phosphorus was dominant (Figure 3.2).

There is no applicable guideline for TP that could be used to interpret the data. However, average TP concentrations observed in the study was within the range for eutrophic status (0.035 to 0.1 mg $L^{-1}$) for lakes and rivers (CCME 2004).

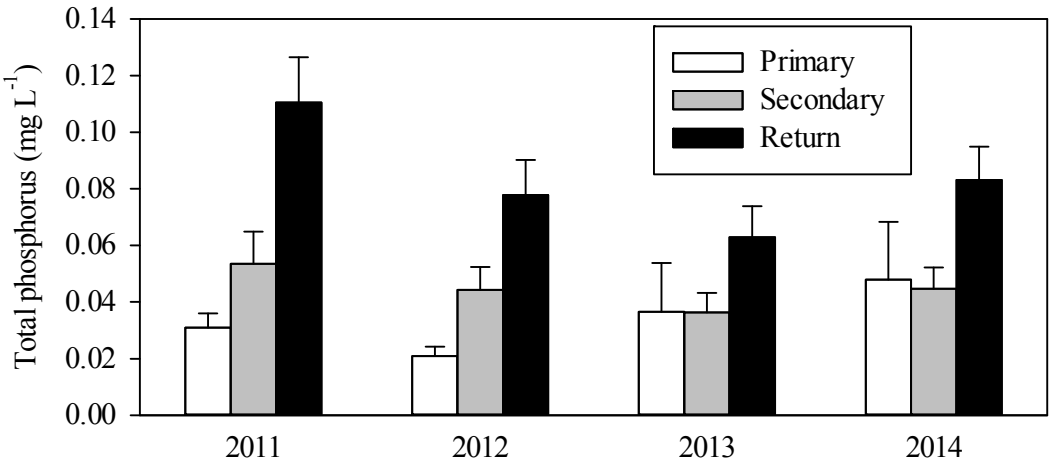


**Figure 3.1. Average total phosphorus concentrations for different site types from 2011, 2012, 2013, and 2014.** Error bars indicate the 90% confidence intervals.

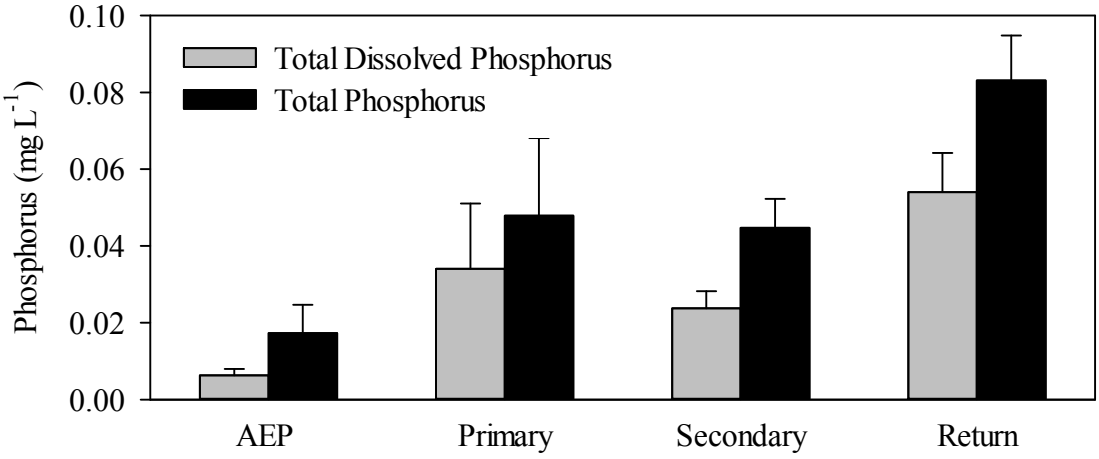


**Figure 3.2. Average total phosphorus and total dissolved phosphorus concentrations for different site types in 2014.** Error bars indicate the 90% confidence intervals**.**

The total nitrogen (TN) concentration among all sites (n=357) ranged from less than the detection limit at 0.06 to 3.10 mg $L^{-1}$ with an average of 0.50 mg $L^{-1}$ in 2014. This was a similar average concentration as in 2013 (0.49 mg $L^{-1}$), but less than 2011 (0.60 mg $L^{-1}$) and 2012 (0.54 mg $L^{-1}$) (Figure 3.3). As in 2013, there was a smaller increase of TN concentration from the primary to the return sites than compared to 2011 and 2012. Compared to 2013, TN concentrations increased for primary and return sites but decreased for secondary sites in 2014; there was also an increase in concentration from secondary to return sites.

**Table 3.5. Annual average nutrient concentrations at the Alberta Environmental Protection (AEP), primary, secondary, and return sites of twelve irrigation districts in 2014.**

| Parameter | Site type | MVID | AID | UID | MID | RID | LNID | TID | SMRID | RCID | WID | BRID | EID |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ---------- (mg $L^{-1}$) ---------- | | | | | | | | | | | |
| TP | AEP | - | - | - | 0.016 | - | - | - | - | - | 0.023 | 0.013 | - |
| | Primary | 0.017 | - | 0.004 | 0.016 | 0.020 | 0.028 | 0.043 | 0.045 | 0.355 | 0.013 | 0.009 | 0.019 |
| | Secondary | - | - | 0.019 | 0.116 | - | 0.037 | 0.053 | 0.061 | - | 0.032 | 0.037 | 0.042 |
| | Return | 0.020 | 0.023 | 0.083 | 0.104 | 0.186 | 0.095 | 0.062 | 0.099 | - | 0.077 | 0.068 | 0.074 |
| TDP | AEP | - | - | - | 0.005 | - | - | - | - | - | 0.008 | 0.007 | - |
| | Primary | 0.014 | - | 0.003 | 0.006 | 0.019 | 0.008 | 0.031 | 0.022 | 0.294 | 0.010 | 0.006 | 0.005 |
| | Secondary | - | - | 0.012 | 0.055 | - | 0.023 | 0.033 | 0.025 | - | 0.021 | 0.017 | 0.024 |
| | Return | 0.017 | 0.019 | 0.023 | 0.035 | 0.152 | 0.039 | 0.036 | 0.064 | - | 0.060 | 0.056 | 0.053 |
| TN | AEP | - | - | - | 0.163 | - | - | - | - | - | 0.350 | 0.685 | - |
| | Primary | 0.293 | - | 0.173 | 0.278 | 0.288 | 0.265 | 0.303 | 0.444 | 1.695 | 0.288 | 0.318 | 0.538 |
| | Secondary | - | - | 0.288 | 0.315 | - | 0.360 | 0.637 | 0.610 | - | 0.338 | 0.679 | 0.466 |
| | Return | 0.295 | 0.380 | 0.340 | 0.583 | 0.520 | 0.496 | 0.663 | 0.674 | - | 0.448 | 0.633 | 0.473 |
| $NO_3$-N | AEP | - | - | - | 0.093 | - | - | - | - | - | 0.145 | 0.550 | - |
| | Primary | 0.008 | - | 0.103 | 0.128 | 0.110 | 0.125 | 0.018 | 0.041 | 0.019 | 0.030 | 0.005 | 0.448 |
| | Secondary | - | - | 0.009 | 0.068 | - | 0.031 | 0.029 | 0.028 | - | 0.015 | 0.011 | 0.146 |
| | Return | 0.006 | 0.020 | 0.069 | 0.241 | 0.033 | 0.093 | 0.029 | 0.049 | - | 0.012 | 0.019 | 0.059 |
| $NO_2$-N | AEP | - | - | - | 0.003 | - | - | - | - | - | 0.006 | 0.007 | - |
| | Primary | 0.003 | - | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.004 | 0.005 | 0.003 | 0.003 | 0.005 |
| | Secondary | - | - | 0.003 | 0.003 | - | 0.003 | 0.003 | 0.003 | - | 0.003 | 0.003 | 0.003 |
| | Return | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.004 | 0.003 | 0.004 | - | 0.003 | 0.003 | 0.003 |
| $NH_3$-N | AEP | - | - | - | 0.025 | - | - | - | - | - | 0.025 | 0.025 | - |
| | Primary | 0.025 | - | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | 0.047 | 0.046 | 0.025 | 0.025 | 0.025 |
| | Secondary | - | - | 0.025 | 0.025 | - | 0.025 | 0.025 | 0.030 | - | 0.025 | 0.025 | 0.029 |
| | Return | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | 0.037 | 0.034 | - | 0.025 | 0.025 | 0.026 |
| n[z] | AEP | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 |
| | Primary | 4 | 0 | 4 | 4 | 4 | 4 | 4 | 11[y] | 4 | 8 | 4 | 4 |
| | Secondary | 0 | 0 | 4 | 4 | | 20 | 11[y] | 20 | 0 | 16 | 20 | 32 |
| | Return | 4 | 4 | 11[y] | 4 | 8 | 16 | 8 | 28 | 0 | 8 | 24 | 48 |

[z] n = number of samples.

[y] Three samples were missed in 2014 (SMC-P1, T-S3 on September 2, and U-R4 on September 4) resulting in missing values for all nutrients.

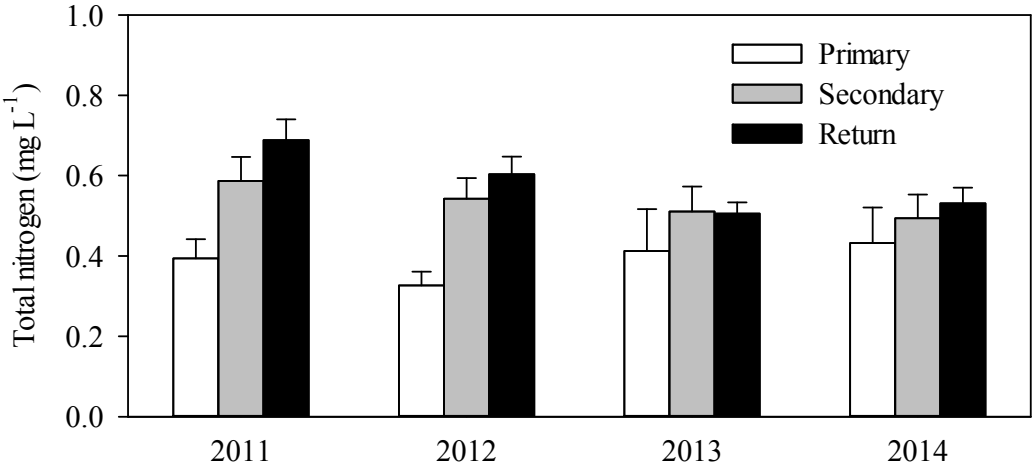


**Figure 3.3. Average total nitrogen concentrations for different site types in 2014.** Error bars indicate the 90% confidence intervals.

As in previous years, most of the TN was in particulate and dissolved organic forms. Among the irrigation districts, average ammonia-nitrogen ($NH_3$-N) and nitrite-nitrogen ($NO_2$-N) accounted for 5.6% and 0.6% of TN concentration, respectively, and these percentages were similar among site types (Figure 3.4; Table 3.5). The concentration of nitrate-nitrogen ($NO_3$-N) accounted for an average of 13% of TN concentration and generally decreased from AEP to return sites.

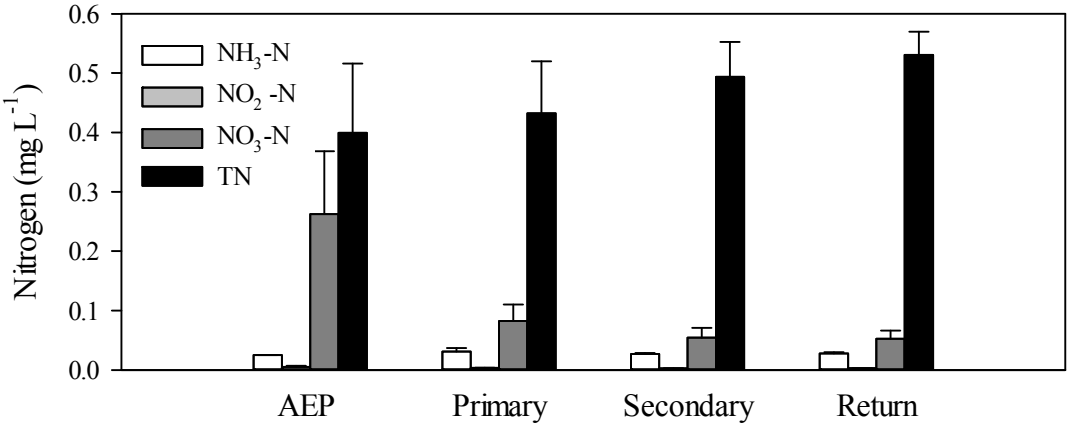


**Figure 3.4. Average ammonia-nitrogen ($NH_3$-N), nitrite-nitrogen ($NO_2$-N), nitrate-nitrogen ($NO_3$-N), and total nitrogen (TN) concentrations for different site types in 2014.** Error bars indicate the 90% confidence intervals.

### 3.3.2 Salinity and Hardness

In 2014, the total dissolved solids (TDS) concentration ranged from 89 to 981 mg $L^{-1}$ and averaged 247 mg $L^{-1}$. The average concentration of TDS was similar among years for the AEP and primary sites (Figure 3.5). However, average concentration of TDS decreased with time at the secondary and return sites. Average TDS concentration increased from the AEP to the return sites in 2014 and this was consistent with the previous three years (Figure 3.5). As seen in the three previous years, there were lower TDS concentrations in the more westerly districts (MVID, AID, UID, MID, LNID) compared to the other districts in 2014 (Table 3.6).

The irrigation guideline for TDS varies from 500 mg $L^{-1}$ for strawberries, raspberries, beans, and carrots to 3,500 mg $L^{-1}$ for other crops including oat, rye, wheat, sugar beet, and barley (ESRD 2014, CCME 2005). The irrigation guideline of 500 mg $L^{-1}$ was exceeded in 3.1% (11/357) of the samples. The highest TDS concentrations (>500 mg $L^{-1}$) were observed at one primary site (RCID) and return sites of the WID, MID, RID, and BRID, with the highest concentrations at R-R1 (891 mg $L^{-1}$ on July 8) and BR-R3 (981 mg $L^{-1}$ on September 3). Electrical conductivity (EC) values in 2014 ranged from 0.17 to 1.36 dS $m^{-1}$ at 25°C. The highest EC values were at the same sites that had the highest TDS concentrations, since these two parameters are directly related.

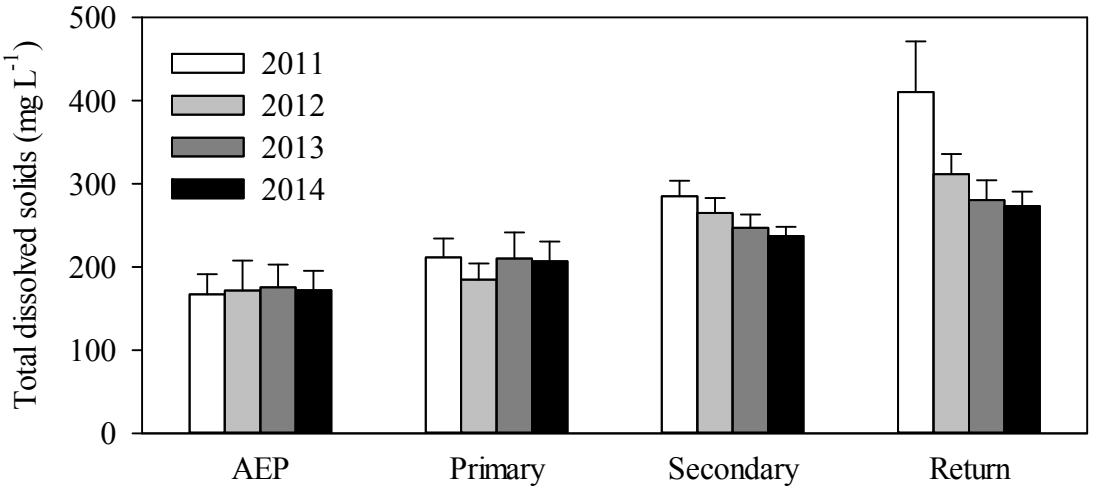


**Figure 3.5. Average total dissolved solids concentrations for different site types from 2011, 2012, 2013 and 2014.** Error bars indicate the 90% confidence intervals.

Sodium adsorption ratios (SAR) ranged from 0.05 to 3.7 among all the samples in 2014. Values of SAR less than or equal to 5 are considered safe for irrigation, but unsuitable when equal to or greater than 10 (AFRD 2002, Buckland et al. 2002). As in 2013, no samples exceeded the guideline value of % for SAR in 2014. The low SAR values observed in the irrigation districts

indicates the water is safe for long-term irrigation and will not adversely affect soil structure. As with other salinity variables, SAR tended to decrease during the irrigation season in previous years. However, this trend was not as clear in 2014 (Figure 3.6).The increase from August to September was associated with precipitation. Similar to TDS, average SAR and EC values increased from the AEP and primary sites to the return sites, and higher values at primary sites were observed in RCID and BRID (Table 3.6).

Water hardness, measured as $CaCO_3$ concentration, ranged from 86 to 402 mg $L^{-1}$ with an average of 163 mg $L^{-1}$. Water with values less than or equal to 100 mg $L^{-1}$ is considered soft; whereas, water with values from 101 to 2,000 mg $L^{-1}$ is considered hard (AFRD 2007). As hardness level increases, scaling on distribution pipes and other water fixtures may occur. As well, water hardness greater than 350 mg $L^{-1}$ can reduce the effectiveness of glyphosate (ARD 2003). Irrigation water was considered hard with 98% of the samples with hardness values greater than 100 mg $L^{-1}$ as $CaCO_3$, but only one sample was greater than 350 mg $L^{-1}$. The average water hardness generally increased from upstream (AEP or primary sites) to downstream (return sites) (Table 3.6).

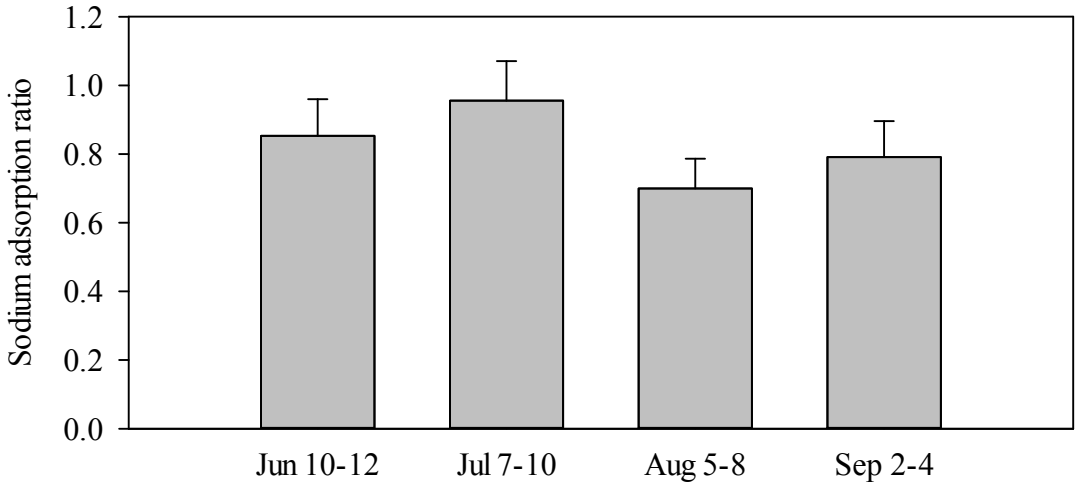


**Figure 3.6. Average sodium adsorption ratio for different sampling events in 2014.** Error bars indicate the 90% confidence intervals.

Chloride (Cl) concentrations ranged from 0.2 to 28.7 mg $L^{-1}$, which was well below the irrigation guideline of 100 mg $L^{-1}$ (ESRD 2014). Average Cl concentration increased as water moved through the irrigation districts in 2014 (Table 3.6). The highest concentrations were found in RCID, WID, BRID, and EID.

**Table 3.6. Annual average of salinity parameters at the Alberta Environmental Protection (AEP), primary, secondary, and return sites of twelve irrigation districts in 2014.**

| Parameters | Site type | MVID | AID | UID | MID | RID | LNID | TID | SMRID | RCID | WID | BRID | EID |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TDS | AEP | - | - | - | 108 | - | - | - | - | - | 212 | 197 | - |
| (mg $L^{-1}$) | Primary | 144 | - | 102 | 121 | 139 | 157 | 179 | 176 | 510 | 240 | 328 | 201 |
| | Secondary | - | - | 123 | 184 | - | 197 | 232 | 189 | - | 256 | 357 | 230 |
| | Return | 149 | 147 | 136 | 349 | 341 | 207 | 262 | 215 | - | 354 | 419 | 279 |
| EC | AEP | - | - | - | 0.20 | - | - | - | - | - | 0.38 | 0.35 | - |
| (µS $cm^{-1}$) | Primary | 0.27 | - | 0.19 | 0.22 | 0.25 | 0.27 | 0.30 | 0.30 | 0.82 | 0.41 | 0.54 | 0.35 |
| | Secondary | - | - | 0.23 | 0.31 | - | 0.33 | 0.38 | 0.33 | - | 0.44 | 0.58 | 0.40 |
| | Return | 0.27 | 0.27 | 0.25 | 0.60 | 0.54 | 0.35 | 0.42 | 0.36 | - | 0.58 | 0.66 | 0.46 |
| SAR | AEP | - | - | - | 0.07 | - | - | - | - | - | 0.50 | 0.30 | - |
| | Primary | 0.13 | - | 0.05 | 0.20 | 0.30 | 0.20 | 0.50 | 0.54 | 1.98 | 0.73 | 1.13 | 0.35 |
| | Secondary | - | - | 0.16 | 0.53 | - | 0.61 | 1.02 | 0.62 | - | 0.90 | 1.55 | 0.64 |
| | Return | 0.20 | 0.23 | 0.21 | 1.48 | 1.41 | 0.61 | 1.31 | 0.71 | - | 1.56 | 1.66 | 0.86 |
| Hardness | AEP | - | - | - | 103 | - | - | - | - | - | 164 | 170 | - |
| as $CaCO_3$ | Primary | 136 | - | 101 | 108 | 109 | 139 | 137 | 131 | 256 | 169 | 203 | 165 |
| (mg $L^{-1}$) | Secondary | - | - | 109 | 135 | - | 145 | 142 | 134 | - | 167 | 196 | 167 |
| | Return | 138 | 134 | 118 | 188 | 181 | 152 | 144 | 147 | - | 192 | 223 | 186 |
| Cl | AEP | - | - | - | 0.75 | - | - | - | - | - | 11.40 | 7.80 | - |
| (mg $L^{-1}$) | Primary | 0.65 | - | 0.55 | 0.78 | 1.20 | 1.08 | 1.60 | 1.96 | 10.33 | 12.96 | 11.23 | 8.70 |
| | Secondary | - | - | 0.68 | 1.20 | - | 1.91 | 3.71 | 2.31 | - | 14.33 | 13.10 | 10.33 |
| | Return | 0.93 | 0.90 | 0.75 | 2.10 | 4.16 | 2.33 | 4.78 | 3.86 | - | 16.09 | 14.22 | 11.28 |
| $SO_4$ | AEP | - | - | - | 8 | - | - | - | - | - | 45 | 37 | - |
| (mg $L^{-1}$) | Primary | 5 | - | 5 | 12 | 22 | 17 | 39 | 42 | 184 | 65 | 109 | 41 |
| | Secondary | - | - | 17 | 48 | - | 47 | 81 | 47 | - | 76 | 136 | 60 |
| | Return | 5 | 7 | 21 | 145 | 141 | 51 | 103 | 60 | - | 124 | 172 | 86 |
| n[z] | AEP | 0 | 0 | 0 | 4[y] | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 |
| | Primary | 4 | 0 | 4 | 4 | 4 | 4 | 4 | 11 | 4 | 8 | 4 | 4 |
| | Secondary | 0 | 0 | 4 | 4 | 0 | 20 | 11 | 20 | 0 | 16 | 20 | 32 |
| | Return | 4 | 4 | 11 | 4 | 8 | 16 | 8 | 28 | 0 | 8 | 24 | 48 |

[z] n = number of samples.

[y] There are no SAR results for AEP-S2 (n=15).



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Sulphate ($SO_4$) concentrations ranged from 4 to 588 mg $L^{-1}$ in 2014, which is a decrease of 235 mg $L^{-1}$ in the maximum concentration value from 2013. All samples were less than the livestock watering guideline of 1,000 mg $L^{-1}$ (ESRD 2014). The district with the highest average was RCID but highest sample concentrations were observed in watershed return sites of in RID and BRID. As for other salinity parameter average $SO_4$ concentration decreased from 2011 to 2014 (121mg $L^{-1}$ in 2011, 91mg $L^{-1}$ in 2012, 81mg $L^{-1}$ in 2013, and 74 mg $L^{-1}$ in 2014).

### 3.3.3 Metals

All 25 metals analyzed were detected in 2014. Beryllium, tin, and thallium were detected in only three to nine samples (0.9 to 2.6%) (Table 3.7). Mercury (Hg) on the other hand increased from two (0.6%) detections in 2013 to 52 (14.6%) in 2014. However, this increase in detection frequency does not reflects an increase in Hg concentration, but rather a decrease in the laboratory detection limit which was changed from 0.1 µg $L^{-1}$ in 2011 to 2013 to 0.005 µg $L^{-1}$ in 2014.

The concentrations of most metals do not follow particular trends as their concentrations increased from primary to return sites in some districts and decreased in other districts (Table 3.7). A few of the metals tended to have lower concentrations in the most western districts (MVID, AID, and UID). This was observed for arsenic (As), boron (B), lithium (Li), molybdenum (Mo), selenium (Se) and uranium (U). The trend was reversed for barium (Ba), and titanium (Ti), with concentrations that were lower in the more eastern districts (TID, SMRID, RCID, WID, BRID, and EID). In 2014, among the three districts (MID, WID, BRID) with AEP sites, the average concentration of most metals was higher at the AEP compared to the primary sites, however, the reduction in concentration between the two site types was not as large as in 2013.

Irrigation and/or livestock watering guidelines exist for 19 of the 25 metals analyzed (Chapter 2; Table 2.8). The highest concentrations measured for most of these metals were well below the guideline values in nearly all samples in 2014. However, chromium (Cr), copper (Cu), and B exceeded irrigation guidelines in one to seven of 351 samples (0.3 to 2%). The livestock water guideline was not exceeded in 2014. One site, LN-R1, exceeded all of these metal guidelines for irrigation and livestock watering on June 11, 2014. However, this sample also had a very high TSS concentration.

Protection of aquatic life guidelines exist for 16 of the analyzed metals and nine of these were exceeded at least once in 2014. Guideline exceedance occurred for aluminum (Al), As, Cr, cobalt (Co), Cu, iron (Fe), Hg, Se, and tin (Sn). Frequency of guideline exceedance was the highest for Al (60%), Fe (27%), Cr (6%), Hg (4%), Se (4%), and As (3%). The other three metals (Co, Cu

and Sn) exceeded the protection of aquatic life guidelines in less than 1% of the samples. The protection of aquatic life guidelines that were exceeded in 2014 was less compared to 2013.

Aluminum was detected in 78% of all samples in 2014, with the highest concentration at 4.7 mg $L^{-1}$, which does not exceed the irrigation and livestock guidelines (ESRD 2014). To date, 2014 was the only year that Al did not exceed either agricultural water use guideline. The highest average concentrations in the irrigation districts were found in return sites of UID, MID, RID, and LNID (Table 3.7). The protection of aquatic life guideline is based on pH as Al is more toxic in acidic water. In 2014, as in previous years, all samples were alkaline (pH >7.0). The protection of aquatic life for water pH ≥6.5 is 50 µg $L^{-1}$ (ESRD 2014), which was exceeded in 60% (212/351) of samples. Aluminum may be of particular concern as it was the only metal to greatly exceed the protection of aquatic life guideline in source and return waters. These results for Al were comparable to previous years of the current study and to the 2006-2007 study by Little et al. (2010). It is most likely that the Al in irrigation water comes from geological sources as this metal is present in soils.

Chromium concentrations ranged from the detection limit (0. 5 µg $L^{-1}$) to 5.6 µg $L^{-1}$ (LN-R1) at which the irrigation guideline was exceeded. The protection of aquatic life guideline (1 µg $L^{-1}$; CCME 1999a) was exceeded in 6% of the samples. Although Cr occurs naturally in soils, anthropogenic emissions can increase Cr concentrations considerably as this metal is used in a variety of industrial applications. Further information on source, toxicity, and guideline values for Cr can be found in CCME (1999b).

The highest concentration of Fe measured in 2014 was 5.6 mg $L^{-1}$ from LN-R1. The irrigation guideline (5 mg $L^{-1}$; CCME 2005) was exceeded in only one sample. The mean concentration was highest at the returns of UID, MID, RID, and LNID (Table 3.7). The protection of aquatic life guideline (0.3 mg $L^{-1}$; ESRD 2014) for Fe was exceeded in 27% of the samples. Similar results were found in 2011, 2012, and 2013, by Little et al. (2010). Although Fe is a plant nutrient, it can have deleterious effects on aquatic plants and insects. High concentrations of Fe can also cause blockage of micro irrigation systems and reduce the activity of glyphosate (ARD 2003). As for Al, the Fe concentration is well correlated with TSS, indicating that these metals are probably from natural geological sources.

**Table 3.7. Annual average metal concentrations at the Alberta Environmental Protection (AEP), primary, secondary, and return sites of twelve irrigation districts in 2014.**

| Parameter | Site type | MVID | AID | UID | MID | RID | LNID | TID | SMRID | RCID | WID | BRID | EID |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ---------- ($\mu g\ L^{-1}$) ---------- | | | | | | | | | | | |
| Aluminum | AEP | - | - | - | 568 | - | - | - | - | - | 180 | 203 | - |
| (Al) | Primary | 43 | - | 228 | 153 | 135 | 835 | 113 | 131 | 53 | 61 | 10 | 238 |
| | Secondary | - | - | 35 | 440 | - | 249 | 74 | 130 | - | 167 | 28 | 167 |
| | Return | 93 | 200 | 996 | 1040 | 565 | 611 | 28 | 161 | - | 268 | 62 | 238 |
| Antimony | AEP | - | - | - | 0.10 | - | - | - | - | - | 0.13 | 0.10 | - |
| (Sb) | Primary | 0.10 | - | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.20 | 0.13 | 0.10 | 0.10 |
| | Secondary | - | 0.00 | 0.10 | 0.10 | - | 0.10 | 0.10 | 0.10 | - | 0.10 | 0.11 | 0.10 |
| | Return | 0.10 | 0.10 | 0.10 | 0.10 | 0.13 | 0.10 | 0.10 | 0.10 | - | 0.16 | 0.11 | 0.10 |
| Arsenic | AEP | - | - | - | 0.63 | - | - | - | - | - | 0.50 | 0.40 | - |
| (As) | Primary | 1.00 | - | 0.48 | 0.80 | 1.05 | 0.75 | 2.13 | 1.63 | 8.38 | 0.71 | 1.73 | 0.58 |
| | Secondary | - | - | 0.68 | 1.40 | - | 1.43 | 1.78 | 2.10 | - | 1.09 | 2.36 | 1.41 |
| | Return | 1.08 | 1.60 | 1.30 | 1.98 | 2.63 | 2.14 | 2.23 | 2.44 | - | 2.06 | 2.50 | 1.89 |
| Barium | AEP | - | - | - | 124 | - | - | - | - | - | 54 | 58 | - |
| (Ba) | Primary | 144 | - | 131 | 122 | 117 | 115 | 103 | 104 | 56 | 48 | 66 | 63 |
| | Secondary | - | - | 114 | 123 | - | 98 | 68 | 96 | - | 54 | 64 | 69 |
| | Return | 131 | 152 | 135 | 117 | 107 | 109 | 60 | 95 | - | 60 | 60 | 75 |
| Beryllium | AEP | - | - | - | 0.050 | - | - | - | - | - | 0.050 | 0.050 | - |
| (Be) | Primary | 0.050 | - | 0.050 | 0.050 | 0.050 | 0.063 | 0.050 | 0.050 | 0.050 | 0.050 | 0.050 | 0.050 |
| | Secondary | - | - | 0.050 | 0.050 | - | 0.053 | 0.050 | 0.050 | - | 0.050 | 0.050 | 0.050 |
| | Return | 0.050 | 0.050 | 0.086 | 0.050 | 0.050 | 0.063 | 0.050 | 0.050 | - | 0.050 | 0.050 | 0.055 |
| Boron | AEP | - | - | - | 9 | - | - | - | - | - | 12 | 12 | - |
| (B) | Primary | 9 | - | 7 | 9 | 12 | 14 | 23 | 13 | 70 | 14 | 29 | 15 |
| | Secondary | - | - | 10 | 16 | - | 15 | 15 | 16 | - | 15 | 27 | 21 |
| | Return | 10 | 13 | 12 | 31 | 22 | 20 | 16 | 19 | - | 24 | 37 | 28 |
| Cadmium | AEP | - | - | - | 0.010 | - | - | - | - | - | 0.044 | 0.030 | - |
| (Cd) | Primary | 0.005 | - | 0.006 | 0.005 | 0.005 | 0.024 | 0.011 | 0.008 | 0.005 | 0.020 | 0.005 | 0.018 |
| | Secondary | - | - | 0.005 | 0.023 | 0.000 | 0.008 | 0.005 | 0.008 | - | 0.011 | 0.005 | 0.011 |
| | Return | 0.005 | 0.005 | 0.040 | 0.033 | 0.022 | 0.029 | 0.005 | 0.009 | - | 0.014 | 0.006 | 0.012 |

**Table 3.7. Continued.**

| Parameter | Site type | MVID | AID | UID | MID | RID | LNID | TID | SMRID | RCID | WID | BRID | EID |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ---------- ($\mu g\ L^{-1}$) ---------- | | | | | | | | | | | |
| Chromium | AEP | - | - | - | 0.51 | - | - | - | - | - | 0.49 | 0.65 | - |
| (Cr) | Primary | 0.25 | - | 0.36 | 0.25 | 0.25 | 0.83 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.40 |
| | Secondary | - | - | 0.25 | 0.41 | - | 0.36 | 0.25 | 0.26 | - | 0.32 | 0.25 | 0.36 |
| | Return | 0.34 | 0.25 | 1.01 | 1.06 | 0.67 | 0.91 | 0.25 | 0.29 | - | 0.31 | 0.25 | 0.37 |
| Cobalt | AEP | - | - | - | 0.20 | - | - | - | - | - | 0.15 | 0.16 | - |
| (Co) | Primary | 0.09 | - | 0.09 | 0.06 | 0.10 | 0.31 | 0.26 | 0.16 | 0.63 | 0.08 | 0.08 | 0.23 |
| | Secondary | - | - | 0.06 | 0.40 | - | 0.18 | 0.14 | 0.19 | - | 0.17 | 0.16 | 0.20 |
| | Return | 0.11 | 0.15 | 0.55 | 0.70 | 0.48 | 0.58 | 0.18 | 0.27 | - | 0.28 | 0.20 | 0.33 |
| Copper | AEP | - | - | - | 0.88 | - | - | - | - | - | 1.25 | 0.88 | - |
| (Cu) | Primary | 0.50 | - | 1.38 | 1.00 | 1.00 | 1.75 | 1.75 | 0.90 | 0.63 | 0.94 | 0.75 | 1.00 |
| | Secondary | - | - | 0.50 | 1.50 | 0.00 | 1.03 | 0.94 | 0.93 | - | 0.88 | 2.30 | 0.80 |
| | Return | 0.50 | 0.63 | 2.14 | 2.00 | 2.06 | 2.09 | 0.83 | 1.21 | - | 1.50 | 0.69 | 1.20 |
| Iron | AEP | - | - | - | 418 | - | - | - | - | - | 243 | 221 | - |
| (Fe) | Primary | 115 | - | 183 | 106 | 135 | 748 | 214 | 158 | 83 | 79 | 25 | 285 |
| | Secondary | - | - | 40 | 488 | - | 257 | 88 | 186 | - | 217 | 54 | 216 |
| | Return | 203 | 250 | 985 | 1223 | 715 | 944 | 90 | 317 | - | 309 | 152 | 346 |
| Lead | AEP | - | - | - | 0.30 | - | - | - | - | - | 0.55 | 0.29 | - |
| (Pb) | Primary | 0.06 | - | 0.15 | 0.11 | 0.10 | 0.50 | 0.13 | 0.12 | 0.10 | 0.11 | 0.05 | 0.24 |
| | Secondary | - | - | 0.05 | 0.38 | - | 0.17 | 0.07 | 0.14 | - | 0.18 | 0.07 | 0.18 |
| | Return | 0.11 | 0.16 | 0.77 | 0.85 | 0.45 | 0.58 | 0.08 | 0.19 | - | 0.26 | 0.10 | 0.28 |
| Lithium | AEP | - | - | - | 3.3 | - | - | - | - | - | 4.5 | 4.3 | - |
| (Li) | Primary | 3.5 | - | 2.8 | 3.5 | 4.8 | 5.0 | 12.5 | 6.5 | 61.0 | 5.6 | 10.5 | 4.5 |
| | Secondary | - | - | 4.0 | 6.3 | - | 6.1 | 10.6 | 8.4 | - | 6.3 | 15.2 | 8.6 |
| | Return | 4.0 | 4.5 | 5.0 | 14.5 | 11.5 | 8.6 | 12.8 | 10.0 | - | 12.0 | 23.1 | 15.4 |

**Table 3.7. Continued.**

| Parameter | Site type | MVID | AID | UID | MID | RID | LNID | TID | SMRID | RCID | WID | BRID | EID |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ---------- ($\mu g\ L^{-1}$) ---------- | | | | | | | | | | | |
| Manganese | AEP | - | - | - | 14 | - | - | - | - | - | 17 | 11 | - |
| (Mn) | Primary | 27 | - | 7 | 4 | 12 | 18 | 40 | 55 | 75 | 13 | 6 | 12 |
| | Secondary | - | - | 24 | 41 | - | 24 | 30 | 36 | - | 18 | 17 | 24 |
| | Return | 17 | 14 | 50 | 71 | 49 | 56 | 32 | 55 | - | 37 | 36 | 47 |
| Mercury | AEP | - | - | - | 0.003 | 0.000 | - | - | - | - | 0.003 | 0.003 | - |
| (Hg) | Primary | 0.003 | - | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.008 | 0.004 | 0.003 | 0.004 | 0.003 |
| | Secondary | - | - | 0.003 | 0.014 | - | 0.004 | 0.003 | 0.010 | - | 0.003 | 0.003 | 0.003 |
| | Return | 0.003 | 0.004 | 0.003 | 0.004 | 0.003 | 0.005 | 0.003 | 0.010 | - | 0.003 | 0.003 | 0.004 |
| Molybdenum | AEP | - | - | - | 0.50 | - | - | - | - | - | 0.75 | 0.75 | - |
| (Mo) | Primary | 0.50 | - | 0.50 | 0.50 | 0.50 | 0.50 | 0.88 | 0.50 | 2.00 | 0.94 | 2.00 | 0.75 |
| | Secondary | - | - | 0.50 | 0.50 | - | 0.88 | 0.50 | 0.55 | - | 1.00 | 1.95 | 0.92 |
| | Return | 0.50 | 0.50 | 0.50 | 0.63 | 0.81 | 1.09 | 0.50 | 0.63 | - | 1.19 | 1.52 | 1.08 |
| Nickel | AEP | - | - | - | 0.51 | - | - | - | - | - | 0.73 | 0.84 | - |
| (Ni) | Primary | 0.34 | - | 0.39 | 0.41 | 0.44 | 1.18 | 1.61 | 0.92 | 2.78 | 0.44 | 1.38 | 1.05 |
| | Secondary | - | - | 0.25 | 2.10 | - | 0.94 | 1.20 | 0.96 | - | 0.74 | 1.50 | 1.15 |
| | Return | 0.64 | 0.83 | 1.48 | 2.78 | 1.85 | 2.07 | 1.17 | 1.30 | - | 1.96 | 1.52 | 1.86 |
| Selenium | AEP | - | - | - | 0.13 | - | - | - | - | - | 0.65 | 0.60 | - |
| (Se) | Primary | 0.10 | - | 0.10 | 0.23 | 0.25 | 0.55 | 0.53 | 0.36 | 0.33 | 0.65 | 0.35 | 0.45 |
| | Secondary | - | - | 0.10 | 0.65 | - | 0.55 | 0.40 | 0.35 | - | 0.58 | 0.25 | 0.30 |
| | Return | 0.10 | 0.10 | 0.38 | 1.90 | 1.31 | 0.65 | 0.40 | 0.40 | - | 0.51 | 0.24 | 0.33 |
| Silver | AEP | - | - | - | 0.01 | - | - | - | - | - | 0.02 | 0.03 | - |
| (Ag) | Primary | 0.01 | - | 0.01 | 0.02 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.02 |
| | Secondary | - | - | 0.01 | 0.02 | - | 0.02 | 0.01 | 0.01 | - | 0.03 | 0.01 | 0.02 |
| | Return | 0.01 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | - | 0.02 | 0.01 | 0.02 |

**Table 3.7. Continued.**

| Parameter | Site type | MVID | AID | UID | MID | RID | LNID | TID | SMRID | RCID | WID | BRID | EID |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ---------- ($\mu g\ L^{-1}$) ---------- | | | | | | | | | | | |
| Thallium | AEP | - | - | - | 0.03 | - | - | - | - | - | 0.03 | 0.03 | - |
| (Tl) | Primary | 0.03 | - | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| | Secondary | - | - | 0.03 | 0.03 | - | 0.03 | 0.03 | 0.03 | - | 0.03 | 0.03 | 0.03 |
| | Return | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | - | 0.03 | 0.03 | 0.03 |
| Tin | AEP | - | - | - | 0.50 | - | - | - | - | - | 0.50 | 0.50 | - |
| (Sn) | Primary | 0.50 | - | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| | Secondary | - | - | 0.50 | 0.50 | - | 0.68 | 0.50 | 0.50 | - | 0.50 | 0.58 | 0.50 |
| | Return | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | - | 0.50 | 0.56 | 0.50 |
| Titanium | AEP | - | - | - | 6 | - | - | - | - | - | 3 | 2 | - |
| (Ti) | Primary | 1 | - | 4 | 4 | 3 | 13 | 3 | 3 | 2 | 2 | - | 4 |
| | Secondary | - | - | 1 | 8 | - | 4 | 2 | 3 | - | 4 | 1 | 3 |
| | Return | 2 | 3 | 14 | 20 | 11 | 14 | 1 | 4 | - | 7 | 2 | 5 |
| Uranium | AEP | - | - | - | 0.25 | - | - | - | - | - | 0.85 | 0.73 | - |
| (U) | Primary | 0.25 | - | 0.25 | 0.34 | 0.50 | 0.40 | 1.58 | 0.80 | 1.83 | 1.18 | 1.50 | 0.68 |
| | Secondary | - | - | 0.43 | 0.86 | - | 0.77 | 1.11 | 0.90 | - | 1.33 | 1.41 | 0.81 |
| | Return | 0.40 | 0.48 | 0.64 | 2.60 | 1.92 | 1.20 | 1.27 | 1.03 | - | 1.66 | 1.43 | 1.12 |
| Vanadium | AEP | - | - | - | 1.1 | - | - | - | - | - | 0.8 | 0.7 | - |
| (V) | Primary | 0.6 | - | 0.5 | 0.7 | 0.8 | 1.9 | 1.2 | 0.9 | 3.7 | 0.6 | 0.5 | 0.8 |
| | Secondary | - | - | 0.3 | 1.6 | - | 1.2 | 1.0 | 1.1 | - | 1.0 | 0.9 | 0.9 |
| | Return | 0.7 | 1.4 | 2.7 | 3.2 | 2.7 | 2.7 | 1.2 | 1.3 | - | 2.1 | 0.9 | 1.2 |
| Zinc | AEP | - | - | - | 3.6 | - | - | - | - | - | 7.8 | 4.8 | - |
| (Zn) | Primary | 3.8 | - | 3.8 | 3.0 | 4.1 | 5.3 | 4.0 | 3.8 | 3.8 | 4.1 | 2.5 | 4.5 |
| | Secondary | - | - | 2.8 | 6.5 | 0.0 | 3.8 | 3.6 | 3.9 | - | 4.4 | 3.6 | 3.6 |
| | Return | 4.0 | 4.8 | 8.5 | 8.0 | 5.9 | 8.4 | 3.7 | 4.8 | - | 4.3 | 4.0 | 5.1 |
| n[z] | AEP | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 |
| | Primary | 4 | 0 | 4 | 4 | 4 | 4 | 4 | 10[y] | 4 | 8 | 4 | 4 |
| | Secondary | 0 | 0 | 4 | 4 | 0 | 20 | 8[y] | 20 | 0 | 16 | 20 | 32 |
| | Return | 4 | 4 | 11[y] | 4 | 8 | 16 | 6[y] | 28 | 0 | 8 | 24 | 48 |

[z] n = number of samples.

[y] Nine metals samples were missed in 2014 (T-S1, T-S2, T-S3, T-R1, T-R2, and SMC-P1 on August 5 and SMC-P1, T-S3 on September 2, and U-R4 on September 4) resulting in missing values for all metals.

### 3.3.4 Physical Parameters and pH

Sample temperature ranged from 7.4 to 26.3°C in 2014. The average sample temperature was 18.6°C as compared to 19.4°C in 2013, 17.7°C in 2012, and 19.9°C in 2011. As in the previous years (2011 to 2013), on average, water temperature was cooler at the AEP and primary sites compared to the secondary and return sites, and this probably reflects the size of the canals and the travel time required for the water to warm from the colder river source water. (Figure 3.7; Table 3.8). Water temperature increased during the sampling season with AEP and primary sites temperature varing less than return and secondary sites (data not shown). The extent of tempertaure variation among the site types decreased as the sampling season progressed.

Total suspended solids varied from 1 to 423 mg $L^{-1}$ in 2014. The average concentration was 15.5 mg $L^{-1}$, which was less than previous years (Figure 3.8). The highest average TSS values were at the return sites and there was a decrease in concentration from the AEP to the primary sites (Figure 3.8; Table 3.8). The reduction in TSS concentration could be explained by the sedimentation in Chestermere, McGregor, Travers, and St. Mary reservoirs between the AEP and primary sites. Concentrations of TSS was highest in early July for the AEP, primary and secondary sites, and this could be explained by the precipitation event at the end of June 2014 (Figure 3.9).

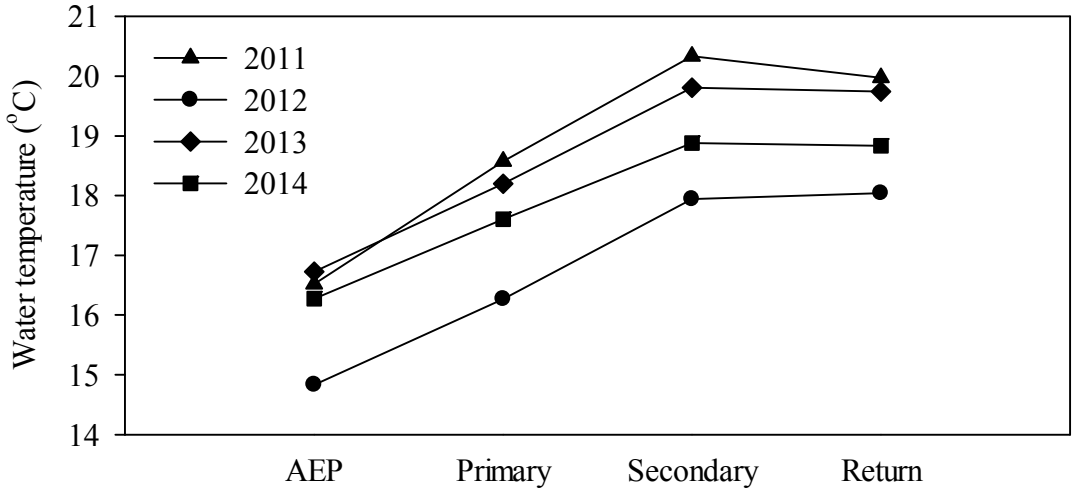


**Figure 3.7. Average water temperature for the different sampling site types in 2011 to 2014.**

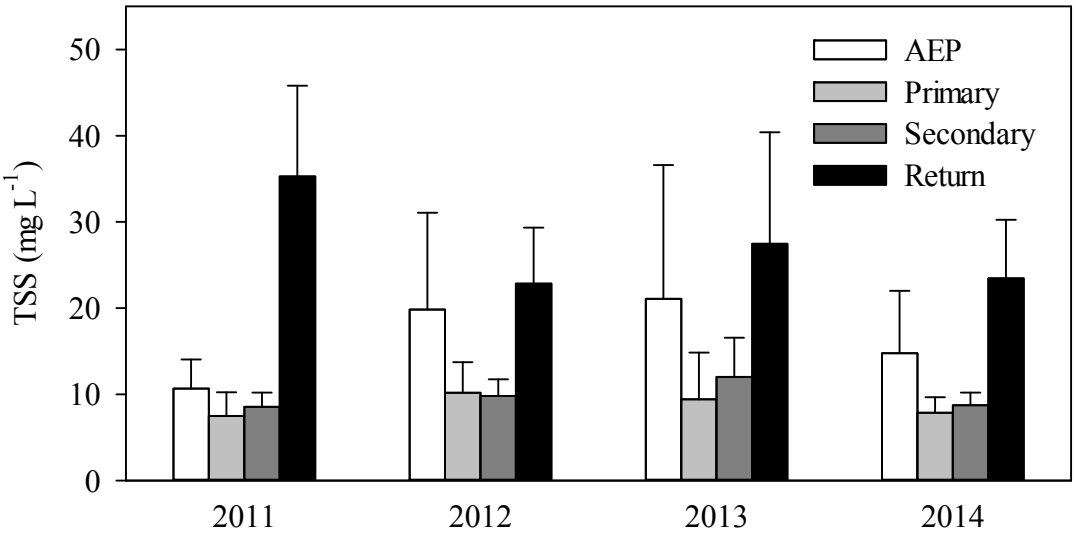


**Figure 3.8. Average total suspended solids (TSS) for the different sampling site types in 2011 to 2014.**

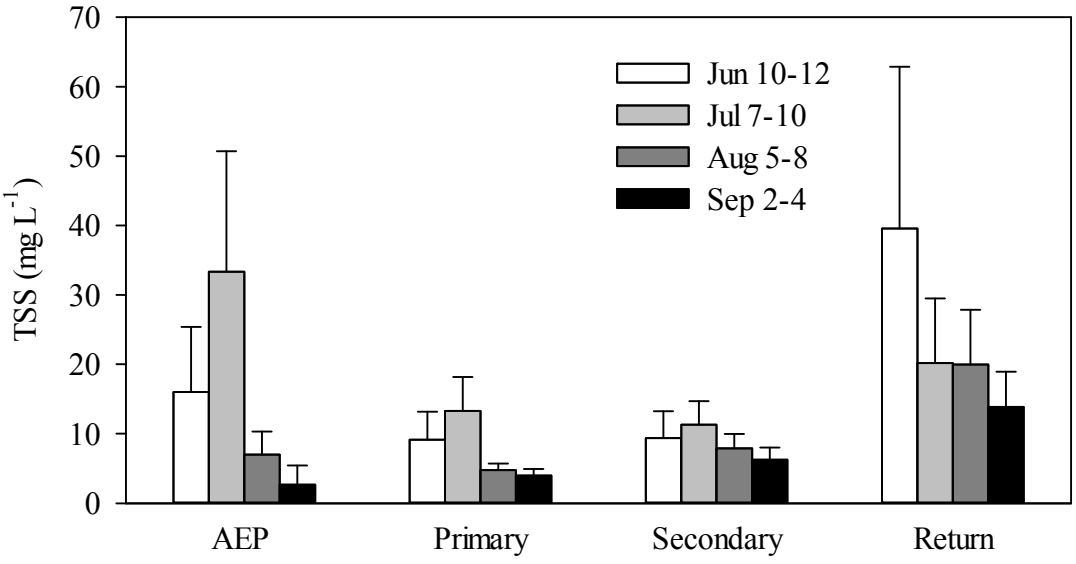


**Figure 3.9. Average total suspended solids (TSS) concentrations for the different sampling site types and sampling dates in 2014.**

**Table 3.8. Annual average of selected physical parameters at the Alberta Environmental Protection (AEP), primary, secondary, and return sites of twelve irrigation districts in 2014.**

| Parameter | Site type | MVID | AID | UID | MID | RID | LNID | TID | SMRID | RCID | WID | BRID | EID |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water | AEP | - | - | - | 17.0 | - | - | - | - | - | 16.1 | 15.8 | - |
| temperature | Primary | 17.6 | - | 12.8 | 16.7 | 18.4 | 11.4 | 18.6 | 18.9 | 20.4 | 18.2 | 18.6 | 19.1 |
| (°C) | Secondary | - | - | 17.9 | 16.8 | - | 16.7 | 20.3 | 19.3 | - | 19.6 | 19.6 | 19.2 |
| | Return | 16.7 | 16.0 | 18.4 | 17.1 | 18.0 | 18.1 | 21.0 | 19.2 | - | 19.1 | 19.2 | 19.1 |
| Total | AEP | - | - | - | 16.5 | - | - | - | - | - | 16.0 | 11.8 | - |
| suspended | Primary | 3.4 | - | 10.1 | 4.5 | 7.5 | 19.8 | 4.3 | 8.9 | 7.3 | 6.1 | 2.3 | 12.5 |
| solids | Secondary | - | - | 2.4 | 18.0 | - | 7.8 | 5.0 | 10.8 | - | 8.9 | 6.0 | 10.6 |
| (mg $L^{-1}$) | Return | 6.3 | 4.1 | 75.5 | 60.0 | 28.0 | 52.6 | 6.6 | 14.8 | - | 6.9 | 6.1 | 20.4 |
| pH | AEP | - | - | - | 8.3 | - | - | - | - | - | 8.3 | 8.3 | - |
| | Primary | 8.4 | - | 8.3 | 8.3 | 8.3 | 8.4 | 8.5 | 8.4 | 9.0 | 8.5 | 8.4 | 8.4 |
| | Secondary | - | - | 8.6 | 8.2 | - | 8.6 | 8.9 | 8.5 | - | 8.5 | 8.7 | 8.5 |
| | Return | 8.4 | 8.2 | 8.4 | 8.2 | 8.3 | 8.4 | 9.1 | 8.4 | - | 8.3 | 8.5 | 8.4 |
| n[z] | AEP | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 |
| | Primary | 4 | 0 | 4 | 4 | 4 | 4 | 4 | 11 | 4 | 8 | 4 | 4 |
| | Secondary | 0 | 0 | 4 | 4 | 0 | 20 | 11 | 20 | 0 | 16 | 20 | 32 |
| | Return | 4 | 4 | 11 | 4 | 8 | 16 | 8 | 28 | 0 | 8 | 24 | 48 |

[z] n = number of samples

[y] Three samples were missed in 2014 (SMC-P1, T-S3 on September 2, and U-R4 on September 4) resulting in missing values for all physical parameters.

Similarly to previous years, the pH of irrigation water was alkaline and varied from 7.9 to 9.8 in 2014. Also, as in 2011 to 2013, the average pH value increased from AEP to secondary sites and then slightly decreased in the return sites. The pH values in 2014 were most similar to that of 2013, and these two years had higher average pH values compared to the 2001 and 2012 (Figure 3.10). The second sampling date (July 7 to 10) had the highest pH measured in 2014 at nearly all site types except the AEP sites, where the fourth sampling date had the highest pH (data not shown). The protection of aquatic life guideline for pH (6.5 to 9.0) was exceeded in 7.6% of the samples in 2014 as compared to 5.9% in 2013. Water samples with a pH above 9.5 were measured at two sites (T-S2 and BR-S2).

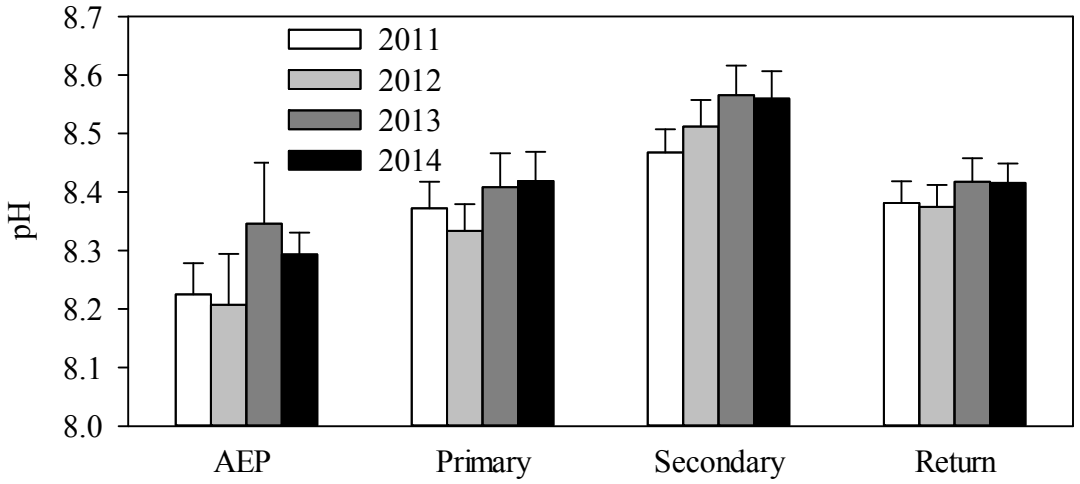


**Figure 3.10. Average pH for the different sampling site types from 2011 to 2014.**

### 3.3.5 Biological Parameters

#### 3.3.5.1 Generic *Escherichia. coli*

In 2014, the median concentration of generic *E. coli* was 44 CFU 100 $mL^{-1}$. Median *E. coli* concentrations increased slightly throughout the sampling season at primary, secondary, and return sites (Figure 3.11). At the AEP sites, median concentrations increased steadily from June to August, followed by a sharp decrease in September. Interestingly, while median *E. coli* concentrations were highest at AEP sites during the August sampling event, median concentrations were lowest at primary sites during the same time period (Figure 3.11). Similar to 2013, overall a median E. coli concentration increased from primary to return sites within each sampling period (Figure 3.11) and was consistent within each irrigation district (Table 3.9). Median *E. coli* concentrations were generally higher at AEP sites than at the primary and

secondary sites, but lower than at return sites. This was the general trend observed among the irrigation districts (Table 3.9) and sampling periods (Figure 3.11).

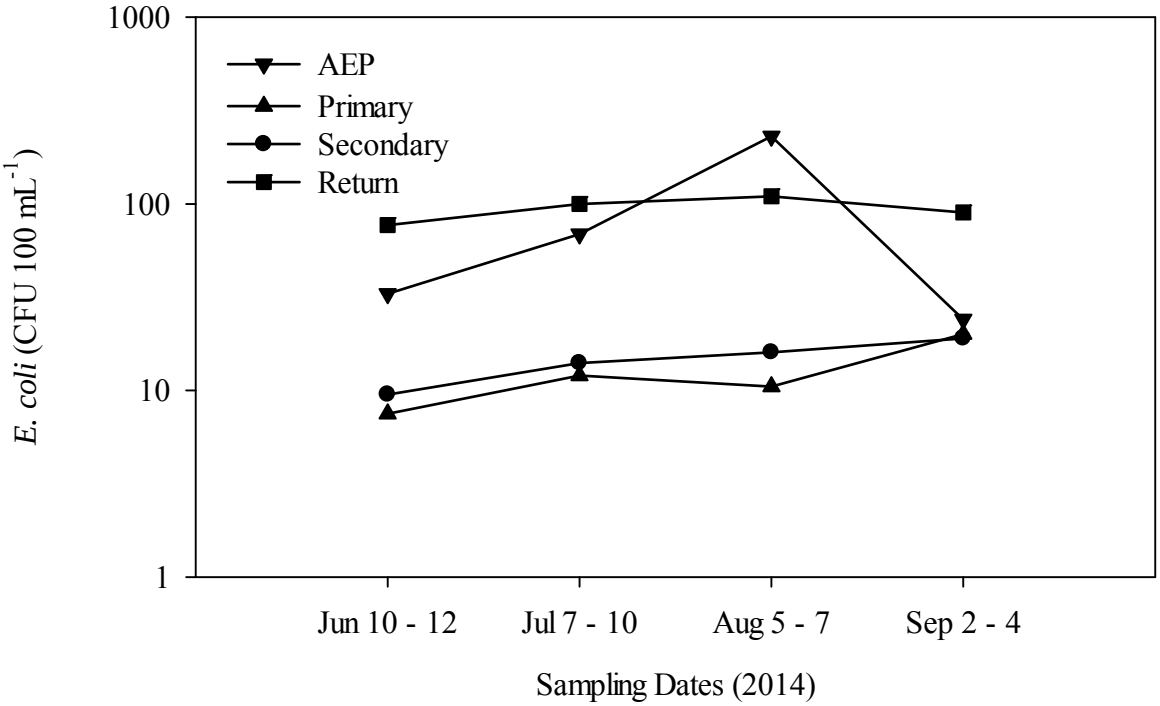


**Figure 3.11. Median *Escherichia coli* (*E. coli*) concentrations in colony forming units (CFU) per 100 mL for each type of sampling site for four sampling dates in 2014.**

The irrigation guideline for *E. coli* (100 CFU 100 $mL^{-1}$; ESRD 2014) was exceeded in 25% (90/356) of the water samples. Specifically, the guideline was exceeded in 25% (3/12) of AEP, 9% (5/55) of primary, 6% (8/127) of secondary, and 46% (74/162) of return site samples. A sub-index representing exceedance of the *E. coli* irrigation guideline was calculated for each site and included with the overall irrigation water quality index (Section 3.3.8). The higher percentage of samples exceeding the irrigation guideline at the return sites is consistent with the expected degradation of water quality as water moves downstream. It should be noted that although a large proportion of return sites exceeded the irrigation water quality guideline for *E. coli*, water in returns or at the end of the irrigation water conveyance networks is generally not applied to crops.

**Table 3.9. Median coliform concentrations and irrigation guideline (ESRD 2014) exceedance at the Alberta Environmental Protection (AEP), primary, secondary, and return sites of twelve irrigation districts in 2014.**

| Parameter | Site type | MVID | AID | UID | MID | RID | LNID | TID | SMRID | RCID | WID | BRID | EID |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Escherichia coli* | AEP | - | - | - | 22 | - | - | - | - | - | 245 | 65 | - |
| (CFU 100 $mL^{-1}$) | Primary | 7 | | 29 | 4 | 11 | 86 | 8 | 7 | 33 | 10 | 2 | 36 |
| | Secondary | - | - | 5 | 77 | - | 25 | 5 | 17 | - | 37 | 4 | 9 |
| | Return | 49 | 366 | 101 | 250 | 148 | 210 | 17 | 92 | - | 160 | 87 | 63 |
| Guideline | AEP | - | - | - | 0 | - | - | - | - | - | 50 | 25 | - |
| exceedance of | Primary | 0 | - | 0 | 0 | 0 | 50 | 25 | 0 | 25 | 0 | 0 | 25 |
| *Escherichia coli* | Secondary | - | - | 0 | 25 | - | 15 | 9 | 0 | - | 19 | 0 | 0 |
| (%) | Return | 25 | 100 | 55 | 100 | 75 | 60 | 0 | 43 | - | 63 | 42 | 35 |
| n[z] | AEP | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 |
| | Primary | 4 | 0 | 4 | 4 | 4 | 4 | 4 | 11[y] | 4 | 8 | 4 | 4 |
| | Secondary | 0 | 0 | 4 | 4 | 0 | 20 | 11[y] | 20 | 0 | 16 | 20 | 32 |
| | Return | 4 | 4 | 11[y] | 4 | 8 | 15[y] | 8 | 28 | 0 | 8 | 24 | 48 |

[z] n = number of samples.

[y] Four *E. coli* samples were missed in 2014; (SMC-P1 and T-S3 on September 2, U-R4 and LN-R2 on September 3.)

*Escherichia coli* are present in the intestines of animals and humans, and are thus used as general indicators of fecal contamination. A high concentration of *E. coli* in surface water (i.e., exceeding irrigation water quality guidelines) indicates that there is an increased likelihood enteric pathogens (e.g., *Salmonella*, *E. coli* O157:H7, and/or *Campylobacter)* are present. Exceedance of the *E. coli* guideline is of greatest concern for irrigated crops that are consumed raw such as some vegetables, (especially leafy greens, which have a large surface area and are difficult to wash), and soft fruits. There is minimal health risk associated with pathogen contamination for processed crops such as potatoes, corn, and grains, as any pathogens that are present are likely destroyed during processing. Likewise, pathogen contamination of forage crops is of minimal concern with respect to human health since consumption of these crops is limited to livestock, and livestock are generally not affected by these pathogens. It should be noted that some studies have reported poor correlation between concentrations of fecal indicator bacteria and enteric pathogens (Dechesne and Soyeux 2007). Further analyses for specific pathogens at sites that exceed the guideline may be warranted.

#### 3.3.5.2 Pathogen Samples

The median *E. coli* concentration among the 40 samples analyzed for bacterial pathogens was 75 CFU 100mL$^{-1}$. In total, 43% (17/40) of the samples exceeded the irrigation guideline for *E. coli*. This was not unexpected since the specific sites analyzed for pathogens were selected based on having guideline exceedances above 20% in previous years (Charest et al., 2012, 2013, 2014); that is, site selection was biased toward samples with a greater probability of exceeding *E. coli* guidelines.

*Campylobacter* spp. was not detected at any of the sites in 2014, although it was detected in five water samples collected at three irrigation return sites and one secondary irrigation site in 2013. *Escherichia. coli* O157:H7 was not detected in any of the water samples during the 2012, 2013 or 2014 seasons. Similar to 2013, only one of the 40 samples was positive for *Salmonella enterica* subspecies *enterica* in 2014. Specifically, *Salmonella* serovar Typhimurium was detected from an irrigation return site (T-S3) at a concentration of 23 MPN 100mL$^{-1}$. The generic *E. coli* concentrations of the same sample exceeded the irrigation guideline (100 CFU 100 mL$^{-1}$). *Salmonella* and *E. coli* O157:H7 are of the greatest concern as they are the only two bacterial pathogens (to date) that have been conclusively linked to disease outbreaks caused by irrigation water as the source of contamination (Pachepsky et al. 2011). *Salmonella* serovar Typhimurium has been among the top three serovars most commonly reported as causing human salmonellosis in Canada for the past several years (NESP 2014). This serovar may be isolated from a variety of animal sources (e.g., cattle, hogs, poultry, and wild birds); however, without advanced molecular subtyping, it was impossible to know the source of the serovar in this particular sample.

There is evidence that generic *E. coli* concentrations alone cannot provide conclusive information about the presence of pathogens in surface waters used for irrigation purposes (Pachepsky et al. 2014). This is supported in the current study. Although none of the three bacterial pathogens were detected when *E. coli* concentrations was less than the irrigation guideline, they were neither detected in 94% of the samples where the guideline was exceeded. The guideline tends to be more conservative to reduce the chance of obtaining false negative results with respect to pathogen presence. A more conservative guideline is expected for water with a high risk of accidental consumption by humans; however, the guideline may not be appropriate for certain irrigated crops where the health risk associated with pathogen contamination is minimal.

### 3.3.6 Pesticides

Of the 109 pesticides analyzed in 2014, 18 were detected. At least one pesticide was detected in 310 of the 358 samples (86.6%) analyzed. The pesticides that were detected included 15 herbicides, two insecticides (diazinon and chlorpyrifos) and one fungicide (propiconazole) (Table 3.10). No other type of pesticide analyzed (acaricide, nematicide, bactericide, or growth regulator) was detected. The pesticides most frequently detected were 2,4-D (81%), MCPA (30%), glyphosate (28%), dicamba (25%), fluroxypyr, (19%) and bentazon (14%) (Table 3.10; Figure 3.12). All other pesticides and one metabolite (AMPA) were detected in 8% or less of all samples. The type of pesticides detected, their detection frequency and concentrations were generally consistent with previous studies in Alberta (Anderson 2005; Lorenz et al. 2008).

In 2014, as in 2013, 18 different pesticides were detected in the irrigation water, compared to 14 pesticides in 2012 and 22 pesticides in 2011. For pesticides detected every year so far (2011to 2014) such as 2,4-D, dicamba and MCPA, detection frequencies were similar to those from 2012to 2014, but slightly lower than those found in 2011. In addition, a number of pesticides (fluroxypyr, bentazon, atrazine, clopyralid, EPTC, and bromoxynil) had higher detection frequencies in 2014 compared to 2013. For all pesticides detected in 2014, the average detected concentrations were lower in 2014 compared to previous years, but maximum detected concentrations were higher. EPTC and triallate were detected in 2013 and 2014 but were not found in 2011 nor 2012. Bentazon, fluroxypyr and triclopyr were analytes included in the pesticide analytical suite in 2013, and were detected in 2013 and 2014. Diazinon (insecticide) and propiconazole (fungicide) were detected at low frequencies (1% or less) in 2014. Diazinon was included in the analytical suite in 2013 and was also detected that year. Propiconazole was included in the analytical suite in 2014.

**Table 3.10. Summary of pesticides detected in 2014.**

| Pesticide[z] | Number of samples with detection[y] | Detection frequency (%) | Average (µg $L^{-1}$) | Average of detected (µg $L^{-1}$) | Median of detected (µg $L^{-1}$) | Minimum detected (µg $L^{-1}$) | Maximum detected (µg $L^{-1}$) |
|---|---|---|---|---|---|---|---|
| 2,4-D | 290 | 81 | 0.104 | 0.129 | 0.082 | 0.024 | 1.439 |
| MCPA | 106 | 30 | 0.035 | 0.117 | 0.048 | 0.024 | 3.383 |
| Glyphosate | 32 | 28 | 0.210 | 0.753 | 0.400 | 0.200 | 4.400 |
| Dicamba | 90 | 25 | 0.072 | 0.287 | 0.081 | 0.024 | 4.685 |
| Fluroxypyr | 69 | 19 | 0.022 | 0.114 | 0.044 | 0.026 | 3.254 |
| Bentazon | 49 | 14 | 0.011 | 0.081 | 0.062 | 0.025 | 0.821 |
| Atrazine | 30 | 8 | 0.004 | 0.043 | 0.035 | 0.024 | 0.167 |
| Clopyralid | 25 | 7 | 0.004 | 0.056 | 0.038 | 0.026 | 0.237 |
| MCPP | 22 | 6 | 0.003 | 0.054 | 0.031 | 0.025 | 0.291 |
| EPTC | 15 | 4 | 0.006 | 0.134 | 0.055 | 0.031 | 0.996 |
| AMPA | 2 | 2 | 0.046 | 2.650 | 2.650 | 1.000 | 4.300 |
| Bromoxynil | 6 | 2 | 0.003 | 0.164 | 0.074 | 0.041 | 0.377 |
| Simazine | 6 | 2 | 0.001 | 0.088 | 0.082 | 0.043 | 0.172 |
| Diazinon | 5 | 1 | 0.002 | 0.136 | 0.080 | 0.025 | 0.415 |
| Chlorpyrifos | 1 | 0.3 | 0.000 | 0.067 | 0.067 | 0.067 | 0.067 |
| Dichlorprop | 1 | 0.3 | 0.000 | 0.027 | 0.027 | 0.027 | 0.027 |
| Propiconazole | 1 | 0.3 | 0.001 | 0.190 | 0.190 | 0.190 | 0.190 |
| Triallate | 1 | 0.3 | 0.000 | 0.164 | 0.164 | 0.164 | 0.164 |

[z] All pesticides detected were herbicides except for the insecticides diazinon and chlorpyrifos and the fungicide propiconazole.
[y] A total of 358 samples were analyzed except for glyphosate, glufosinate-ammonium and AMPA (115 samples).

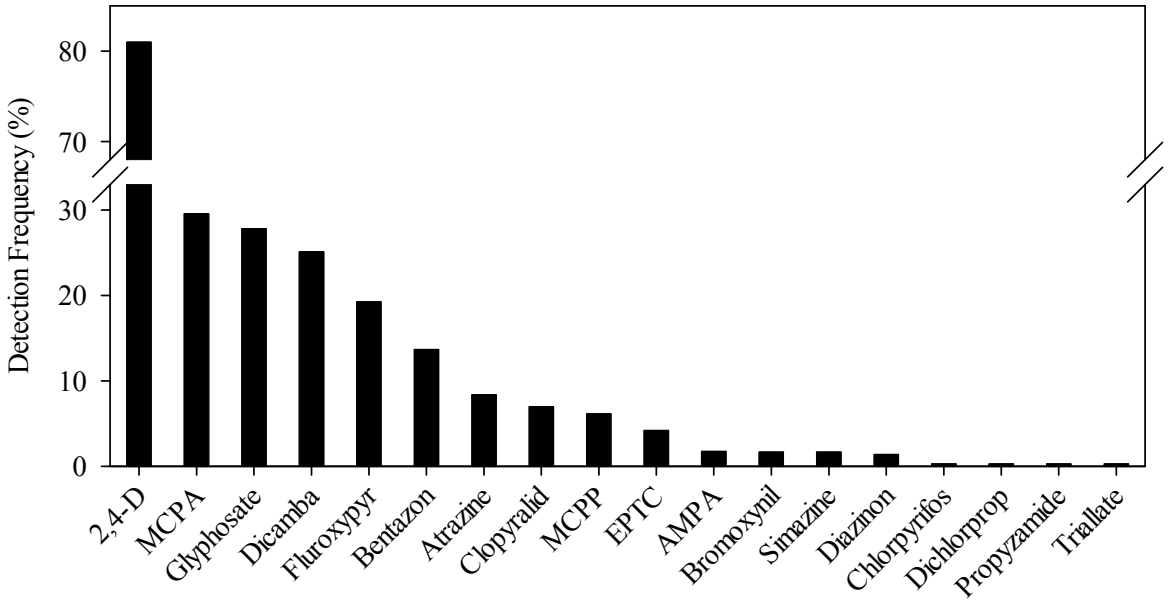


**Figure 3.12. Pesticide detection frequencies in 2014.**

Of the samples that contained pesticides (n = 310), nearly half of the samples contained either one pesticide or two pesticides (Figure 3.13). The maximum number of different pesticides detected in a single sample was nine (LN-R3 on September 3, 2014). For all 358, the average number of pesticides detected per sample was 2.1. Samples with five or more pesticides (n = 34) were detected almost exclusively in July and September 2014, and were collected mainly from secondary and return sites. This contrasts with 2013, when samples with four or more pesticides (n = 13) were only detected in June. Rain events, in part, may explain some of the disparities between 2013 and 2014.

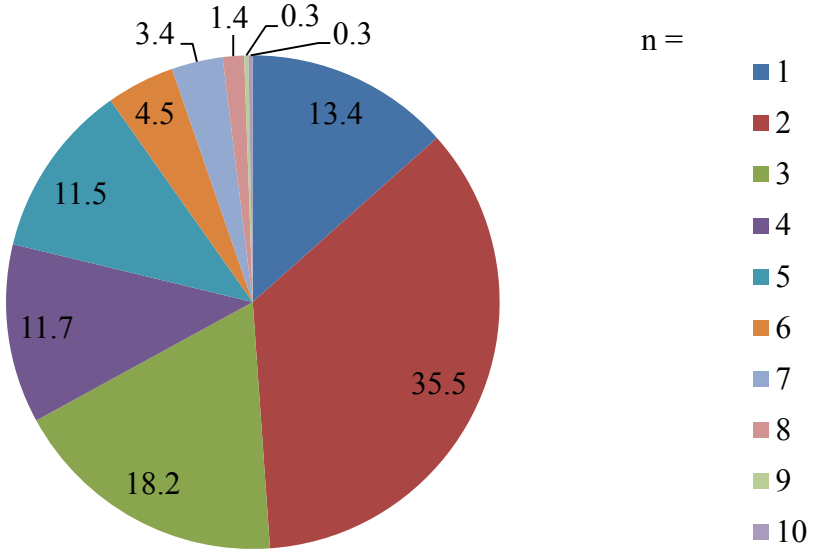


**Figure 3.13. Distribution (%) of the number of pesticides (n) detected per sample for samples with detected pesticides (n=310) 2014.**

The number of pesticides detected within irrigation districts in 2014 varied from two (MVID and RCID) to 13 pesticides (LNID) (Table 3.11). The irrigation district with the highest number of different pesticides detected (LNID; 13 pesticides) did not correspond to the irrigation district with the highest detection frequency. Only two of the 90 sites (E-S6 and U-P1) did not have pesticides detected at any time throughout the 2014 sampling period. Detection frequency (i.e., number of samples with at least one pesticide per total number of samples for a given district) for all irrigation districts ranged from 37.5% (MVID) to 100% (TID, WID). Detection frequency per irrigation district was higher in 2014 compared to 2013. Five districts (WID, BRID, TID, SMRID and RID) had detection frequencies higher than 90% in 2014 compared to only three districts in 2013 (WID, BRID and TID). In addition, the number of different pesticides detected in water samples from these irrigation districts increased (7 to 9 in 2013 compared to 7 to 12 in 2014) (Table 3.11).

Generally, the 2014 results are consistent with the results from 2011to 2013 and from 2006 to 2007 study (Little et al. 2010), with a slight increase in the number of pesticides detected and detection frequency per irrigation district. Detection frequency per irrigation district was very similar to that of previous years, with MVID having the lowest (37.5%) and TID and WID having the highest (100%). However, it should be noted that MVID's detection frequency of 37.5% was the highest observed for that district since 2006.

**Table 3.11. Pesticide detection summary in twelve irrigation districts in 2014.**

| | MVID | AID | UID | MID | RID | LNID | TID | SMRID | RCID | WID | BRID | EID | All districts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pesticide molecules detected | 2 | 3 | 6 | 6 | 9 | 13 | 11 | 12 | 2 | 7 | 10 | 10 | 18 |
| Total samples collected (n) | 8 | 4 | 19 | 16 | 12 | 40 | 24 | 60 | 4 | 36 | 52 | 83 | 358 |
| Detection frequency (%) | 38 | 75 | 68 | 69 | 92 | 88 | 100 | 98 | 75 | 100 | 94 | 76 | 87 |
| Samples in excess of guidelines[z] (%) | 0 | 50 | 68 | 38 | 50 | 40 | 42 | 23 | 0 | 14 | 15 | 42 | 32 |

[z] Irrigation, livestock watering, or protection of aquatic life guideline for pesticides from ESRD (2014).

The concentration and distribution of the most frequently detected pesticides varied among the irrigation districts (Table 3.12). Similar to previous years of this study, 2,4-D was the sole pesticide present in all irrigation districts. However, other pesticides with high detection frequencies were detected in a majority of districts, such as MCPA, dicamba, bentazon, fluroxypyr and glyphosate (8 to 10 irrigation districts each). Pesticides detected at low frequencies (i.e., <5%) were typically found in one or few irrigation districts. Chlorpyrifos, dichlorprop, propiconazole, and triallate each only occurred in one sample throughout the sampling season.

Pesticides were detected at all types of sampling sites (AEP, primary, secondary, return), with higher detection frequencies and average detected concentrations in secondary and return sites compared to AEP and primary sites (Table 3.12). Pesticide concentration tended to increase as water flowed from upstream to downstream sites within an irrigation district. However, trends in pesticide concentration among the sampling type sites varied according to the pesticide and irrigation district. For example, in WID, the concentration of the most frequently detected pesticides was fairly stable from primary to return sites; whereas in BRID and EID, pesticide concentrations increased from primary to return sites for most pesticides. These results are similar to those obtained in 2013.

**Table 3.12. Average detected concentration of the six most commonly detected pesticides at the AEP, primary, secondary, and return sites in twelve irrigation districts in 2014.[z]**

| Parameter | Site type | MVID | AID | UID | MID | RID | LNID | TID | SMRID | RCID | WID | BRID | EID |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ---------- ($\mu g\ L^{-1}$) ---------- | | | | | | | | | | | |
| 2,4-D | AEP | -[y] | - | - | nd[x] | - | - | - | - | - | 0.281 | 0.048 | - |
| | Primary | 0.181 | - | nd | 0.048 | 0.078 | 0.112 | 0.121 | 0.118 | 0.084 | 0.150 | 0.080 | 0.072 |
| | Secondary | - | - | 0.034 | 0.047 | - | 0.098 | 0.277 | 0.115 | - | 0.161 | 0.144 | 0.068 |
| | Return | 0.027 | 0.096 | 0.070 | 0.064 | 0.109 | 0.106 | 0.370 | 0.193 | - | 0.161 | 0.099 | 0.070 |
| MCPA | AEP | - | - | - | nd | - | - | - | - | - | 0.040 | nd | - |
| | Primary | nd | - | nd | 0.051 | 0.048 | nd | 0.080 | 0.064 | nd | 0.031 | nd | nd |
| | Secondary | - | - | 0.109 | 0.150 | - | 0.137 | 0.056 | 0.045 | - | 0.029 | 0.038 | 0.105 |
| | Return | nd | 0.049 | 0.101 | 0.067 | 0.051 | 0.497 | 0.057 | 0.071 | - | 0.039 | 0.039 | 0.149 |
| Glyphosate | AEP | - | - | - | nd | - | - | - | - | - | nd | nd | - |
| | Primary | nd | - | nd | nd | nd | nd | 0.300 | 0.500 | nd | 0.400 | nd | nd |
| | Secondary | - | - | nd | nd | - | nd | 0.400 | 0.350 | - | nd | nd | nd |
| | Return | nd | nd | 4.400 | nd | 0.367 | 1.500 | 0.300 | 0.788 | - | 0.300 | 0.300 | 0.720 |
| Dicamba | AEP | - | - | - | nd | - | - | - | - | - | 0.043 | nd | - |
| | Primary | nd | - | nd | nd | 0.035 | nd | nd | nd | nd | 0.047 | nd | nd |
| | Secondary | - | - | 0.139 | 0.183 | nd | 0.114 | 0.083 | nd | - | nd | 0.060 | 0.242 |
| | Return | nd | 0.027 | 0.469 | 0.076 | 0.262 | 0.276 | 0.074 | 0.033 | - | nd | 0.077 | 0.475 |
| Fluroxypyr | AEP | - | - | - | nd | - | - | - | - | - | nd | nd | - |
| | Primary | nd | - | nd | 0.030 | 0.075 | nd | 0.064 | 0.079 | nd | nd | nd | nd |
| | Secondary | - | - | 0.058 | 0.042 | - | 0.031 | 0.068 | 0.049 | - | nd | nd | 0.029 |
| | Return | nd | nd | 0.069 | 0.040 | 0.101 | 1.107 | 0.043 | 0.078 | - | nd | 0.191 | 0.092 |
| Bentazon | AEP | - | - | - | nd | - | - | - | - | - | nd | nd | - |
| | Primary | nd | - | nd | nd | 0.089 | nd | 0.073 | 0.045 | 0.078 | 0.054 | 0.059 | nd |
| | Secondary | - | - | nd | 0.029 | - | nd | 0.080 | 0.046 | - | nd | 0.097 | nd |
| | Return | nd | nd | 0.040 | 0.821 | 0.082 | 0.087 | 0.052 | 0.056 | - | 0.036 | 0.081 | 0.053 |

[z] The number of values (n) used to calculate averages ranged from n = 1 to 30. This range depended on the number of the same site types within an irrigation district and pesticide detection frequency.

[y] - = Site type is nonexistent for a specific district.

[x] nd = not detected.

For the most commonly detected pesticides including 2,4-D, and MCPA, the highest detection frequency was found in July 2014 (Figure 3.14). Dicamba's detection frequency peaked in August 2014 (33%), slightly higher than that of July (31%). In this regard, 2014 differed from previous years for pesticides detection frequency and detected concentrations among the sampling events. In previous years, pesticide detection frequency and detected concentrations for the most commonly detected pesticides tended to decrease during the duration of the sampling period (early June to end of August). This was not the case in 2014. For example, in 2014, 2,4-D's detection frequency ranged from 73% (August 2014) to 90% (July 2014), MCPA ranged from 17% (June and September 2014) to 53% (July 2014), and dicamba had its lowest detection frequency in June 2014 (14%). With regards to detected concentrations, 2,4-D peaked in July 2014, MCPA in September 2014, while dicamba peaked in June 2014 without a significant decrease from July to September. Glyphosate was analyzed only for the June and September sampling events. The average detected concentration of glyphosate was similar for sampling events in 2014, but detection frequency increased from 10% in June to 26% in September 2014.

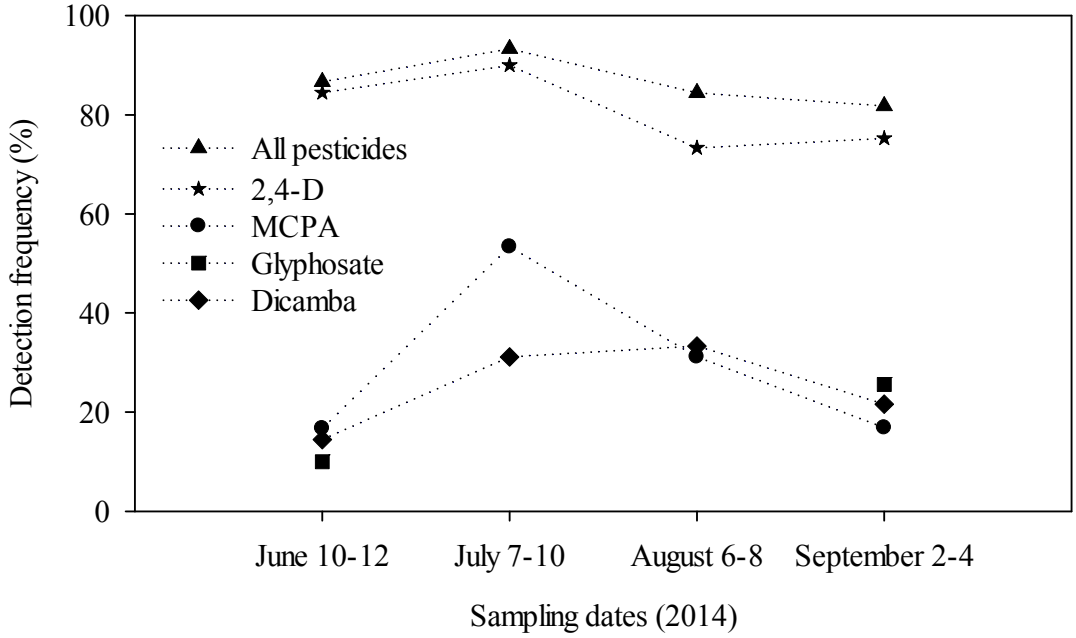


**Figure 3.14. Pesticide detection frequency for each sampling event in 2014.**

Overall pesticide detection frequency was fairly consistent throughout the 2014 sampling season. Detection frequency varied from 82% (September) to 93% (July) (Figure 3.14). This was similar to 2013, but differs from the other years of this study as well as from findings presented in Little et al. (2010), when spring samples (May-June) typically had a higher detection frequency and contained higher concentrations of pesticides compared to samples collected later in the sampling season (July-September). Results similar to Little et al. (2010) were reported by Brytus

et al. (2002) for a variety of surface and irrigation water studies in Alberta. The 2014 results could be explained by the most prevalent rain events that occurred at the end of June and early September (Appendix B). Lorenz et al. (2008) found that pesticides typically peaked during spring snowmelt and in the summer, suggesting that the processes of transport may be through soil sorption in the spring and drift in the summer.

Pesticide detection frequency in the irrigation districts in 2014 did match the 2008 pesticide sales in Alberta, to some extent. The latest pesticide sales records in Alberta are from 2008 and were compiled by Byrtus (2011). Pesticides with higher market shares in Alberta such as glyphosate, 2,4-D and MCPA (first, second and third most sold by % of active ingredient, respectively) were among the most commonly detected pesticides in 2014 (ranked third, first and second, respectively). Glyphosate has by far the highest sales in Alberta, and 28% of the analyzed samples were positive for this herbicide in 2014. This is similar to other studies where glyphosate detection frequency in surface water ranged from 22 to 33% (Humphries et al. 2005, or Lorenz 2009). The degradation product (metabolite) of glyphosate, AMPA, has typically been detected as often as glyphosate in the previous years of this study. In 2014 however, AMPA was detected at a much lower detection frequency than its parent compound glyphosate (2 versus 28%). This lower detection frequency is highly unusual and requires further probing to determine the most probable cause. The 2014 detection frequency for glyphosate was similar to 2012 (27%), but much higher compared to 2013 (4%). Of note, the limit of detection for glyphosate and AMPA was 0.1 $\mu g\ L^{-1}$, which is higher than that of most other pesticides (about 0.025 $\mu g\ L^{-1}$). This higher detection value explains in part why the average and average detected concentration values were higher for these two compounds compared to the other pesticides detected in 2014 (Table 3.10). It should be also noted that both compounds had high maximum concentration detected (over 4 $\mu g\ L^{-1}$ each) as compared to other pesticides.

In 2014, two new pesticides were added to the analytical suite; the herbicide clodinafop-propargyl and the fungicide propiconazole. The latter was detected once in 2014. Detection frequencies for bentazon and fluroxypyr were 14 and 19%, respectively which was higher than in 2013 (2 and 4%). Detection frequencies reported by Anderson (2005) for monitoring studies of pesticides in Alberta and by Lorenz et al. (2008) found detection frequencies of 5% for bentazon and fluroxypyr.

In 2014, dicamba and MCPA are the only two pesticides that surpassed their respective water quality guidelines. However, it should be noted that nine of the 18 pesticides detected in 2014 do not have water quality guidelines (AMPA, bentazon, chlorpyrifos, clopyralid, diazinon, dichlorprop, EPTC, fluroxypyr and propiconazole) (Table 3.13). Those for which water quality guidelines exist (ESRD 2014), the guidelines for livestock watering were not surpassed. The water quality guidelines for irrigation, however, were surpassed in all samples with dicamba detection (25%), due to the fact that the minimum limit of detection for dicamba analysis

exceeds the irrigation guideline. MCPA exceeded the irrigation guideline in 16% of the samples. MCPA is the only pesticide that exceeded the protection of aquatic life guideline, and it occurred once (0.3%). These results were generally consistent with previous studies (Byrtus et al. 2002, Anderson 2005, Saffran 2005, Lorenz et al. 2008, Little et al. 2010). There were 148 samples out of 358 samples (41% of all samples) that contained at least one pesticide in exceedance of its guidelines. There was general increase in pesticide detections and concentrations as the water moved through the irrigation infrastructure from primary site to return site. Guideline exceedances were present in most irrigation districts except for MVID and RCID. Non-compliance in the other irrigation districts ranged from 14% (WID) to 68% (UID) (Table 3.11).

**Table 3.13. Pesticide guidelines exceedance in 2014.**

| Pesticide[z] | Irrigation guideline ($\mu g\ L^{-1}$) | Protection of aquatic life guideline ($\mu g\ L^{-1}$) | Number of samples with detection[y] | Number of sample exceeding guideline | Average of detected ($\mu g\ L^{-1}$) | Maximum detected ($\mu g\ L^{-1}$) |
|---|---|---|---|---|---|---|
| 2, 4-D | - | 4 | 288 | 0 | 0.129 | 1.439 |
| AMPA | - | - | 2 | - | 2.650 | 4.300 |
| Atrazine | 10 | 1.8 | 30 | 0 | 0.043 | 0.167 |
| Bentazon | - | - | 48 | - | 0.081 | 0.821 |
| Bromoxynil | 0.44 | 5 | 6 | 0 | 0.164 | 0.377 |
| Chlorpyrifos | - | - | 1 | - | 0.067 | 0.067 |
| Clopyralid | - | - | 24 | - | 0.056 | 0.237 |
| Diazinon | - | - | 4 | - | 0.027 | 0.027 |
| Dicamba | 0.008 | 10 | 89 | 89 | 0.136 | 0.415 |
| Dichloroprop | - | - | 1 | - | 0.287 | 4.685 |
| EPTC | - | - | 15 | - | 0.134 | 0.996 |
| Fluroxpyr | - | - | 68 | - | 0.114 | 3.254 |
| Glyphosate | - | 65 | 31 | 0 | 0.753 | 4.400 |
| MCPA | 0.04 | 2.6 | 106 | 59 | 0.117 | 3.383 |
| Mecoprop | - | 13 | 20 | 0 | 0.054 | 0.291 |
| Propiconazole | - | - | 1 | - | 0.190 | 0.190 |
| Simazine | 0.5 | 10 | 6 | 0 | 0.088 | 0.172 |
| Triallate | - | 0.24 | 1 | 0 | 0.164 | 0.164 |

[z] All pesticides detected were herbicides except for Diazinon and Chlorpyrifos-methyl which are insecticides and Propiconazole which is an insecticide.

[y] A total of 358 samples was analyzed except for AMPA, Glufosinate-ammonium and Glyphosate (115 samples).

### 3.3.7 Veterinary Pharmaceutical

All seven veterinary pharmaceuticals were detected in the water samples with detection frequency that varied from 1 % (sulfamethazine) to 100 % (chlortetracycline and tetracycline ) (Table 3.14). The order of average detected concentrations for the seven veterinary pharmaceuticals was tetracycline (72.0 ng $L^{-1}$) > chlortetracycline > tylosin > monensin > erythromycin > lincomycin > sulfamethazine (1.5 ng $L^{-1}$). Median values ranked with tetracycline (70.9 ng $L^{-1}$) > chlortetracycline > erythromycin > monensin > tylosin = lincomycin = sulfamethazine. The maximum detected concentration was 155.2 ng $L^{-1}$ for tetracycline (at a secondary site in BRID in September 2014 sampling).

**Table 3.14. Summary of veterinary pharmaceuticals detected in 2014**

| Pharmaceutical | No. of samples with detection[z] > LOQ[y] | Detection frequency (%) | No. of samples with ND[x] | Average (ng $L^{-1}$) | Median of detected (ng $L^{-1}$) | Minimum detected (ng $L^{-1}$) | Maximum detected (ng $L^{-1}$) |
|---|---|---|---|---|---|---|---|
| Chlortetracycline | 96 | 100 | 0 | 34.1 | 32.6 | 13.0 | 68.8 |
| Sulfamethazine | 1 | 1.0 | 80 | 1.5[x] | <LOQ | <LOQ | 3.0 |
| Tylosin | 3 | 3.1 | 71 | 12.2 | <LOQ | <LOQ | 117.0 |
| Monensin | 9 | 9.4 | 68 | 4.9 | 3.3 | <LOQ | 20.3 |
| Lincomycin | 14 | 14.6 | 41 | 2.3[w] | <LOQ | <LOQ | 4.8 |
| Erythromycin | 35 | 36.5 | 50 | 4.7 | 4.5 | <LOQ | 13.0 |
| Tetracycline | 96 | 100 | 0 | 72.0 | 70.9 | 28.4 | 155.2 |

[z] 96 samples were analyzed.

[y] Limit of quantification.

[x] ND = Not detected.

[w] Average value < LOQ due to inclusion of 50% LOQ values (1.25 ng $L^{-1}$) where values were from 50 to 100% LOQ for statistical purposes.

All seven veterinary pharmaceuticals were detected in the eight irrigation districts sampled (Table 3.15). Of the seven pharmaceuticals, four were ubiquitous throughout all districts (chlortetracycline, lincomycin, erythromycin, and tetracycline). The MVID was chosen as a benchmark of sorts (lower cattle numbers, limited confined feedlots, and more grazing animals) compared to irrigation districts with higher cattle populations and larger feedlots (LNID, WID). Four pharmaceuticals (chlortetracycline, lincomycin, erythromycin, and tetracycline) were detected in MVID. However, MVID was the only irrigation district with four veterinary pharmaceuticals while the other irrigation districts had five to seven veterinary pharmaceuticals. Of the eight irrigation districts, water samples from four districts (TID, WID, BRID, and EID) had all seven measured veterinary pharmaceuticals.

| Table 3.15. Veterinary pharmaceutical (VP) detection in eight irrigation districts in 2014. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | UID | LNID | TID | SMRID | WID | BRID | MVID | EID | All Districts |
| VP residues detected[z] | 5 | 5 | 7 | 6 | 7 | 7 | 4 | 7 | 4 |
| Chlortetracycline | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Sulfamethazine | × | × | ✓ | × | ✓ | ✓ | × | ✓ | × |
| Tylosin | × | ✓ | ✓ | ✓ | ✓ | ✓ | × | ✓ | × |
| Monensin | ✓ | × | ✓ | ✓ | ✓ | ✓ | × | ✓ | × |
| Lincomycin | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Erythromycin | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Tetracycline | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Total samples collected | 8 | 20 | 12 | 16 | 12 | 12 | 4 | 12 | 96 |
| Detection frequency[z] (%) | 37.5 | 40.0 | 51.2 | 42.0 | 42.9 | 47.6 | 35.7 | 41.7 | 42.9 |

✓= detected, × = not detected

[z] Detected at least ≥ 50% of the limit of quantification.

No trend was observed in the detected concentrations in the secondary and return sites. Both site types generally contained similar veterinary pharmaceuticals concentrations, except in a few instances (Table 3.16). For example, concentrations of veterinary pharmaceuticals were higher (greater than two times) in the secondary sites than the return sites for erythromycin in June 2014 samples (13.0 vs. 6 ng $L^{-1}$) and tylosin in September 2014 samples (59.1 vs. 3.0 ng $L^{-1}$).

Detection frequency was 100 % for chlortetracycline and tetracycline during all four sampling events (Figure 3.15). Sulfamethazine was detected (> limit of quantification (LOQ)) only during the September, 2014 sampling event. Erythromycin detection frequency was 4 to 33% during the first three sampling events, and then its detection frequency increased to 96% in September.

Average detected concentrations were higher for June sampling for chlortetracycline and erythromycin (Figure 3.16), while the opposite was true for tylosin, which had an average detected concentration much higher in September (40.4 ng $L^{-1}$) than in June (< LOQ). Average concentration of sulfamethazine was < LOQ for all sampling events. Only one sample showed concentration >LOQ of 3 ng $L^{-1}$, however, when averaged for all sites in the same sampling event, the resulting average was <LOQ. Average concentration of tetracycline was lowest in June (56.8 ng $L^{-1}$) compared to September (84.6 ng $L^{-1}$).

**Table 3.16. Average detected concentrations of seven veterinary pharmaceuticals at secondary and return sites in eight irrigation districts during June, July, August, and September, 2014.**

| Pharmaceutical | Site type | June | July | August | September | Overall Average |
|---|---|---|---|---|---|---|
| | | ng $L^{-1}$ | | | | |
| Chlortetracycline | Secondary[z] | 41.1 | 26.4 | 23.0 | 37.0 | 31.9 |
| | Return[y] | 40.5 | 31.7 | 31.4 | 38.2 | 35.4 |
| Sulfamethazine | Secondary | ND[x] | ND | ND | <LOQ | <LOQ |
| | Return | <LOQ[w] | ND | ND | <LOQ | <LOQ |
| Tylosin | Secondary | ND | <LOQ | ND | 59.1 | 30.2 |
| | Return | <LOQ | <LOQ | <LOQ | 3.0 | <LOQ |
| Monensin | Secondary | ND | <LOQ | 6.8 | 2.9 | 4.9 |
| | Return | ND | ND | 4.4 | 6.5 | 5.0 |
| Lincomycin | Secondary | <LOQ | <LOQ | ND | <LOQ | <LOQ |
| | Return | <LOQ | 3.2 | <LOQ | <LOQ | <LOQ |
| Erythromycin | Secondary | 13.0 | 3.5 | ND | 4.3 | 4.7 |
| | Return | 6.0 | 5.0 | 1.3 | 4.8 | 4.6 |
| Tetracycline | Secondary | 58.9 | 75.2 | 73.9 | 90.7 | 74.7 |
| | Return | 55.6 | 77.7 | 67.2 | 81.0 | 70.4 |

[z] The number of values used to calculate averages, $n = 9$ (for each sampling date) and $n = 36$ (for overall average).
[y] The number of values used to calculate averages, $n = 15$ (for each sampling date) and $n = 60$ (for overall average).
[x] ND: Not detected includes all samples with no detection as well as those with < 50% LOQ i.e., < 1.25 ng $L^{-1}$.
[w] LOQ: Limit of quantification = 2.5 ng $L^{-1}$.

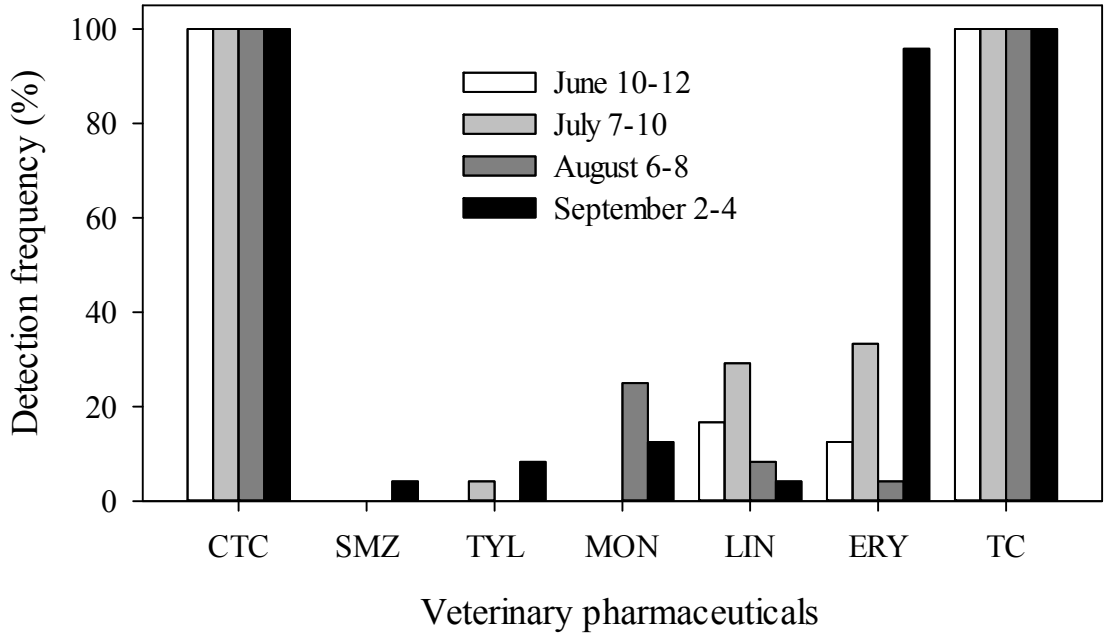


**Figure 3.15. Detection frequency (>2.5 ng $L^{-1}$) of veterinary pharmaceuticals for four sampling dates in 2014**. CTC: chlortetracycline; SMZ: sulfamethazine; TYL: tylosin; MON: monensin; LIN: lincomysin; ERY: erythromycin, TC: Tetracycline.

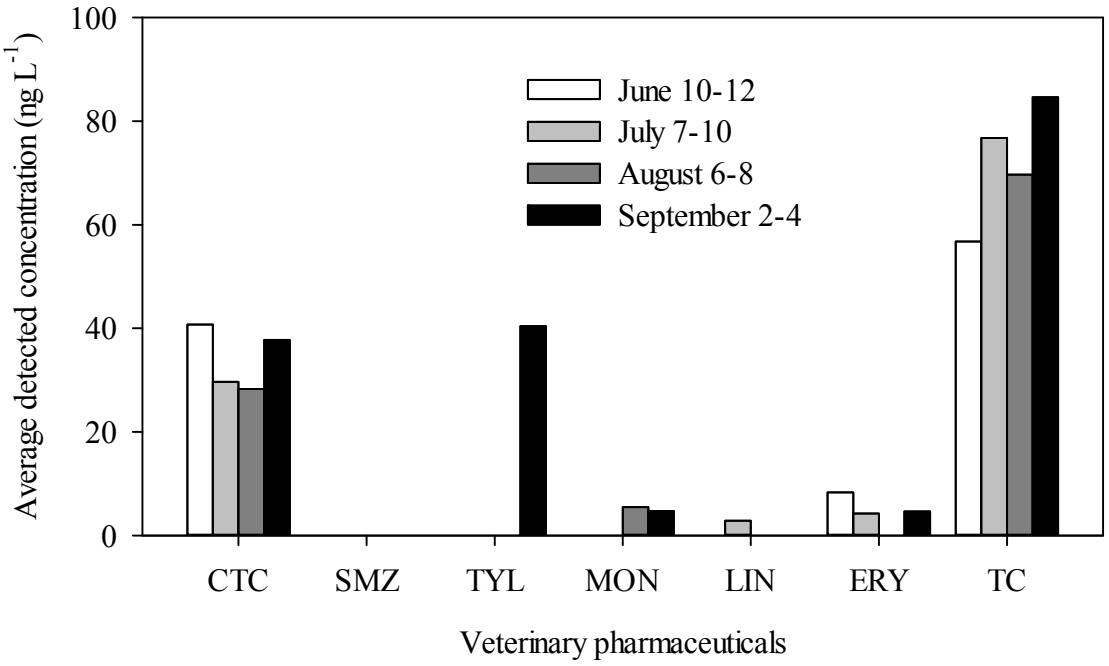


**Figure 3.16. Average detected concentrations of veterinary pharmaceuticals for four sampling dates in 2014.** CTC: chlortetracycline; SMZ: sulfamethazine; TYL: tylosin; MON: monensin; LIN: lincomysin; ERY: erythromycin, TC: Tetracycline. <LOQ: below limit of quantification (2.5 ng $L^{-1}$).

Detection frequency of chlortetracycline increased from 65.5 to 100% from 2013 to 2014. Detection frequencies of sulfamethazine, tylosin, and erythromycin decreased in 2014 compared to the previous year. Average concentration of only one veterinary pharmaceutical, chlortetracycline, increased (34.1 ng $L^{-1}$ vs. 9.8 ng $L^{-1}$) while the others either decreased (sulfamethazine, tylosin, erythromycin) or remained the same (monensin: 4.9 ng $L^{-1}$ and lincomycin: 2.5 ng $L^{-1}$) in 2014 compared to 2013. Maximum concentration of chlortetracycline detected increased from 27.2 ng $L^{-1}$ in 2013 to 68.8 ng $L^{-1}$ in 2014 whereas; the maximum detected tylosin concentration was similar in both years (117.0 ng $L^{-1}$ vs 101.0 ng $L^{-1}$). Detection frequency of tylosin reduced from 96.6 % in 2013 to 3.1 % in 2014. Detection frequency of lincomycin increased to 14.6 % (in 2014) from 0 % (in 2013) because of a change in the LOQ. The LOQ of lincomycin was 5 ng $L^{-1}$ in 2013 whereas it was 2.5 ng $L^{-1}$ in 2014. The maximum detected concentration of lincomycin in 2014 sampling was 4.8 ng $L^{-1}$, which was less than the LOQ in 2013. Tetracycline was detected in 100% of the samples collected. It was also detected at a higher concentration than any of the other veterinary pharmaceutical measured, with a maximum concentration detected at 155.2 ng $L^{-1}$.

The only other Alberta study to compare our data with is that of Forrest et al. (2011) who sampled water in 23 streams in agricultural watersheds in 2005 to 2006. They used different LOQ values, so direct comparisons are difficult. However, they found higher detection frequencies for monensin. For sulfamethazine, they found a detection frequency of 8.1% which was higher than our 2014 results (1%) but lower than the 2013 results (13.8%). For lincomycin they had a detection frequency of 1.2 % (LOQ = 10 ng $L^{-1}$); whereas, we had zero in 2013 (LOQ = 5 ng $L^{-1}$) and 14.6% in 2014 (LOQ = 2.5 ng $L^{-1}$). For chlortetracycline, Forrest et al. (2011) had a detection frequency of only 0.8% (LOQ = 10 ng $L^{-1}$) compared to 65.5% and 100% in the current study using LOQ values two and four times more sensitive in 2013 and 2014, respectively. Similar results were observed for erythromycin with higher detection frequencies in the current study using a lower LOQ value.

### 3.3.8 Water Quality Indices

The average irrigation water quality index value for all sites was 91.9 in 2014, giving an overall excellent rating for irrigation water in the province (Figure 3.17; Table 3.17). This compares similar to the overall index scores of in the previous three years. The recalculated index scores for 2011 to 2013, with the updated irrigation guidelines (ESRD 2014), were slightly higher than the scores calculated with the CCME guidelines (CCME 2005). The index score slightly decrease but remained excellent from AEP and primary sites (98.5 each) to secondary sites (95.0) and return sites (86.9). Watershed return sites that are the least representative of irrigation water had an average score of 84.3. Of the 90 irrigation district monitoring sites, 82% had an excellent rating, 9% had a good rating, 7% had a fair rating, and 2% had a marginal rating for irrigation water quality. A few sites in UID, LNID, and EID, in particular, had a lower index score than in 2013. This could be explained by higher frequency and magnitude of irrigation guideline exceedance for *E. coli*, dicamba, and MCPA. There were two sites in 2014 with a marginal index score; EID return sites E-R2a and E-R7. The return site E-R2a exceeded the *E. coli* guideline for three of the four sampling events in 2014, and exceeded the guideline for dicamba all four sampling events, but its lower score was mainly attributed to the elevated dicamba concentration (4.7 µg $L^{-1}$) on August 7, 2014. The return site E-R7 was similar, exceeding the *E. coli* guideline two of the four sampling events and exceeded the dicamba guideline for three of the four events with a concentration of 4.3 µg $L^{-1}$ on June 12, 2014. On the other hand, the sites with fair or marginal irrigation index scores in 2013 all improved in 2014.

Because several parameters were used to calculate the irrigation water quality index (Table 3.2), sub-indices were calculated for salinity, metals, pesticides, and fecal coliforms to facilitate interpretation of the results. Some parameters exceeded the irrigation guidelines more often or by higher proportions than others. As in previous years, *E. coli* and pesticides had more effect in

reducing the average irrigation water quality index because they generally had lower sub-index scores (Table 3.18). Metals, on the other hand, had the most positive effect on the index followed by salinity parameters. Marginal or poor ratings of the irrigation water quality sub-indices tended to be at the return sites. However, AEP-P2, located on the Bow River diversion canal for WID also had poor *E. coli* irrigation sub-index score. In 2013, it was AEP-P3 that had a poor *E. coli* irrigation sub-index scores. However, the WID primary sites had irrigation water quality index scores of 100. Water quality often improves downstream of reservoirs where concentration of suspended solids, nutrients, metals, coliforms, and pesticides are often reduced.

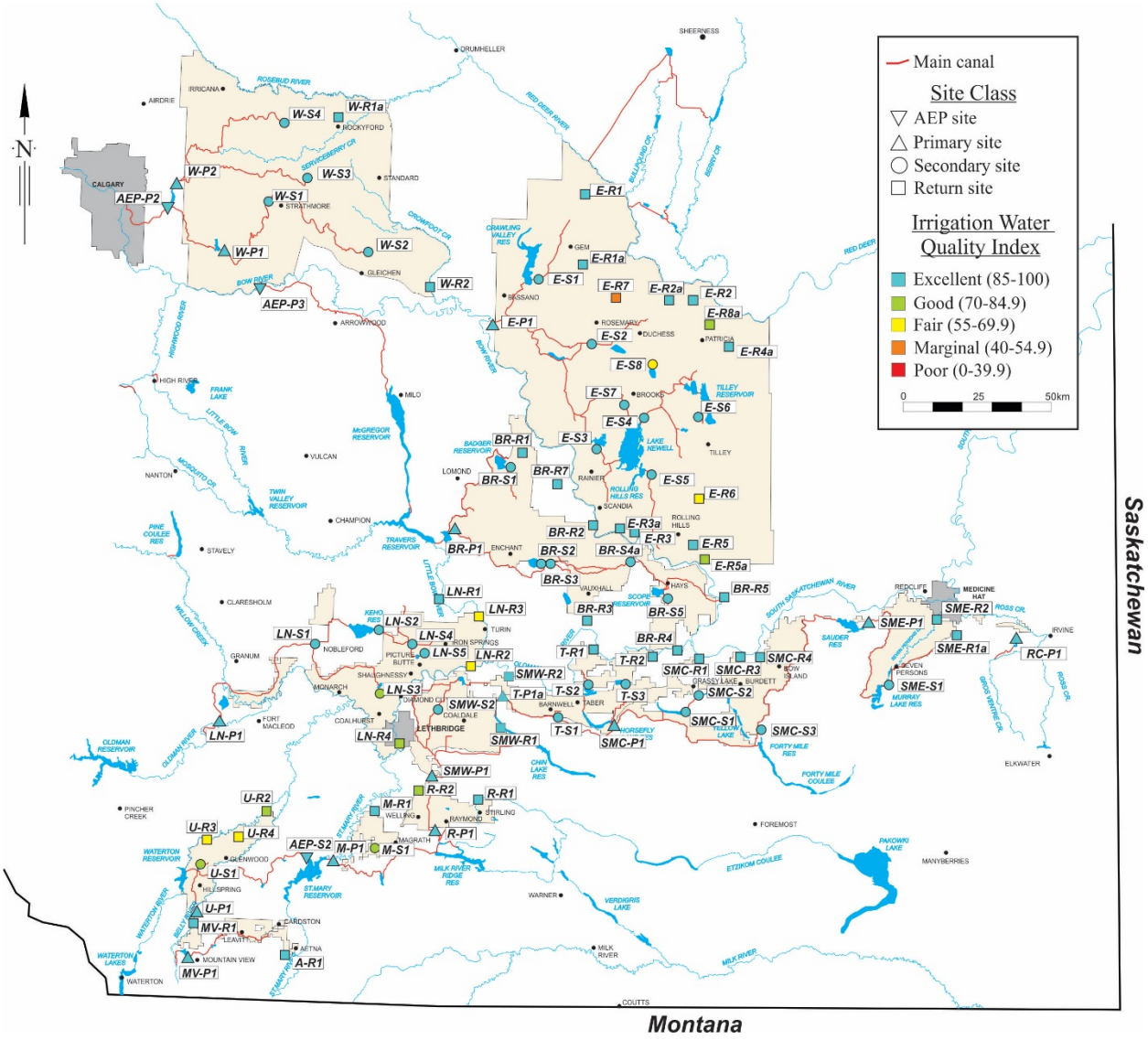


**Figure 3.17. Irrigation water quality index scores in 2014.**

**Table 3.17. Irrigation water quality index scores and rankings[z] for each site in 2011, 2012, 2013 and 2014.**

| Irrigation District | Site | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|
| MVID | MV-P1 | 100.0 | 100.0 | 100.0 | 100.0 |
| | MV-R1 | 100.0 | 100.0 | 100.0 | 100.0 |
| AID | A-R1 | 96.8 | 100.0 | 100.0 | 95.7 |
| UID | U-P1 | 97.3 | 100.0 | 58.9 | 100.0 |
| | U-S1 | 55.2 | 100.0 | 80.8 | 81.9 |
| | U-R2 | 52.7 | 94.5 | 89.6 | 73.7 |
| | U-R3 | 62.9 | 91.7 | 77.9 | 55.8 |
| | U-R4 | - | 100.0 | 70.2 | 66.0 |
| MID | M-P1 | 93.6 | 100.0 | 100.0 | 97.9 |
| | M-S1 | 96.6 | 97.1 | 81.8 | 82.2 |
| | M-R1 | 97.4 | 97.8 | 100.0 | 87.2 |
| RID | R-P1 | 96.8 | 100.0 | 100.0 | 95.5 |
| | R-R1 | 87.7 | 90.2 | 95.5 | 95.8 |
| | R-R2 | 91.6 | 97.9 | 100.0 | 78.8 |
| LNID | LN-P1 | 100 | 100.0 | 95.9 | 100.0 |
| | LN-S1 | 97.5 | 100.0 | 97.9 | 100.0 |
| | LN-S2 | 100.0 | 100.0 | 100.0 | 100.0 |
| | LN-S3 | 97.9 | 92.2 | 71.9 | 79.4 |
| | LN-S4 | 97.8 | 97.3 | 100.0 | 95.6 |
| | LN-S5 | 93.9 | 93.9 | 77.3 | 91.8 |
| | LN-R1 | 91.6 | 92.6 | 89.0 | 93.3 |
| | LN-R2 | 86.6 | 86.4 | 72.8 | 67.8 |
| | LN-R3 | 96.5 | 100.0 | 83.6 | 60.0 |
| | LN-R4 | - | 83.4 | 64.9 | 79.9 |
| TID | T-P1a | 97.5 | 97.9 | 100.0 | 97.7 |
| | T-S1 | 97.9 | 97.9 | 97.0 | 97.5 |
| | T-S2 | 91.9 | 96.1 | 93.8 | 87.8 |
| | T-S3 | 86.1 | 89.7 | 92.2 | 89.5 |
| | T-R1 | 91.2 | 94.1 | 96.2 | 93.0 |
| | T-R2 | 86.1 | 88.5 | 92.5 | 91.0 |
| SMRID | SMW-P1 | 95.4 | 100.0 | 100.0 | 97.9 |
| | SMW-S2 | 95.5 | 100.0 | 97.9 | 97.9 |
| | SMW-R1 | 93.4 | 79.4 | 95.7 | 96.0 |
| | SMW-R2 | 90.6 | 94.5 | 94.8 | 94.5 |
| | SMC-P1 | 97.6 | 97.8 | 100.0 | 97.1 |
| | SMC-S1 | 100.0 | 100.0 | 100.0 | 97.9 |
| | SMC-S2 | 100.0 | 100.0 | 100.0 | 97.9 |
| | SMC-S3 | 97.6 | 97.9 | 97.9 | 97.8 |
| | SMC-R1 | 100 | 100.0 | 100.0 | 100.0 |
| | SMC-R3 | 97.9 | 97.9 | 100.0 | 100.0 |
| | SMC-R4 | 97.6 | 100.0 | 97.8 | 97.8 |
| | SME-P1 | 92.5 | 100.0 | 97.9 | 97.5 |
| | SME-S1 | 100.0 | 100.0 | 100.0 | 100.0 |
| | SME-R1a | 97.8 | 100.0 | 100.0 | 100.0 |
| | SME-R2 | 91.4 | 100.0 | 97.9 | 100.0 |

| Irrigation District | Site | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|
| RCID | RC-P1 | - | - | 95.5 | 97.2 |
| WID | W-P1 | 94.9 | 97.6 | 97.3 | 100.0 |
| | W-P2 | 89.5 | 95.4 | 96.1 | 95.3 |
| | W-S1 | 90.9 | 94.0 | 97.0 | 100.0 |
| | W-S2 | 95.7 | 97.7 | 95.6 | 100.0 |
| | W-S3 | 92 | 94.8 | 93.6 | 100.0 |
| | W-S4 | 94.8 | 95.6 | 93.9 | 100.0 |
| | W-R1a | 97.5 | 97.4 | 94.7 | 100.0 |
| | W-R2 | 93.5 | 92.4 | 95.5 | 95.9 |
| BRID | BR-P1 | 100.0 | 100.0 | 100.0 | 100.0 |
| | BR-S1 | 97.5 | 100.0 | 100.0 | 94.4 |
| | BR-S2 | 92.9 | 97.5 | 97.5 | 100.0 |
| | BR-S3 | 100.0 | 100.0 | 100.0 | 95.3 |
| | BR-S4a | 100.0 | 100.0 | 94.6 | 93.7 |
| | BR-S5 | 100.0 | 100.0 | 100.0 | 97.7 |
| | BR-R1 | 100.0 | 100.0 | 100.0 | 100.0 |
| | BR-R2 | 96.7 | 100.0 | 93.3 | 93.5 |
| | BR-R3 | 96.9 | 97.0 | 94.6 | 97.0 |
| | BR-R4 | 97.9 | 95.7 | 95.4 | 97.5 |
| | BR-R5 | 100.0 | 97.5 | 100.0 | 94.1 |
| | BR-R7 | | 97.4 | 94.9 | 100.0 |
| EID | E-P1 | 100.0 | 100.0 | 100.0 | 100.0 |
| | E-S1 | 95.2 | 96.4 | 100.0 | 100.0 |
| | E-S2 | 100.0 | 100.0 | 100.0 | 100.0 |
| | E-S3 | 94.4 | 96.9 | 95.4 | 96.7 |
| | E-S4 | 48.4 | 100.0 | 89.0 | 100.0 |
| | E-S5 | 100.0 | 100.0 | 100.0 | 100.0 |
| | E-S6 | 97.6 | 100.0 | 100.0 | 100.0 |
| | E-S7 | 95.5 | 97.1 | 79.2 | 96.1 |
| | E-S8 | 69.2 | 70.4 | 63.5 | 68.6 |
| | E-R1 | - | 57.1 | 90.0 | 97.4 |
| | E-R1a | 84.4 | 57.5 | 97.9 | 95.7 |
| | E-R2 | - | 89.9 | 45.5 | 85.9 |
| | E-R2a | 58.1 | 84.9 | 97.8 | 51.2 |
| | E-R3 | | 78.3 | 91.6 | 89.8 |
| | E-R3a | 81.7 | 85.7 | 91.6 | 93.5 |
| | E-R4a | - | 77.0 | 79.7 | 87.8 |
| | E-R5 | - | 100.0 | 92.2 | 91.4 |
| | E-R5a | 69.6 | 86.6 | 81.2 | 73.2 |
| | E-R6 | 51.9 | 74.6 | 83.0 | 62.5 |
| | E-R7 | 49.8 | 87.3 | 97.9 | 52.3 |
| | E-R8a | 89.3 | 70.2 | 75.7 | 71.1 |
| ESRD canals | AEP-P2 | 96.3 | 93.9 | 100.0 | 95.4 |
| | AEP-P3 | 100.0 | 90.7 | 100.0 | 100 |
| | AEP-S2 | 88.3 | 97.7 | 97.9 | 100 |
| Average | All sites | 91.2 | 94.3 | 92.6 | 91.9 |

[z] Blue = excellent (85 to 100), green = good (70 to 84.9), yellow = fair (55 to 69.9), orange = marginal (40 to 54.9), and red = poor (0 to 39.9).
[y] Site not sample in 2011and/or 2012.

**Table 3.18. Irrigation water quality index and sub-index scores and rankings[z] for each site in 2014**

| Irrigation district | Site | All parameters | Salinity | Metals | Pesticides | *E. coli* |
|---|---|---|---|---|---|---|
| MVID | MV-P1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | MV-R1 | 100.0 | 100.0 | 100.0 | 100.0 | 76.6 |
| AID | A-R1 | 95.7 | 100.0 | 100.0 | 84.5 | 4.8 |
| UID | U-P1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | U-S1 | 81.9 | 100.0 | 100.0 | 61.1 | 100.0 |
| | U-R2 | 73.7 | 100.0 | 100.0 | 53.3 | 64.0 |
| | U-R3 | 55.8 | 100.0 | 100.0 | 44.5 | 40.3 |
| | U-R4 | 66.0 | 100.0 | 100.0 | 48.3 | 44.9 |
| MID | M-P1 | 97.9 | 100.0 | 100.0 | 92.5 | 100.0 |
| | M-S1 | 82.2 | 100.0 | 100.0 | 61.5 | 49.6 |
| | M-R1 | 87.2 | 94.1 | 100.0 | 68.6 | 10.1 |
| RID | R-P1 | 95.5 | 100.0 | 100.0 | 83.9 | 100.0 |
| | R-R1 | 95.8 | 92.7 | 100.0 | 92.5 | 25.4 |
| | R-R2 | 78.8 | 100.0 | 100.0 | 58.3 | 42.8 |
| LNID | LN-P1 | 100.0 | 100.0 | 100.0 | 100.0 | 62.9 |
| | LN-S1 | 100.0 | 100.0 | 100.0 | 100.0 | 82.3 |
| | LN-S2 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | LN-S3 | 79.4 | 100.0 | 100.0 | 58.6 | 81.6 |
| | LN-S4 | 95.6 | 100.0 | 100.0 | 84.2 | 81.2 |
| | LN-S5 | 91.8 | 100.0 | 100.0 | 75.1 | 100.0 |
| | LN-R1 | 93.3 | 100.0 | 93.4 | 89.0 | 24.5 |
| | LN-R2 | 67.8 | 100.0 | 100.0 | 49.1 | 33.1 |
| | LN-R3 | 60.0 | 100.0 | 100.0 | 46.4 | 6.6 |
| | LN-R4 | 79.9 | 100.0 | 100.0 | 59.1 | 100.0 |
| TID | T-P1a | 97.7 | 100.0 | 100.0 | 91.8 | 71.8 |
| | T-S1 | 97.5 | 100.0 | 100.0 | 91.6 | 100.0 |
| | T-S2 | 87.8 | 100.0 | 100.0 | 70.5 | 100.0 |
| | T-S3 | 89.5 | 100.0 | 100.0 | 75.9 | 40.9 |
| | T-R1 | 93.0 | 100.0 | 100.0 | 79.4 | 100.0 |
| | T-R2 | 91.0 | 100.0 | 100.0 | 75.7 | 100.0 |
| SMRID | SMW-P1 | 97.9 | 100.0 | 100.0 | 92.5 | 100.0 |
| | SMW-S2 | 97.9 | 100.0 | 100.0 | 92.5 | 100.0 |
| | SMW-R1 | 96.0 | 100.0 | 100.0 | 86.9 | 34.6 |
| | SMW-R2 | 94.5 | 100.0 | 100.0 | 81.3 | 68.7 |
| | SMC-P1 | 97.1 | 100.0 | 100.0 | 91.2 | 100.0 |
| | SMC-S1 | 97.9 | 100.0 | 100.0 | 92.6 | 100.0 |
| | SMC-S2 | 97.9 | 100.0 | 100.0 | 92.6 | 100.0 |
| | SMC-S3 | 97.8 | 100.0 | 100.0 | 92.0 | 100.0 |
| | SMC-R1 | 100.0 | 100.0 | 100.0 | 100.0 | 81.2 |
| | SMC-R3 | 100.0 | 100.0 | 100.0 | 100.0 | 58.6 |
| | SMC-R4 | 97.8 | 100.0 | 100.0 | 92.2 | 44.8 |
| | SME-P1 | 97.5 | 100.0 | 100.0 | 90.8 | 100.0 |
| | SME-S1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | SME-R1a | 100.0 | 100.0 | 100.0 | 100.0 | 68.1 |
| | SME-R2 | 100.0 | 100.0 | 100.0 | 100.0 | 13.7 |
| RCID | RC-P1 | 97.2 | 76.4 | 100.0 | 100.0 | 74.5 |
| WID | W-P1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | W-P2 | 95.3 | 100.0 | 100.0 | 83.3 | 100.0 |
| | W-S1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | W-S2 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | W-S3 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | W-S4 | 100.0 | 100.0 | 100.0 | 100.0 | 24.8 |
| | W-R1a | 100.0 | 100.0 | 100.0 | 100.0 | 60.2 |
| | W-R2 | 95.9 | 93.8 | 100.0 | 92.5 | 28.8 |
| BRID | BR-P1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | BR-S1 | 94.4 | 100.0 | 100.0 | 81.0 | 100.0 |
| | BR-S2 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | BR-S3 | 95.3 | 100.0 | 100.0 | 85.0 | 100.0 |
| | BR-S4a | 93.7 | 100.0 | 100.0 | 81.4 | 100.0 |
| | BR-S5 | 97.7 | 100.0 | 100.0 | 91.6 | 100.0 |
| | BR-R1 | 100.0 | 100.0 | 100.0 | 100.0 | 82.2 |
| | BR-R2 | 93.5 | 100.0 | 100.0 | 81.0 | 80.1 |
| | BR-R3 | 97.0 | 74.6 | 100.0 | 100.0 | 38.7 |
| | BR-R4 | 97.5 | 100.0 | 100.0 | 91.0 | 21.6 |
| | BR-R5 | 94.1 | 100.0 | 100.0 | 80.3 | 100.0 |
| | BR-R7 | 100.0 | 100.0 | 100.0 | 100.0 | 47.7 |
| EID | E-P1 | 100.0 | 100.0 | 100.0 | 100.0 | 81.2 |
| | E-S1 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | E-S2 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | E-S3 | 96.7 | 100.0 | 100.0 | 88.8 | 100.0 |
| | E-S4 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | E-S5 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | E-S6 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| | E-S7 | 96.1 | 100.0 | 100.0 | 87.3 | 100.0 |
| | E-S8 | 68.6 | 100.0 | 100.0 | 50.6 | 100.0 |
| | E-R1 | 97.4 | 100.0 | 100.0 | 90.7 | 34.3 |
| | E-R1a | 95.7 | 100.0 | 100.0 | 86.0 | 60.5 |
| | E-R2 | 85.9 | 100.0 | 100.0 | 67.8 | 26.8 |
| | E-R2a | 51.2 | 100.0 | 100.0 | 42.6 | 33.8 |
| | E-R3 | 89.8 | 100.0 | 100.0 | 73.9 | 100.0 |
| | E-R3a | 93.5 | 100.0 | 100.0 | 81.1 | 41.1 |
| | E-R4a | 87.8 | 100.0 | 100.0 | 70.8 | 100.0 |
| | E-R5 | 91.4 | 100.0 | 100.0 | 76.7 | 100.0 |
| | E-R5a | 73.2 | 100.0 | 100.0 | 53.3 | 100.0 |
| | E-R6 | 62.5 | 100.0 | 100.0 | 47.1 | 77.4 |
| | E-R7 | 52.3 | 100.0 | 100.0 | 44.7 | 61.0 |
| | E-R8a | 71.1 | 100.0 | 100.0 | 51.9 | 41.9 |
| ESRD canals | AEP-P2 | 95.4 | 100.0 | 100.0 | 85.2 | 36.6 |
| | AEP-P3 | 100.0 | 100.0 | 100.0 | 100.0 | 75.2 |
| | AEP-S2 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Average | All sites | 91.9 | 99.2 | 99.9 | 84.1 | 74.9 |

[z] Blue = excellent (85 to 100), green = good (70 to 84.9), yellow = fair (55 to 69.9), orange = marginal (40 to 54.9), and red = poor (0 to 39.9).

The water quality index for livestock watering was excellent for all sites and averaged 100.0 (Table 3.19), which was essentially the same as for the previous years (99.9 in 2011 to 2013). Aluminum was the only parameter that exceeded the livestock watering guideline in four samples in 2013.

The protection of aquatic life water quality indices were excellent for nearly all sites except four sites that were rated as good in 2014 (Table 3.20). Most incidences of guideline exceedance were from metals (Al, As, Cr, Cu, Fe, Hg, and Se), as well as few incidences of guideline exceedance for pH, $NH_3$, $SO_4$, and the pesticide diazinon. The average protection of aquatic life index score was 96.1 in 2014, and this score was better than in the three previous years. This could be explained by a reduced number of samples exceeding the Al and Fe guidelines in particular, and a lower number of pesticides exceeding guidelines. The lower concentration of several metals can be explained by the lower average TSS concentration measured in 2014.

In 2014, the average recreational water quality index score was 86.2 (Table 3.19), which was still considered excellent and comparable with the 2013 results. *E*scherichia *coli* was the only parameter used in the recreation index. Therefore, the index value decreased when the concentration exceeded the guideline of 200 CFU 100 $mL^{-1}$ (Health Canada 2012). The guideline proposed in the Environmental Quality Guidelines for Alberta Surface Waters (ESRD 2014) was not used because the sampling regime did not allow for the calculation of a 30-d interval geometric mean. Poor recreation water quality index score were only found in return sites (Table 3.19). These sites, however, are typically not used for recreation purposes. Sites with recreational activities were generally rated as excellent except for AEP-P2 and AEP-P3, which were the Bow River diversion sites downstream of Calgary. The highest concentration of *E. coli* was found at SME-R2 on September 4, 2014and could be attributed to runoff from the high precipitation event during the days prior to sampling.

While the irrigation canals are not intended for recreation, some irrigation water contributes to rivers, lakes and reservoirs that provide recreational opportunities. The potential risk to recreational users is uncertain, as microbe populations constantly change. Alberta Health Services monitors and posts advisories for commonly used beaches. More information is available from Environmental Public Health (2013).

**Table 3.19. Water quality index scores and rankings[z] for livestock watering and recreational use in 2014.**

| Irrigation district | Site | Livestock watering | Recreation |
|---|---|---|---|
| MVID | MV-P1 | 100.0 | 100.0 |
| | MV-R1 | 100.0 | 82.3 |
| AID | A-R1 | 100.0 | 32.9 |
| UID | U-P1 | 100.0 | 100.0 |
| | U-S1 | 100.0 | 100.0 |
| | U-R2 | 100.0 | 100.0 |
| | U-R3 | 100.0 | 52.5 |
| | U-R4 | 100.0 | 74.4 |
| MID | M-P1 | 100.0 | 100.0 |
| | M-S1 | 100.0 | 62.5 |
| | M-R1 | 100.0 | 45.9 |
| RID | R-P1 | 100.0 | 100.0 |
| | R-R1 | 100.0 | 100.0 |
| | R-R2 | 100.0 | 55.4 |
| LNID | LN-P1 | 100.0 | 100.0 |
| | LN-S1 | 100.0 | 100.0 |
| | LN-S2 | 100.0 | 100.0 |
| | LN-S3 | 100.0 | 100.0 |
| | LN-S4 | 100.0 | 100.0 |
| | LN-S5 | 100.0 | 100.0 |
| | LN-R1 | 100.0 | 34.4 |
| | LN-R2 | 100.0 | 44.8 |
| | LN-R3 | 100.0 | 12.6 |
| | LN-R4 | 100.0 | 100.0 |
| TID | T-P1a | 100.0 | 81.2 |
| | T-S1 | 100.0 | 100.0 |
| | T-S2 | 100.0 | 100.0 |
| | T-S3 | 100.0 | 51.7 |
| | T-R1 | 100.0 | 100.0 |
| | T-R2 | 100.0 | 100.0 |
| SMRID | SMW-P1 | 100.0 | 100.0 |
| | SMW-S2 | 100.0 | 100.0 |
| | SMW-R1 | 100.0 | 77.4 |
| | SMW-R2 | 100.0 | 79.7 |
| | SMC-P1 | 100.0 | 100.0 |
| | SMC-S1 | 100.0 | 100.0 |
| | SMC-S2 | 100.0 | 100.0 |
| | SMC-S3 | 100.0 | 100.0 |
| | SMC-R1 | 100.0 | 100.0 |
| | SMC-R3 | 100.0 | 72.2 |
| | SMC-R4 | 100.0 | 57.5 |
| | SME-P1 | 100.0 | 100.0 |
| | SME-S1 | 100.0 | 100.0 |
| | SME-R1a | 100.0 | 79.4 |
| | SME-R2 | 100.0 | 25.6 |
| RCID | RC-P1 | 100.0 | 82.0 |
| WID | W-P1 | 100.0 | 100.0 |
| | W-P2 | 100.0 | 100.0 |
| | W-S1 | 100.0 | 100.0 |
| | W-S2 | 100.0 | 100.0 |
| | W-S3 | 100.0 | 100.0 |
| | W-S4 | 100.0 | 34.8 |
| | W-R1a | 100.0 | 82.2 |
| | W-R2 | 100.0 | 55.0 |
| BRID | BR-P1 | 100.0 | 100.0 |
| | BR-S1 | 100.0 | 100.0 |
| | BR-S2 | 100.0 | 100.0 |
| | BR-S3 | 100.0 | 100.0 |
| | BR-S4a | 100.0 | 100.0 |
| | BR-S5 | 100.0 | 100.0 |
| | BR-R1 | 100.0 | 100.0 |
| | BR-R2 | 100.0 | 100.0 |
| | BR-R3 | 100.0 | 60.5 |
| | BR-R4 | 100.0 | 77.4 |
| | BR-R5 | 100.0 | 100.0 |
| | BR-R7 | 100.0 | 73.8 |
| EID | E-P1 | 100.0 | 100.0 |
| | E-S1 | 100.0 | 100.0 |
| | E-S2 | 100.0 | 100.0 |
| | E-S3 | 100.0 | 100.0 |
| | E-S4 | 100.0 | 100.0 |
| | E-S5 | 100.0 | 100.0 |
| | E-S6 | 100.0 | 100.0 |
| | E-S7 | 100.0 | 100.0 |
| | E-S8 | 100.0 | 100.0 |
| | E-R1 | 100.0 | 40.4 |
| | E-R1a | 100.0 | 73.8 |
| | E-R2 | 100.0 | 62.5 |
| | E-R2a | 100.0 | 61.7 |
| | E-R3 | 100.0 | 100.0 |
| | E-R3a | 100.0 | 100.0 |
| | E-R4a | 100.0 | 100.0 |
| | E-R5 | 100.0 | 100.0 |
| | E-R5a | 100.0 | 100.0 |
| | E-R6 | 100.0 | 100.0 |
| | E-R7 | 100.0 | 100.0 |
| | E-R8a | 100.0 | 100.0 |
| ESRD canals | AEP-P2 | 100.0 | 47.7 |
| | AEP-P3 | 100.0 | 82.1 |
| | AEP-S2 | 100.0 | 100.0 |
| Average | All sites | 100.0 | 86.2 |

[z] Blue = excellent (85 to 100), green = good (70 to 84.9), yellow = fair (55 to 69.9), orange = marginal (40 to 54.9), and red = poor (0 to 39.9).

**Table 3.20. Protection of aquatic life water quality index scores and rankings[z] for each site in 2011, 2012, 2013 and 2014.**

| Irrigation District | Site | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|
| MVID | MV-P1 | 100.0 | 100.0 | 100.0 | 97.3 |
| | MV-R1 | 94.9 | 96.0 | 95.3 | 98.7 |
| AID | A-R1 | 93.0 | 95.4 | 96.2 | 96.9 |
| UID | U-P1 | 96.7 | 94.3 | 98.4 | 96.5 |
| | U-S1 | 100.0 | 98.6 | 100.0 | 100.0 |
| | U-R2 | 91.9 | 91.7 | 81.8 | 93.7 |
| | U-R3 | 77.4 | 69.4 | 61.4 | 77.4 |
| | U-R4 | - | 89.9 | 94.3 | 97.8 |
| MID | M-P1 | 98.5 | 98.6 | 100.0 | 98.3 |
| | M-S1 | 94.8 | 87.8 | 96.0 | 93.3 |
| | M-R1 | 84.4 | 84.5 | 83.5 | 84.8 |
| RID | R-P1 | 97.8 | 97.0 | 98.6 | 98.2 |
| | R-R1 | 80.7 | 78.8 | 84.4 | 88.1 |
| | R-R2 | 73.6 | 91.4 | 91.2 | 90.7 |
| LNID | LN-P1 | 86.5 | 86.7 | 79.6 | 89.1 |
| | LN-S1 | 90.0 | 86.8 | 80.2 | 88.4 |
| | LN-S2 | 97.5 | 97.3 | 98.5 | 100.0 |
| | LN-S3 | 98.5 | 98.6 | 95.9 | 95.8 |
| | LN-S4 | 94.9 | 93.0 | 90.7 | 96.8 |
| | LN-S5 | 97.1 | 96.7 | 94.4 | 98.6 |
| | LN-R1 | 67.9 | 61.8 | 72.0 | 76.6 |
| | LN-R2 | 96.2 | 94.7 | 93.9 | 95.0 |
| | LN-R3 | 96.3 | 97.4 | 95.2 | 93.3 |
| | LN-R4 | - | 97.3 | 98.7 | 98.5 |
| TID | T-P1a | 98.6 | 98.5 | 98.7 | 97.1 |
| | T-S1 | 98.1 | 89.6 | 98.5 | 98.3 |
| | T-S2 | 97.3 | 94.0 | 98.0 | 97.9 |
| | T-S3 | 100.0 | 92.0 | 98.4 | 98.1 |
| | T-R1 | 74.1 | 95.7 | 97.1 | 97.9 |
| | T-R2 | 100.0 | 97.2 | 98.4 | 98.3 |
| SMRID | SMW-P1 | 95.7 | 96.3 | 98.3 | 97.8 |
| | SMW-S2 | 95.8 | 94.3 | 96.5 | 95.9 |
| | SMW-R1 | 93.8 | 90.9 | 94.2 | 94.7 |
| | SMW-R2 | 94.7 | 93.5 | 95.1 | 92.1 |
| | SMC-P1 | 92.8 | 96.8 | 97.1 | 95.8 |
| | SMC-S1 | 98.6 | 100.0 | 100.0 | 100.0 |
| | SMC-S2 | 98.5 | 100.0 | 95.6 | 98.7 |
| | SMC-S3 | 93.3 | 97.2 | 89.0 | 96.7 |
| | SMC-R1 | 95.7 | 96.7 | 98.7 | 100.0 |
| | SMC-R3 | 98.0 | 98.5 | 98.1 | 97.2 |
| | SMC-R4 | 97.7 | 98.3 | 96.8 | 95.8 |
| | SME-P1 | 98.7 | 98.5 | 95.9 | 98.7 |
| | SME-S1 | 95.5 | 90.8 | 97.2 | 94.4 |
| | SME-R1a | 95.6 | 92.7 | 98.6 | 96.0 |
| | SME-R2 | 93.6 | 94.2 | 93.5 | 96.4 |
| RCID | RC-P1 | - | - | 95.4 | 95.1 |
| WID | W-P1 | 98.7 | 98.5 | 100.0 | 98.7 |
| | W-P2 | 100.0 | 98.5 | 100.0 | 100.0 |
| | W-S1 | 97.5 | 98.1 | 100.0 | 98.6 |
| | W-S2 | 98.6 | 93.8 | 97.3 | 96.2 |
| | W-S3 | 98.3 | 97.1 | 98.6 | 98.6 |
| | W-S4 | 97.3 | 95.6 | 95.7 | 96.0 |
| | W-R1a | 97.0 | 97.0 | 94.5 | 98.1 |
| | W-R2 | 94.0 | 80.2 | 89.7 | 93.4 |
| BRID | BR-P1 | 97.1 | 100.0 | 100.0 | 100.0 |
| | BR-S1 | 100.0 | 100.0 | 94.2 | 100.0 |
| | BR-S2 | 94.0 | 94.0 | 94.1 | 94.1 |
| | BR-S3 | 98.6 | 98.6 | 98.6 | 100.0 |
| | BR-S4a | 100.0 | 98.6 | 100.0 | 98.6 |
| | BR-S5 | 100.0 | 98.7 | 100.0 | 100.0 |
| | BR-R1 | 100.0 | 100.0 | 100.0 | 100.0 |
| | BR-R2 | 90.6 | 96.5 | 97.0 | 97.1 |
| | BR-R3 | 86.7 | 93.5 | 93.1 | 92.9 |
| | BR-R4 | 100.0 | 100.0 | 96.0 | 98.6 |
| | BR-R5 | 100.0 | 100.0 | 100.0 | 100.0 |
| | BR-R7 | - | 95.8 | 100.0 | 100.0 |
| EID | E-P1 | 96.3 | 92.1 | 88.0 | 96.2 |
| | E-S1 | 98.6 | 98.3 | 100.0 | 100.0 |
| | E-S2 | 95.5 | 94.0 | 93.0 | 96.6 |
| | E-S3 | 91.7 | 88.9 | 83.1 | 91.7 |
| | E-S4 | 100.0 | 96.4 | 98.6 | 100.0 |
| | E-S5 | 100.0 | 100.0 | 100.0 | 100.0 |
| | E-S6 | 100.0 | 97.1 | 98.6 | 98.4 |
| | E-S7 | 90.2 | 88.7 | 81.2 | 92.3 |
| | E-S8 | 98.6 | 97.8 | 98.6 | 100.0 |
| | E-R1 | - | 98.6 | 98.7 | 97.0 |
| | E-R1a | 98.6 | 97.2 | 97.4 | 98.7 |
| | E-R2 | - | 97.2 | 95.9 | 98.4 |
| | E-R2a | 72.9 | 77.8 | 89.4 | 81.8 |
| | E-R3 | - | 95.4 | 100.0 | 97.1 |
| | E-R3a | 91.6 | 94.9 | 88.3 | 93.6 |
| | E-R4a | - | 100.0 | 100.0 | 100.0 |
| | E-R5 | - | 98.7 | 100.0 | 100.0 |
| | E-R5a | 95.3 | 93.9 | 96.6 | 97.0 |
| | E-R6 | 94.3 | 97.2 | 97.2 | 98.7 |
| | E-R7 | 96.0 | 96.3 | 98.4 | 97.2 |
| | E-R8a | 89.4 | 94.0 | 92.0 | 95.7 |
| ESRD canals | AEP-P2 | 92.9 | 93.1 | 90.9 | 95.6 |
| | AEP-P3 | 98.1 | 62.3 | 91.6 | 95.3 |
| | AEP-S2 | 95.3 | 93.2 | 97.3 | 92.2 |
| Average | All sites | 94.5 | 94.0 | 94.8 | 96.1 |

[z] Blue = excellent (85 to 100), green = good (70 to 84.9), yellow = fair (55 to 69.9), orange = marginal (40 to 54.9), and red = poor (0 to 39.9).

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# 4 Contribution of Irrigation Returns to Rivers

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## 4.1 Introduction

Irrigation districts in Alberta currently return approximately 20% of diverted water to rivers (AECOM Canada Ltd. 2009). Water quality from irrigation returns is usually poorer than the original source water (Little et al. 2010), and this leads to questions regarding the potential effects of irrigation returns on rivers. Depending on the watershed, studies have shown that returns may have negligible, detrimental, or beneficial effects on receiving stream water quality (Greenlee et al. 2000, Ontkean et al. 2005). The effect of a single irrigation return may be negligible given the relatively small volume of water from a return compared to the much larger volume of a river. However, recognizing the concern of irrigation returns as non-point source contamination, it is of interest to quantify the cumulative effect that irrigation returns may have on receiving water bodies. This study addressed the secondary objective of the Irrigation Districts Water Quality Project – to assess the cumulative effect of irrigation returns on river water quality (Chapter 1).

In 2011 and 2012, loading calculations were done using data from irrigation return sites sampled for the main study along with some river sites on the Oldman, Bow, and South Saskatchewan rivers. Some results were inconclusive while others showed the effect of irrigation returns on river water quality may be negligible. To further investigate this, synoptic surveys were completed in 2014.

A synoptic survey is a method of water quality sampling and flow metering a single parcel of water as it moves downstream. This type of survey allows for assessment of when and where changes occur in the river relative to contribution sources to the river. All contributions of water to the river, such as irrigation returns, coulee runoff, tributaries, and municipal and industrial discharges, are monitored as well as the river itself.

## 4.2 Methods

### 4.2.1 Sampling Sites

For the 2014 synoptic survey, the same river stretch was used as in 2011 and 2012 (Villeneuve 2013). Topographic maps, Google Earth™ (Version 6.0.1, Google Inc., 2013) and ground

truthing were used to identify 46 synoptic survey sampling sites along the Oldman River (Figure 4.1, Table 4.1). Sites were named using OS to identify them as Oldman Synoptic sites and their downstream distance in kilometres from the first site (e.g., OS-1.9 was 1.9 km downstream of the first site, OS-0.0). Six sites were located in the river to provide a detailed description of water quality changes in the river. Forty potential contribution sources to the river were found. The contribution source sites included 12 irrigation returns in the Lethbridge Northern Irrigation District (LNID), St. Mary River Irrigation District (SMRID), and Bow River Irrigation District (BRID); 21 natural coulees that were more than 1.5 km long; four municipal discharges (Taber wastewater treatment plant, Taber industrial wastewater lagoons, and two Taber stormwater outflows); one industrial discharge; one tributary (Little Bow River), and one site (OS-45.4) in a coulee that was the combination of the industrial discharge, an irrigation return, and a municipal stormwater outflow (Figure 4.1). The irrigation water (OS-45.4a), the industrial discharge (OS-45.4b), and the stormwater (OS-45.4c) were sampled individually before the water entered the coulee and the combined water was sampled before it discharged into the river at Site OS-45.4. Two of the irrigation sites (OS-39.4 and OS-68.4) and one of the municipal stormwater sites (OS-43.1) were also combined source sites as they were located in coulees where natural flow occurred during the runoff survey, but not during the dry-season survey.

Six of the irrigation returns were monitored where water entered into pipelines prior to discharge into the river (Table 4.1). Other contribution source sites were monitored as close to the river as access would allow. Access was available directly at the river for 22 sites and 12 sites were located from 0.2 to 3.5 km away from the river because of steep coulees or otherwise poor access. Road access was available for all but five sites. These five sites were coulees that had boat access only. These sites were not monitored during the runoff survey because of unsafe boat conditions, and they were assumed to be dry during the dry-season survey. This meant that a total of 41 sites (river and contribution sources) were monitored during the surveys. Some of these sites were the same as sampled by Alberta Environment and Parks during synoptic surveys in 1998, 2000, and 2005 (Table 4.1) (Saffran 2005, Kromrey et al. 2011).

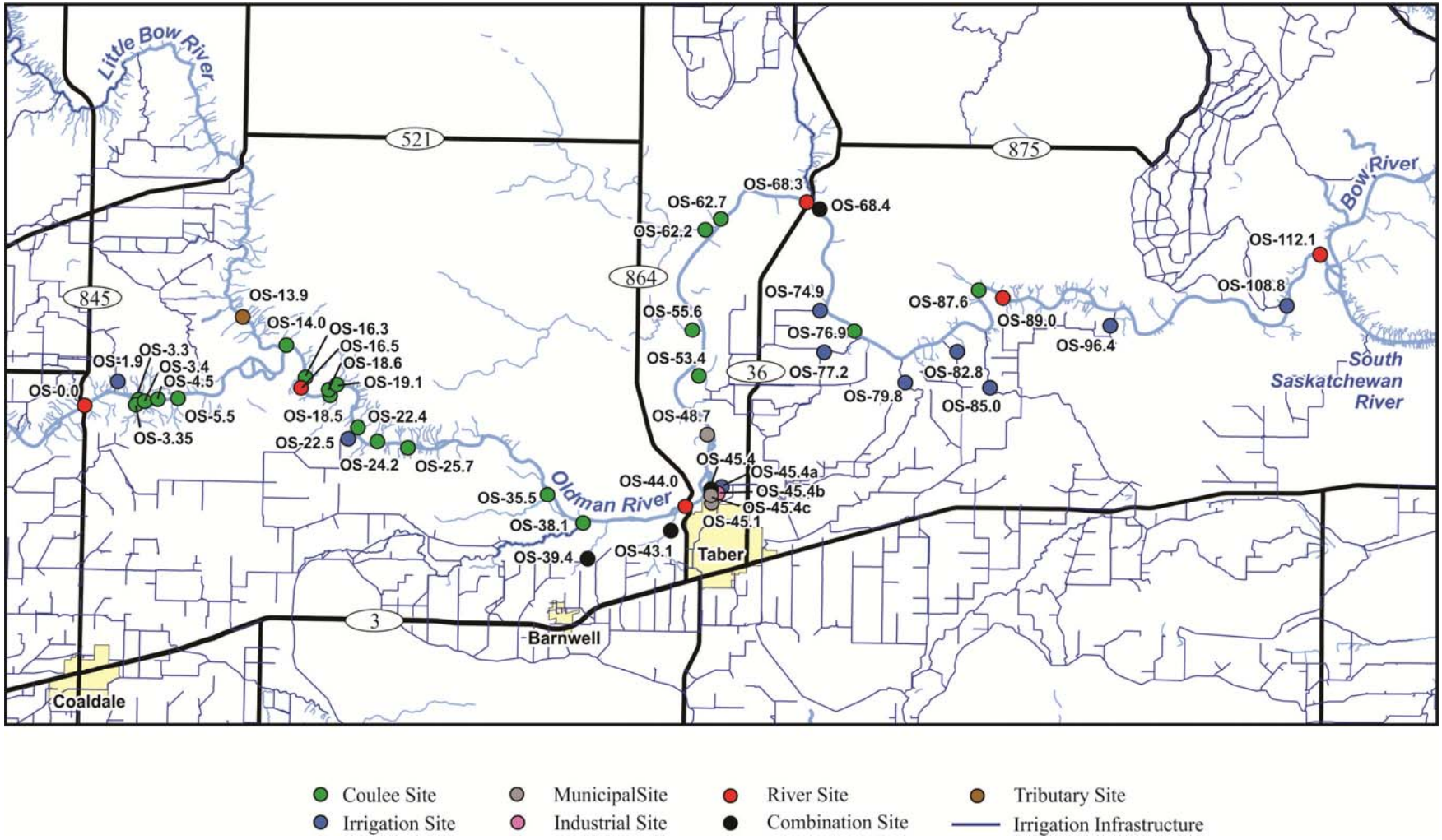


**Figure 4.1. Synoptic survey sites on the Oldman River in 2014.**

**Table 4.1. Synoptic survey sites on the Oldman River.**

| Site name | Site type | Access | Latitude (degree) | Longitude (degree) | Description |
|---|---|---|---|---|---|
| OS-0.0[z] | river | road | 49.8572 | -112.6228 | At Hwy 845 |
| OS-1.9[z] | irrigation[y] | road | 49.8692 | -112.5985 | Battersea Drain/LN-R2[x] (LNID) |
| OS-3.3 | coulee | road | 49.8605 | -112.5827 | |
| OS-3.35[w] | coulee | boat | 49.8580 | -112.5847 | |
| OS-3.4 | coulee | road | 49.8598 | -112.5781 | |
| OS-4.5 | coulee | road | 49.8609 | -112.5683 | |
| OS-5.5[w] | coulee | boat | 49.8616 | -112.5532 | |
| OS-13.9[z] | tributary | road | 49.9019 | -112.5063 | Little Bow River |
| OS-14.0[w] | coulee | boat | 49.8891 | -112.4701 | |
| OS-16.3 | coulee | road | 49.8730 | -112.4585 | |
| OS-16.5 | river | road | 49.8679 | -112.4616 | North of Chin |
| OS-18.5 | coulee | road | 49.8645 | -112.4399 | |
| OS-18.6 | coulee | road | 49.8672 | -112.4410 | |
| OS-19.1 | coulee | road | 49.8697 | -112.4350 | |
| OS-22.4 | coulee | road | 49.8494 | -112.4186 | |
| OS-22.5 | irrigation[y] | road | 49.8439 | -112.4257 | Cameron Extension 7/ SMW-R2[x] (TID) |
| OS-24.2 | coulee | road | 49.8429 | -112.4039 | |
| OS-25.7[w] | coulee | boat | 49.8400 | -112.3810 | |
| OS-35.5 | coulee | road | 49.8186 | -112.2763 | |
| OS-38.1 | coulee | road | 49.8049 | -112.2494 | Bountiful Coulee |
| OS-39.4[z] | irrigation/coulee | road | 49.7878 | -112.2456 | Lateral 1B Barnwell (TID) |
| OS-43.1 | municipal/coulee | road | 49.8020 | -112.1839 | Taber stormwater outflow |
| OS-44.0[z] | river | road | 49.8138 | -112.1733 | At Hwy 864 |
| OS-45.1 | municipal | road | 49.8168 | -112.1537 | Taber Wastewater Treatment Plant |
| OS-45.4a | irrigation | road | 49.8237 | -112.1465 | Southwest Big Bend Drain (TID) |
| OS-45.4b[z] | industrial | road | 49.8207 | -112.1493 | . |
| OS-45.4c | municipal | road | | | Taber stormwater outflow |
| OS-45.4 | irrigation/industrial/ municipal | road | 49.8221 | -112.1545 | |
| OS-48.7 | municipal | road | 49.8489 | -112.1579 | Taber Industrial Wastewater Lagoons |
| OS-53.4 | coulee | road | 49.8770 | -112.1648 | |
| OS-55.6 | coulee | road | 49.8993 | -112.1702 | |
| OS-62.2 | coulee | road | 49.9475 | -112.1616 | |
| OS-62.7 | coulee | road | 49.9528 | -112.1502 | |
| OS-68.3[z] | river | road | 49.9615 | -112.0861 | At Hwy 36 |
| OS-68.4[z] | irrigation/coulee | road | 49.9609 | -112.0817 | Expanse Coulee (BRID) |
| OS-74.9 | irrigation[y] | road | 49.9097 | -112.0751 | Lateral E Big Bend Spillway (TID) |
| OS-76.9 | coulee | road | 49.9000 | -112.0492 | |
| OS-77.2 | irrigation[y] | road | 49.8893 | -112.0715 | G7 Big Bend Spillway/T-R1[x] (TID) |
| OS-79.8 | irrigation | road | 49.8752 | -112.0107 | Lateral K Spillway (TID) |
| OS-82.8[z] | irrigation[y] | road | 49.8905 | -111.9722 | North Fincastle West Canal (TID) |
| OS-85.0 | irrigation | road | 49.8732 | -111.9473 | East Horsefly Drain (TID) |
| OS-87.6[w] | coulee | boat | 49.9205 | -111.9568 | |
| OS-89.0[z] | river | road | 49.9169 | -111.9387 | North of Purple Springs |
| OS-96.4 | irrigation[y] | road | 49.9042 | -111.8581 | North Fincastle East Canal Spill /T-R2[x] (TID) |
| OS-108.8 | irrigation | road | 49.9147 | -111.7263 | Drain TA/BR-R4[x] (BRID) |
| OS-112.1 | river | road | 49.9393 | -111.7017 | Near convergence with Bow River |

[z] Sampled during previous synoptic surveys by Alberta Environment and Parks

[y] Sampled where water entered pipelines prior to discharge to the river.

[x] Site sampled as part of main study (Chapter 2).

[w] Site not monitored because of unsafe conditions during runoff survey and assumption of no flow during dry-season survey.

### 4.2.2 Sampling Times

The velocity of the river was used to calculate sampling times during each survey. A relationship curve of velocity and the river flow was developed using Oldman River hydrographs from Water Survey of Canada (WSC) stations 05AD007 and 05AG006 (Environment Canada 2013). These stations were the upstream and downstream flow stations for the stretch of Oldman River monitored for the synoptic surveys in 2014 (Figure 4.2). The hydrographs were overlaid and peaks and valleys of flow were used to identify the same parcel of water as it flowed downstream (Figure 4.3). The travel time of these parcels was then calculated. A velocity was generated using the distance between the stations (143.2 km) divided by the travel time. Hydrographs from 2011 and 2012 were used to collect a sufficient number of data points for curve fitting.

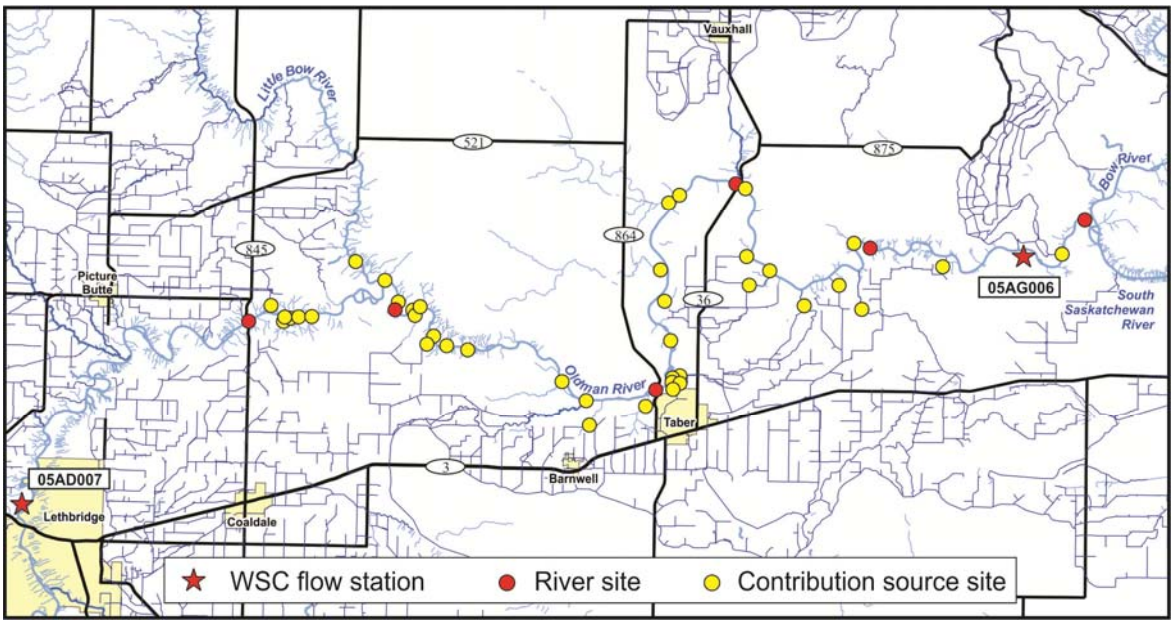


**Figure 4.2. Location of Water Survey of Canada (WSC) flow stations and Oldman River synoptic survey sites in 2014.**

Velocities were plotted against the river flows (Figure 4.4) and a power curve was fit to the data (Equation 4.1). Because most of the synoptic survey sites were within the stretch of river as the WSC flow stations, this relationship was used to determine the corresponding river velocity for the river flow at the start of each synoptic survey. River velocity was used with the distances between synoptic sampling sites to determine sample times. The start times of the synoptic surveys were planned to minimize the number of sites sampled in the dark.

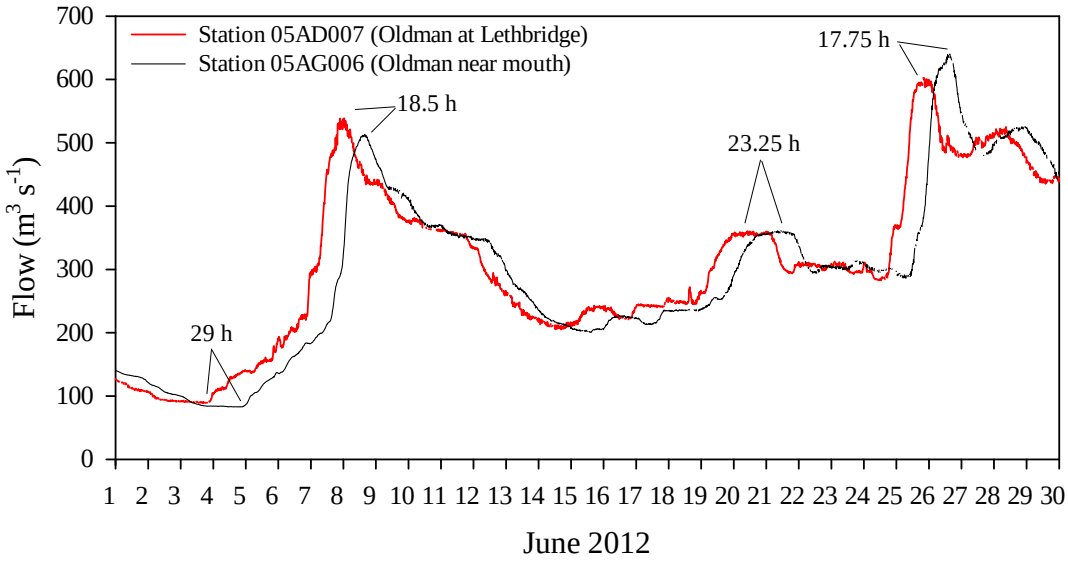


**Figure 4.3. Examples of peaks and valleys of flow on Oldman River hydrographs used to calculate travel times of water.**

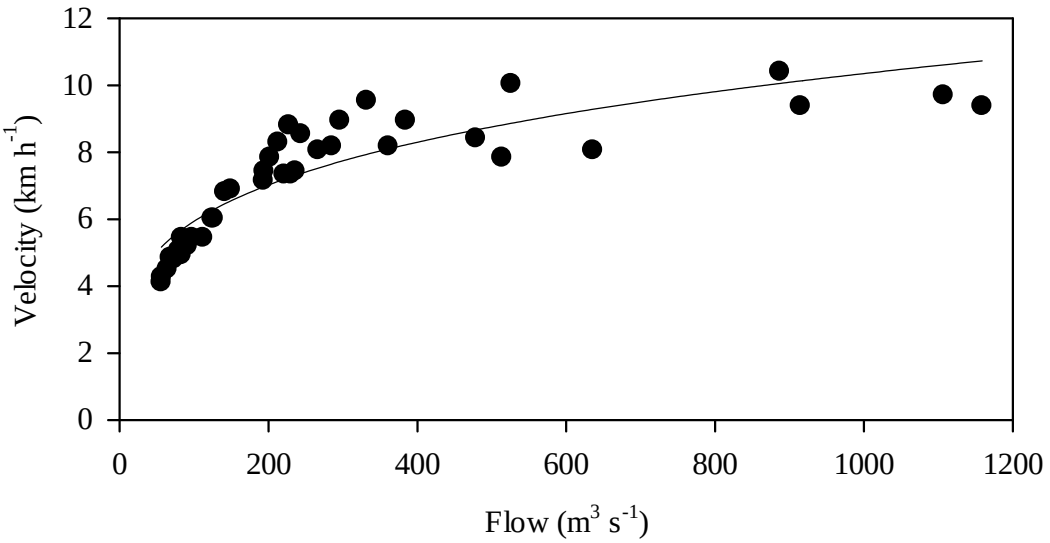


**Figure 4.4. Power curve showing the relationship between velocity and flow on the Oldman River in 2011 and 2012.**

$$y = 1.959x^{0.241}$$ **Equation 4.1**

Where: $y$ = velocity (km $h^{-1}$)
$x$ = flow (m $s^{-1}$)

### 4.2.3 Sampling Periods

Two surveys (runoff and dry-season) were conducted on the Oldman River in 2014 during the irrigation season when irrigation returns were actively flowing and during a time when the returns would likely have the most effect on the water quality of the river (i.e., low river flow to allow the influence of contributions to be more easily discerned). The runoff survey was conducted during a period of runoff when irrigation returns may have poorer water quality than the river. The dry-season survey was conducted during the dry conditions of late summer when irrigation returns were assumed to be the dominant contribution source to the river.

The runoff survey was conducted on June 18, 2014, following heavy rainfall (72.5 mm in Lethbridge) on June 17, 2014 (Appendix B). Conditions were favorable for runoff as the ground had been pre-wetted by rain in the preceding days. Thirty of the 41 synoptic sites monitored were flowing and sampled during the runoff survey (Table 4.2). Most sites were sampled at or within 30 min of the calculated sample times. Based on the velocity of the river, the runoff survey took 11.7 h to complete.

The dry-season survey was conducted on Aug 14, 2014. There had been very little to no rainfall since the precipitation event in June when the runoff survey was completed (Appendix B) so the area was dry and municipal contributions were the only potential runoff to the river. Twenty-five of the 41 synoptic sites monitored were flowing and sampled during the dry-season survey (Table 4.2). Most sites were sampled within 5 min of the calculated sample time, with four sites sampled within approximately 30 min of the calculated sample time. Based on the velocity of the river, the dry-season survey took 22.5 h to complete.

### 4.2.4 Flow Measurements

Since logistics and safety did not allow flow measurement of the river during the synoptic surveys, flows for the river sites were based on nearby WSC flow stations. Flow ($m^3 s^{-1}$) at the WSC station near Lethbridge (05AD007) was used for Site OS-0.0 as it was the nearest flow station and 43 km upstream of OS-0.0 (Figure 4.2). Flow for OS-112.1 was calculated using flow measured at OS-108.8 added to the flow from the WSC station 05AG006 near the mouth of the Oldman River (Fig. 4.2). This WSC station was 10 km upstream of OS-112.1 and OS-108.8 entered the river 6.5 km downstream of the WSC station. Flow ($m^3 s^{-1}$) was calculated for four river sites (OS-16.5, OS-44.0, OS-68.3, and OS-89.0) by adding the flows of the contributing sources between sites to the upstream river site of each stretch (Table 4.2). Daily volumes ($m^3 d^{-1}$) were calculated by multiplying flow ($m^3 s^{-1}$) by 86,400 s $d^{-1}$.

**Table 4.2. Sites monitored during the runoff and dry-season synoptic surveys of the Oldman River in 2014.**

| | Runoff synoptic survey | | Dry-season synoptic survey | |
|---|---|---|---|---|
| Site | Sampled | Flow measurement | Sampled | Flow measurement |
| OS-0.0 | ✓ | Water Survey Canada | ✓ | Water Survey Canada |
| OS-1.9 | ✓ | Weir formula | ✓ | Weir formula |
| OS-3.3 | | | | |
| OS-3.4 | ✓ | Estimation | | |
| OS-4.5 | ✓ | Estimation | | |
| OS-13.9 | ✓ | WSC | ✓ | WSC |
| OS-16.3 | | | | |
| OS-16.5 | ✓ | Calculation[z] | ✓ | Calculation[z] |
| OS-18.5 | | | | |
| OS-18.6 | | | | |
| OS-19.1 | ✓ | Estimation | | |
| OS-22.4 | | | | |
| OS-22.5 | ✓ | Weir formula | ✓ | Weir formula |
| OS-24.2 | | | | |
| OS-35.5 | | | | |
| OS-38.1 | ✓ | Estimation | ✓ | Flow metering |
| OS-39.4 | ✓ | Flow metering | ✓ | Flow metering |
| OS-43.1 | ✓ | Flow metering | ✓ | Flow metering |
| OS-44.0 | ✓ | Calculation[z] | ✓ | Calculation[z] |
| OS-45.1 | ✓ | EPCOR | ✓ | EPCOR |
| OS-45.4a | ✓ | Weir formula | ✓ | Weir formula |
| OS-45.4b | ✓ | Flow metering | ✓ | Estimation |
| OS-45.4c | ✓ | Flow metering | ✓ | Estimation |
| OS-45.4 | ✓ | Flow metering | ✓ | Flow metering |
| OS-48.7 | | | | |
| OS-53.4 | | | | |
| OS-55.6 | | | | |
| OS-62.2 | | | | |
| OS-62.7 | ✓ | Estimation | | |
| OS-68.3 | ✓ | Calculation[z] | ✓ | Calculation[z] |
| OS-68.4 | ✓ | Water Survey Canada | ✓ | Water Survey Canada |
| OS-74.9 | ✓ | Weir formula | ✓ | Weir formula |
| OS-76.9 | ✓ | Estimation | | |
| OS-77.2 | ✓ | Weir formula | ✓ | Weir formula |
| OS-79.8 | ✓ | Weir formula | ✓ | Weir formula |
| OS-82.8 | ✓ | Weir formula | ✓ | Weir formula |
| OS-85.0 | ✓ | Weir formula | ✓ | Weir formula |
| OS-89.0 | ✓ | Calculation[z] | ✓ | Calculation[z] |
| OS-96.4 | ✓ | Weir formula | ✓ | Weir formula |
| OS-108.8 | ✓ | Weir formula | ✓ | Weir formula |
| OS-112.1 | ✓ | Calculation[y] | ✓ | Calculation[y] |

[z] Cumulative addition of contribution sources to upstream WSC flow.
[y] Downstream WSC flow added to OS-108.8.

All irrigation return sites had check structures with staff gauges and the appropriate weir formulas were used to calculate flow (Walkowiak 2006). EPCOR Utilities Inc. provided the discharge at the Taber Wastewater Treatment plant (Site OS-45.3) and WSC provided flow for

the Little Bow River and Expanse Coulee (Sites OS-13.9 and OS-68.4, respectively) (ESRD 2014). The flows of the other contribution sources were measured manually using a Flow Tracker (Teledyne RD Washington, United States). Flow Tracker measurements were taken at or less than 1 h after the time of sampling. When accurate manual flow measurement could not be taken (i.e., water too high or too low for metering equipment), flow was visually estimated at the time of sampling (Table 4.2).

### 4.2.5 Water Sampling, Analysis, Flow Weighted Mean, and Load Calculations

All water samples were collected by grab sampling as described in Chapter 2. Samples were shipped or driven to the lab in batches in order to meet the analysis hold times. Water samples were analyzed for nutrients, coliform bacteria, pesticides, salinity, and physical parameters following the protocol also described in Chapter 2. For the purpose of this chapter, only total nitrogen (TN), total phosphorus (TP), total dissolved phosphorus (TDP), total dissolved solids (TDS), total suspended solids (TSS), the herbicide 2,4-D, and the number of different pesticides detected will be presented.

Daily loads were calculated by multiplying the concentration of a parameter (mg $L^{-1}$) by the daily volume (L $d^{-1}$). Flow weighted mean concentrations (FWMCs) were calculated for contribution sources and river sites by dividing the total load by the total volume.

For the runoff survey, flow and load data for the combined source sites (OS-39.4, OS-43.1, and OS-68.4) were divided into equal proportions for each contribution source type because the exact proportions were unknown. For the dry-season survey, because no coulee runoff occurred, the contribution source type for OS-39.4 and OS-68.4 were classified as irrigation and OS-43.1 was classified as municipal. The three different sources for combined site OS-45.4 were quantified by collecting samples at OS-45.4a, b, and c. The data from OS-45.4 were used for total source contributions to the river and Sites OS-45.4a, b, and c were used for individual source types.

#### 4.2.5.1 Comparison of Contribution Sources (Contribution Ratio)

The flow and loads of contribution source types were compared to the total of all contribution sources to the river. Contribution ratios were calculated using total contributions of each source type (irrigation return, coulee, tributary, municipal, or industrial) divided by the total of all contribution sources to the river and expressed as a percentage (Equation 4.2).

$$Contribution\ ratio\ (\%) = \frac{total\ from\ source\ type^*}{total\ from\ all\ source\ types*} \times 100 \qquad \textbf{Equation 4.2}$$

*volume or load

#### 4.2.5.2 Comparison of Contribution Sources to the River (River Ratio)

The flow and load of the contribution sources were compared to the river by calculating the ratio of contribution sources to the downstream (OS-112.1) river site using Equation 4.3.

$$River\ ratio\ (\%) = \frac{total\ from\ source\ type^*}{downstream\ river^*} \times 100 \qquad \textbf{Equation 4.3}$$

*volume or load

#### 4.2.5.3 Comparison of Instream Loads and Cumulative Loads

Calculated loads for the river sites were compared to each other and to contribution sources between each river site. Cumulative loads were calculated by adding the loads from the contribution sources within the stretch between two adjacent river sites to the measured load of the upstream river site of each stretch. This was done for all river sites except for OS-0.0, where the measured load served as the starting river load entering the whole stretch.

## 4.3 Results and Discussion

### 4.3.1 Flow

#### 4.3.1.1 River Flow

The flow in the river (729 $m^3\ s^{-1}$) was relatively high at the time of the runoff survey (Figure 4.3) because of the precipitation event on June 17, 2014 (Appendix B). The flow in the river during the dry-season survey was 49 $m^3\ s^{-1}$, which was within the normal low range expected in late summer ($50^{th}$ percentile) (Figure 4.5). There was nearly a 15-fold difference in flow between the two synoptic surveys.

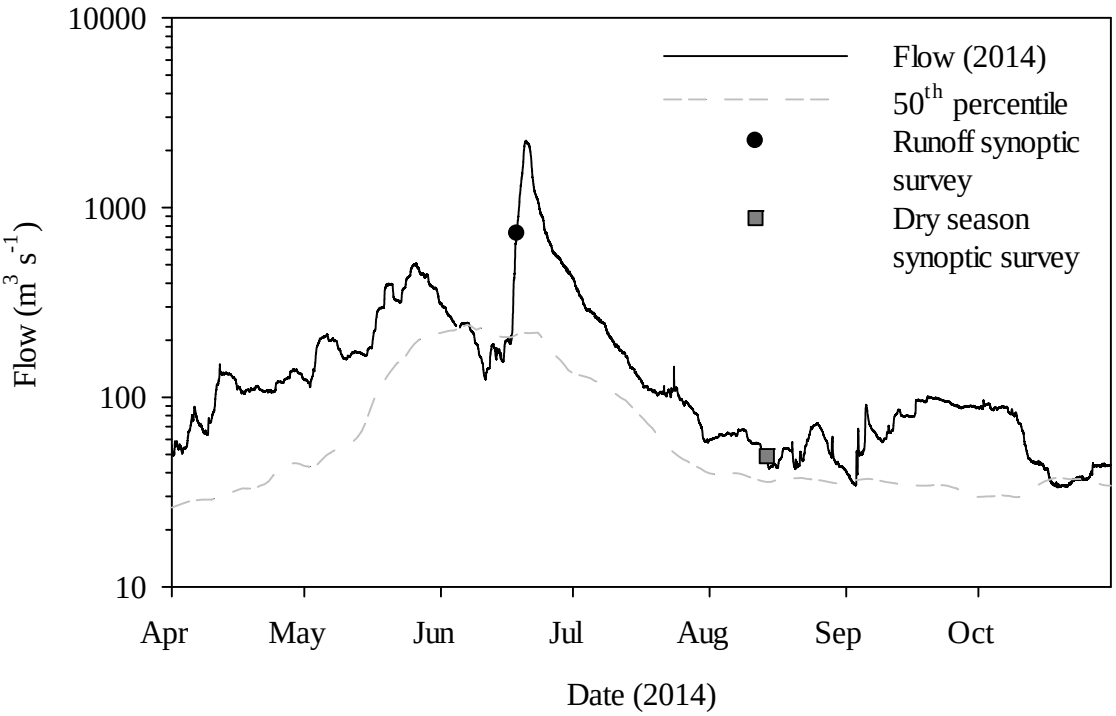


**Figure 4.5. Hydrograph of Oldman River showing the peak in June when the runoff synoptic survey was conducted and the lower flow in August when the dry-season synoptic survey was conducted.**

The flow and volume in the river increased from upstream (OS-0.0) to downstream (OS-112.1) during both surveys (Table 4.3). Flow increased by about 2% during the runoff survey and by about 16% during the dry-season synoptic survey from upstream to downstream. This was expected because of the contributions of water into the river with few to no withdrawals. The calculated cumulative flows for the furthest downstream site (OS-112.1) were very similar to the WSC flow values, differing by only 0.3% and 0.7% for the runoff and dry-season synoptic surveys, respectively (calculation not shown). As a result, this gave confidence in the calculated flows for the other river sites where WSC data were not available.

#### 4.3.1.2 Contribution Source Flows

During the runoff survey, 10 coulee sites were not flowing even after more than 70 mm of rain. Five coulees had low flows compared to other contributions (Figure 4.6) and the low flows ranged from 0.00002 to 0.02 $m^3$ $s^{-1}$ (Table 4.4). Bountiful Coulee (OS-38.1) had a flow of 2.25 $m^3$ $sec^{-1}$, which was much higher flow than the other coulees, and Bountiful Coulee was the second largest contribution of flow to the river during the runoff survey. The Little Bow River tributary (OS-13.9) flow was 7.4 $m^3$ $s^{-1}$, which was the single highest flow contribution during

the runoff survey (Figure 4.6, Table 4.4). All irrigation sites were flowing, with flows that ranged from 0.15 to 2.14 $m^3 s^{-1}$. Most municipal sites, except the Taber Industrial Wastewater Lagoons, were flowing at rates that ranged from 0.05 to 0.59 $m^3 s^{-1}$. The industrial site had flow of 0.01 $m^3 s^{-1}$. Although many contribution sources were flowing during the runoff survey, 74% had flows less than 1.0 $m^3 s^{-1}$ and nearly 50% were less than 0.50 $m^3 s^{-1}$ (Figure 4.6). All contributions were small compared to the river flow of greater than 700 $m^3 s^{-1}$.

**Table 4.3. Flow, volume, and concentration of water quality parameters of river sites during the 2014 Oldman River synoptic surveys.**

| Site | Flow ($m^3 s^{-1}$) | Daily volume ($m^3 d^{-1}$) | TN (mg $L^{-1}$) | TDP (mg $L^{-1}$) | TP (mg $L^{-1}$) | TSS (mg $L^{-1}$) | TDS (mg $L^{-1}$) | 2,4-D (µg $L^{-1}$) | Number of pesticides |
|---|---|---|---|---|---|---|---|---|---|
| | | | | *Runoff survey* | | | | | |
| OS-0.0 | 729 | 62,985,600 | 3.08 | 0.50 | 1.85 | 3810 | 289 | 0.05 | 1 |
| OS-16.5 | 739 | 63,810,926 | 1.44 | 0.01 | 1.97 | 4480 | 218 | 0.06 | 1 |
| OS-44.0 | 745 | 64,341,926 | 1.99 | 0.02 | 1.90 | 3720 | 207 | 0.05 | 1 |
| OS-68.3 | 745 | 64,376,496 | 1.92 | 0.02 | 1.48 | 2190 | 198 | 0.03 | 1 |
| OS-89.0 | 751 | 64,866,650 | 1.24 | 0.02 | 1.54 | 2100 | 198 | 0.03 | 1 |
| OS-112.1 | 747 | 64,572,768 | 1.82 | 0.01 | 1.03 | 1230 | 193 | 0.03 | 1 |
| | | | | *Dry-season survey* | | | | | |
| OS-0.0 | 46.4 | 4,008,960 | 0.31 | 0.01 | 0.01 | 6 | 230 | 0.00 | 0 |
| OS-16.5 | 50.4 | 4,353,040 | 0.26 | 0.02 | 0.02 | 10 | 222 | 0.00 | 0 |
| OS-44.0 | 51.1 | 4,418,295 | 0.23 | 0.01 | 0.01 | 5 | 211 | 0.02 | 1 |
| OS-68.3 | 51.2 | 4,422,356 | 0.22 | 0.01 | 0.01 | 7 | 219 | 0.20 | 6 |
| OS-89.0 | 55.4 | 4,784,066 | 0.43 | 0.01 | 0.01 | 5 | 248 | 0.04 | 1 |
| OS-112.1 | 55.2 | 4,769,280 | 0.23 | 0.01 | 0.01 | 5 | 223 | 0.00 | 0 |

During the dry-season survey, Bountiful Coulee (OS-38.1) was the only coulee flowing at 0.006 $m^3 s^{-1}$ (Figure 4.6, Table 4.5). The Little Bow River tributary site (OS-13.9) flowed at 3.3 $m^3 s^{-1}$, which was about 45% of the flow during the runoff survey. All irrigation sites were flowing, with flows that ranged from 0.03 to 1.3 $m^3 s^{-1}$. Most municipal sites, except for the Taber Industrial Wastewater Lagoons, were flowing with flows that ranged from 0.0002 to 0.03 $m^3 sec^{-1}$. The industrial site flowed at 0.00002 $m^3 s^{-1}$. During the dry-season survey, 89% of contribution sources were less than 1 $m^3 s^{-1}$ and 56% were less than 0.5 $m^3 s^{-1}$.

The number of sites sampled during the dry-season survey was five less than during the runoff survey (Table 4.2). These five sites were coulees that were not flowing during the dry-season survey. Nearly all sites during the dry-season survey had less flow compared to the runoff survey, except for three irrigation sites (OS-22.5, OS-79.8, and OS-82.8). Comparing the dry-season survey to the runoff survey, the industrial site had a 600-fold decrease in flow and coulee sites had a 61-fold decrease in average flow (Table 4.6). A shift in operations accounted for the flow difference at the industrial site (personal communication 2014). Comparing the dry-season survey to the runoff survey, municipal sites had a nine-fold decrease in average flow and the

Little Bow River tributary had a two-fold decrease. The irrigation sites were most similar between the two surveys, with average flow 1.5-fold less in the dry-season survey compared to the runoff survey. This supports previous observation, which showed the flow of irrigation returns remained fairly constant throughout the growing season (Villeneuve 2013).

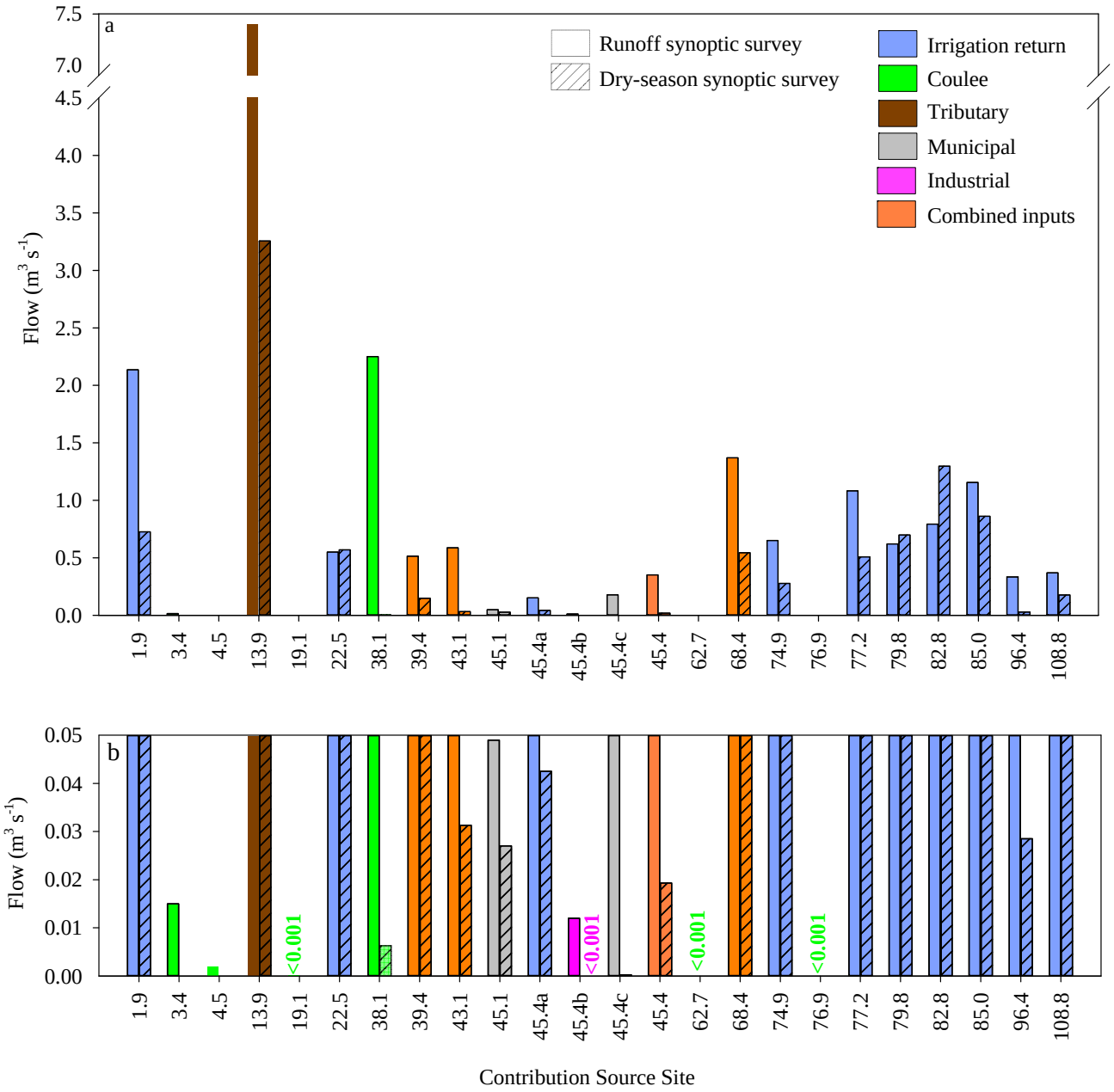


**Figure 4.6. Flows of contribution sources during the Oldman River runoff and dry-season surveys in 2014 shown using (a) large and (b) small scales.**

**Table 4.4. Flow, volumes, and concentrations of contribution sources during the 2014 Oldman River runoff survey.**

| Site | Flow ($m^3 s^{-1}$) | Daily volume ($m^3 d^{-1}$) | TN (mg $L^{-1}$) | TDP (mg $L^{-1}$) | TP (mg $L^{-1}$) | TSS (mg $L^{-1}$) | TDS (mg $L^{-1}$) | 2,4-D (µg $L^{-1}$) | Number of pesticides |
|---|---|---|---|---|---|---|---|---|---|
| | | | | *Coulee* | | | | | |
| OS-3.4 | 0.02 | 1,296 | 10.7 | 0.17 | 0.27 | 90 | 1200 | 0.07 | 1 |
| OS-4.5 | 0.002 | 147 | 0.60 | 0.01 | 0.03 | 9 | 458 | 0.00 | 0 |
| OS-19.1 | 0.0001 | 10.8 | 4.96 | 1.33 | 1.59 | 29 | 459 | 1.22 | 4 |
| OS-38.1 | 2.25 | 194,400 | 5.35 | 0.19 | 1.86 | 2600 | 517 | 1.49 | 10 |
| OS-62.7 | 0.00002 | 1.73 | 1.25 | 0.03 | 0.07 | 29 | 2650 | 0.07 | 1 |
| OS-76.9 | 0.00008 | 6.91 | 4.82 | 0.02 | 0.07 | 40 | 1850 | 0.00 | 0 |
| | | | | *Tributary* | | | | | |
| OS-13.9 | 7.4 | 639,360 | 1.42 | 0.04 | 0.41 | 470 | 400 | 0.00 | 4 |
| | | | | *Irrigation* | | | | | |
| OS-1.9 | 2.14 | 184,497 | 3.67 | 0.09 | 1.45 | 66 | 391 | 3.98 | 8 |
| OS-22.5 | 0.54 | 47,020 | 0.90 | 0.07 | 0.10 | 26 | 139 | 0.60 | 4 |
| OS-39.4[z] | 0.51 | 44,366 | 4.41 | 0.72 | 1.09 | 265 | 759 | 2.70 | 8 |
| OS-45.4a | 0.15 | 13,046 | 1.09 | 0.01 | 0.05 | 21 | 472 | 0.17 | 1 |
| OS-68.4[z] | 1.37 | 118,368 | 3.46 | 0.09 | 0.20 | 51 | 971 | 1.11 | 5 |
| OS-74.9 | 0.65 | 56,246 | 0.66 | 0.06 | 0.11 | 20 | 319 | 0.10 | 2 |
| OS-77.2 | 1.08 | 93,571 | 0.81 | 0.08 | 0.10 | 7 | 375 | 0.14 | 3 |
| OS-79.8 | 0.62 | 53,568 | 1.56 | 0.12 | 0.14 | 9 | 550 | 0.24 | 3 |
| OS-82.8 | 0.79 | 68,515 | 0.52 | 0.04 | 0.05 | 9 | 212 | 0.11 | 1 |
| OS-85.0 | 1.16 | 99,878 | 1.21 | 0.14 | 0.26 | 145 | 334 | 0.42 | 8 |
| OS-96.4 | 0.33 | 28,858 | 0.49 | 0.12 | 0.13 | 6 | 222 | 0.14 | 1 |
| OS-108.8 | 0.37 | 31,968 | 0.68 | 0.04 | 0.06 | 10 | 385 | 0.09 | 3 |
| | | | | *Municipal* | | | | | |
| OS-43.1[y] | 0.59 | 50,760 | 2.55 | 0.09 | 0.46 | 417 | 983 | 1.60 | 9 |
| OS-45.1 | 0.05 | 4,234 | 1.10 | 0.04 | 0.12 | 6 | 867 | 1.43 | 6 |
| OS-45.4c | 0.18 | 15,379 | 1.11 | 0.04 | 0.47 | 593 | 448 | 6.53 | 10 |
| | | | | *Industrial* | | | | | |
| OS-45.4b | 0.01 | 1,037 | 6.43 | 0.65 | 0.79 | 20 | 501 | 2.95 | 14 |
| | | | | *Combination* | | | | | |
| OS-45.4 | 0.35 | 30,326 | 5.83 | 0.07 | 0.59 | 400 | 1180 | 6.99 | 11 |

[z] Irrigation water combined with coulee runoff.

[y] Municipal runoff combined with coulee runoff.

**Table 4.5. Flow, volume, and concentrations of contribution sources during the 2014 Oldman River dry-season survey.**

| Site | Flow ($m^3 s^{-1}$) | Daily volume ($m^3 d^{-1}$) | TN (mg $L^{-1}$) | TDP (mg $L^{-1}$) | TP (mg $L^{-1}$) | TSS (mg $L^{-1}$) | TDS (mg $L^{-1}$) | 2,4-D (µg $L^{-1}$) | Number of pesticides |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | *Coulee* | | | | |
| OS-38.1 | 0.006 | 544 | 0.52 | 0.09 | 0.13 | 41 | 454 | 0.04 | 4 |
| | | | | | *Tributary* | | | | |
| OS-13.9 | 3.26 | 281,318 | 0.35 | 0.03 | 0.08 | 68 | 281 | 0.06 | 1 |
| | | | | | *Irrigation* | | | | |
| OS-1.9 | 0.73 | 62,762 | 0.55 | 0.05 | 0.06 | 13 | 194 | 0.10 | 3 |
| OS-22.5 | 0.57 | 49,173 | 0.36 | 0.04 | 0.05 | 9 | 134 | 0.42 | 1 |
| OS-39.4 | 0.15 | 12,833 | 0.27 | 0.02 | 0.03 | 6 | 159 | 0.09 | 3 |
| OS-45.4a | 0.04 | 3,672 | 4.97 | 0.04 | 0.04 | 2 | 1040 | 0.25 | 5 |
| OS-68.4 | 0.54 | 47,002 | 0.76 | 0.10 | 0.13 | 32 | 447 | 0.11 | 1 |
| OS-74.9 | 0.28 | 24,004 | 0.95 | 0.07 | 0.09 | 14 | 285 | 0.12 | 4 |
| OS-77.2 | 0.51 | 43,985 | 0.96 | 0.07 | 0.08 | 4 | 303 | 0.08 | 3 |
| OS-79.8 | 0.70 | 60,287 | 0.97 | 0.09 | 0.10 | 6 | 293 | 0.23 | 4 |
| OS-82.8 | 1.30 | 112,039 | 1.49 | 0.05 | 0.14 | 12 | 218 | 0.30 | 4 |
| OS-85.0 | 0.86 | 74,393 | 0.85 | 0.04 | 0.07 | 30 | 535 | 0.08 | 1 |
| OS-96.4 | 0.03 | 2,462 | 0.97 | 0.05 | 0.07 | 13 | 204 | 0.28 | 4 |
| OS-108.8 | 0.18 | 15,268 | 0.63 | 0.06 | 0.06 | 3 | 376 | 0.00 | 0 |
| | | | | | *Municipal* | | | | |
| OS-43.1 | 0.03 | 2,704 | 0.82 | 0.07 | 0.08 | 14 | 462 | 0.22 | 7 |
| OS-45.1 | 0.03 | 2,393 | 1.51 | 0.04 | 0.07 | 3 | 947 | 0.55 | 5 |
| OS-45.4c | 0.0002 | 15 | 1.73 | 0.03 | 0.03 | 3 | 1430 | 0.04 | 1 |
| | | | | | *Industrial* | | | | |
| OS-45.4b | 0.00002 | 2 | 39.90 | 0.05 | 0.05 | 0.5 | 2170 | 0.00 | 1 |
| | | | | | *Combination* | | | | |
| OS-45.4 | 0.02 | 1,668 | 4.55 | 0.06 | 0.06 | 10 | 1060 | 0.20 | 4 |

### 4.3.1.3 Comparison of Contribution Source Flows (Contribution Ratio)

During the runoff survey, irrigation returns were 43% of all contributions to the river (Figure 4.7a). Flows from the Little Bow River tributary and coulee runoff were the next largest contributions at 37 and 17%, respectively. Total coulee runoff was dominated by Bountiful Coulee, which contributed flow several orders of magnitude higher than the other coulees (Table 4.4). Municipal and industrial inputs contributed very little flow at 2.6 and 0.1% of total flow, respectively.

**Table 4.6. Flow weighted mean concentrations of water quality parameters during the runoff and dry-season surveys in 2014.**

| Source type | n[z] | Average Flow ($m^3 s^{-1}$) | TN (mg $L^{-1}$) | TDP (mg $L^{-1}$) | TP (mg $L^{-1}$) | TSS (mg $L^{-1}$) | TDS (mg $L^{-1}$) | 2,4-D (µg $L^{-1}$) | Average number of pesticides |
|---|---|---|---|---|---|---|---|---|---|
| | | | | *Runoff survey* | | | | | |
| Coulee | 9[y, x] | 0.39 | 4.70 | 0.20 | 1.35 | 1735 | 666 | 1.51 | 4.1 |
| Tributary | 1 | 7.40 | 1.42 | 0.04 | 0.41 | 470 | 400 | 0.00 | 4.0 |
| Irrigation | 12[y] | 0.73 | 1.88 | 0.10 | 0.48 | 53 | 406 | 1.29 | 3.6 |
| Municipal | 3[x] | 0.17 | 1.92 | 0.07 | 0.43 | 439 | 789 | 3.27 | 8.3 |
| Industrial | 1 | 0.01 | 6.43 | 0.66 | 0.79 | 20 | 501 | 2.95 | 14.0 |
| River | 6 | 743 | 1.92 | 0.09 | 1.63 | 2914 | 217 | 0.04 | 1.0 |
| | | | | *Dry-season survey* | | | | | |
| Coulee | 1 | 0.006 | 0.52 | 0.09 | 0.13 | 41 | 454 | 0.04 | 4.0 |
| Tributary | 1 | 3.26 | 0.35 | 0.03 | 0.08 | 68 | 281 | 0.06 | 1.0 |
| Irrigation | 12 | 0.49 | 0.94 | 0.06 | 0.09 | 15 | 303 | 0.18 | 2.8 |
| Municipal | 3 | 0.02 | 1.15 | 0.06 | 0.08 | 9 | 692 | 0.37 | 4.3 |
| Industrial | 1 | 0.00002 | 39.9 | 0.05 | 0.05 | 0.5 | 2170 | 0.00 | 1.0 |
| River | 6 | 52 | 0.28 | 0.01 | 0.01 | 6 | 226 | 0.04 | 1.3 |

[z] Site OS-45.4 was not included because OS-45.4a, b, and c were applied to their respective individual sources.
[y] Flow for Sites OS-39.4 and OS-68.4 were equally split between irrigation and coulee.
[x] Flow for Site OS-43.1 was equally split between municipal and coulee.

As expected during the dry-season survey, irrigation returns were more dominant than during the runoff survey. During the dry-season, irrigation returns were 64% of the total flow contributions to the river (Figure 4.7b). The Little Bow River tributary was the other large flow source at 35%. With only one coulee flowing, coulee input was low at 0.1%. Municipal and industrial flow inputs were also low at 0.6% and <0.1%, respectively.

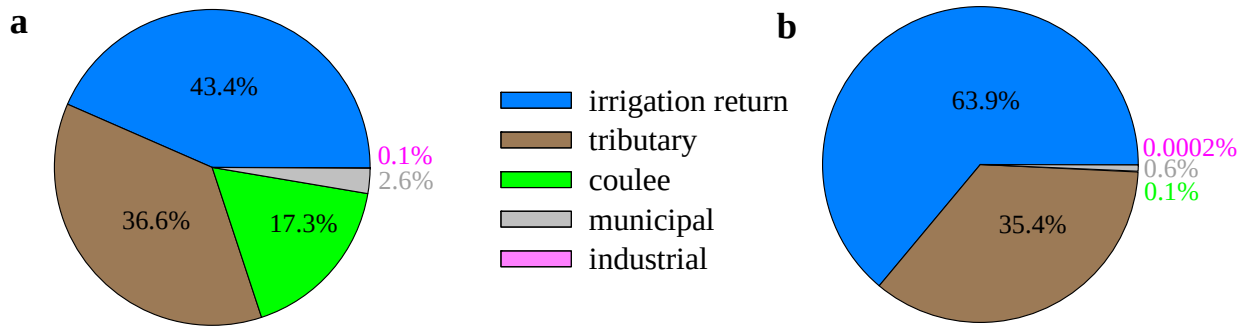


**Figure 4.7. Contribution ratios of flow during the (a) runoff and (b) dry-season surveys in 2014.**

#### 4.3.1.4 Comparison of Contribution Source Flow to River (River Ratio)

The total flow of water contributed (from all sources) relative to the river was 3% during the runoff survey and 17% during the dry-season survey (Table 4.7). These ratios were greater than in 2011 and 2012 (Villeneuve 2013). This was expected, because during the synoptic surveys, all contributions were measured instead of only six irrigation returns in 2011 and 2012. Irrigation contributions added the greatest volume of all contribution source types during the runoff and dry-season surveys at 1% and 11%, respectively (Table 4.7). Ratios were consistently greater during the dry-season survey because changes in flow were greater in the river than changes in flow of contribution sources when comparing the dry and runoff surveys (Figure 4.8). River volume at OS-112.1 was nearly15-fold less during the dry-season survey compared to the runoff survey; whereas, the flow from all sources was only about two-fold less during the dry-season survey compared to the runoff survey. This was also observed in 2011 and 2012 as ratios increased as river flow decreased through the summer.

**Table 4.7. River ratios for the runoff and dry-season surveys in 2014.**

| Site types | Flow | TN | TDP | TP | TSS | TDS | 2,4-D |
|---|---|---|---|---|---|---|---|
| | (%) | | | | | | |
| | | | *Runoff survey* | | | | |
| All contributions | 2.70 | 3.27 | 21.9 | 1.59 | 1.12 | 6.43 | 73.6 |
| Coulee | 0.47 | 1.21 | 7.74 | 0.62 | 0.66 | 1.62 | 21.2 |
| Tributary | 0.99 | 0.77 | 3.47 | 0.40 | 0.38 | 2.05 | 0.00 |
| Irrigation | 1.17 | 1.21 | 10.2 | 0.55 | 0.05 | 2.47 | 45.5 |
| Municipal | 0.07 | 0.07 | 0.40 | 0.03 | 0.025 | 0.29 | 6.83 |
| Industrial | 0.002 | 0.006 | 0.09 | 0.001 | 0.00003 | 0.004 | 0.14 |
| | | | *Dry-season survey* | | | | |
| All contributions | 16.7 | 52.9 | 78.5 | 112 | 111 | 22.3 | na[z] |
| Coulee | 0.01 | 0.03 | 0.10 | 0.11 | 0.09 | 0.02 | na |
| Tributary | 5.90 | 8.98 | 14.8 | 34.5 | 80.2 | 7.43 | na |
| Irrigation | 10.7 | 43.3 | 63.0 | 76.7 | 30.9 | 14.5 | na |
| Municipal | 0.11 | 0.53 | 0.60 | 0.65 | 0.19 | 0.33 | na |
| Industrial | 0.00004 | 0.006 | 0.0002 | 0.0001 | 0.000004 | 0.0004 | na |

[z] na = not applicable, because there was no detection of 2,4-D at downstream river site.

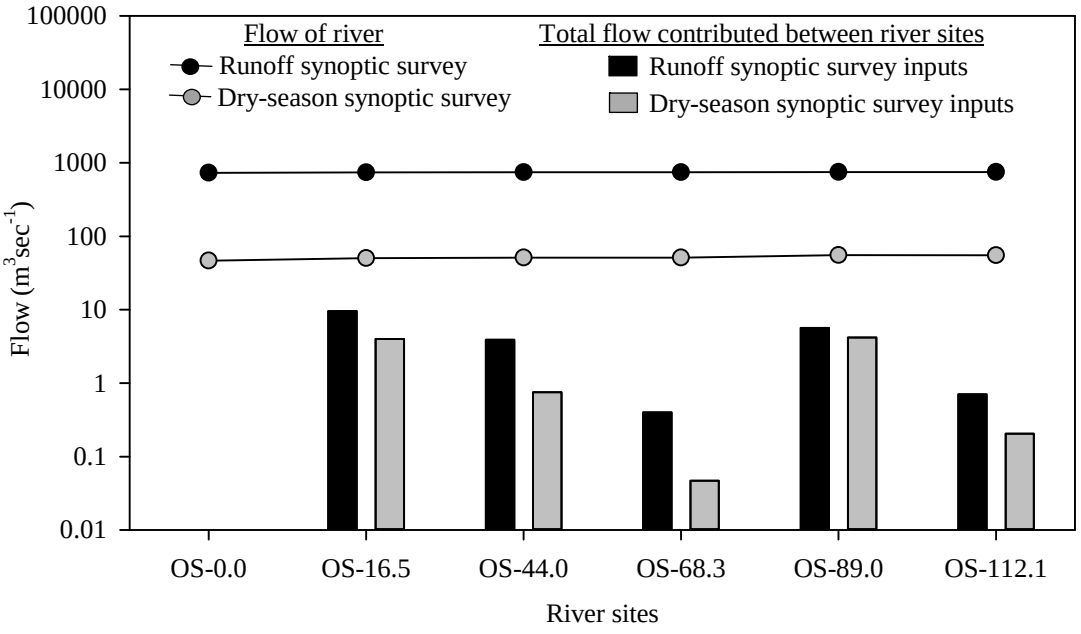


**Figure 4.8. Oldman River flow and flow of contribution sources among river sites during synoptic surveys in 2014.**

### 4.3.2 Concentrations

#### 4.3.2.1 River Sites

Generally, parameter concentrations varied little among the six river sites during the runoff survey with either a slight decrease from upstream to downstream (TP, TSS, TDS, 2,4-D) or no consistent trend (TN, TDP) (Table 4.3, Figure 4.9). The lack of obvious upstream-to-downstream trends was also true for the dry-season survey (Table 4.3, Figure 4.9). These trends were also observed during previous low-flow synoptic surveys conducted in 1998 and 2000 (Saffran 2005) and a high-flow survey conducted in 2005 (Kromrey et al. 2011).

During the runoff survey, Site OS-0.0 had a much higher TDP concentration and a slightly higher TN concentration than the other river sites (Figure 4.9a and b). This may be due, in part, to discharge from the Haney Drain, which is less than 100 m upstream of Site OS-0.0. Data collected previously by Alberta Agriculture and Rural Development (now Alberta Agriculture and Forestry) during a project investigating groundwater in the area showed greater concentrations of TN and TDP in Haney Drain than in nearby Battersea Drain (OS-1.9). The average concentrations of TN and TDP (n=5) in the Haney Drain in 2012 were 4.7 mg $L^{-1}$ and 0.07 mg $L^{-1}$, respectively. Average concentrations of samples taken on the same dates from Battersea Drain were 1.9 mg $L^{-1}$ and 0.03 mg $L^{-1}$, respectively (Alberta Agriculture and Forestry,

unpublished data). Saffran (2005) reported Haney Drain had the highest TN concentration of all tributaries during a low-flow synoptic survey in 2000.

Total phosphorus and TSS concentrations decreased after Site OS-16.5 during the runoff survey (Figure 4.9c and d). This may have been due to a decrease in river velocity, which would have favored the deposition of sediments. The decreasing trends for these two parameters are likely related. On average among the six river sites, TDP represented only about 5% of TP, indicating that most of the TP was in particulate form. Generally, concentrations of TN, TDP, TP, and TSS in the river during the runoff survey and the dry-season survey in 2014 were similar to the high-flow synoptic survey done in 2005 (Kromrey et al. 2011) and low-flow synoptic surveys done in 1998 and 2000 (Saffran 2005), respectively.

The FWMC from the river sites were generally lower than the FWMCs of the contribution source sites (Table 4.6). The exceptions were mostly during the runoff survey when river water was of poorer quality than during the dry-season survey. In particular, the FWMCs of TSS and TP for the river sites were higher than the FWMCs of all the contribution sources types during the runoff survey.

River FWMCs of nutrients and TSS were greater during the runoff survey than during the dry-season survey. Flow weighted mean concentrations were seven-fold higher for TN and TDP, 128-fold for TP, and 463-fold higher for TSS during the runoff survey than the dry-season survey (Table 4.6). However, for TDP, the difference between the two surveys was mainly caused by the difference observed for Site OS-0.0; whereas, concentration was similar between the two surveys for the other five sites (Figure 4.9b). The FWMCs of TDS and 2,4-D were similar between the two surveys. The similarity of TDP (except for OS-0.0), TDS, and 2,4-D concentrations between both surveys suggests that these parameters were less affected by runoff during high flows than the other parameters.

Although 2,4-D concentrations were similar between the two surveys (less than 2 $\mu g\ L^{-1}$ difference), it is interesting that the 2,4-D concentration was much higher at Site 68.3 than any of the other sites during the dry-season survey, and was an order of magnitude higher compared to the runoff survey (Figure 4.9f). Also, during the dry-season survey, 2,4-D was detected in the upstream and downstream sites from OS-68.3, but there was no detection at the other three sites. The number of different pesticides detected was greatest at Site OS-68.3 also during the dry-season survey. Site OS-68.3 was the first river site after the municipal and industrial discharges from the Town of Taber.

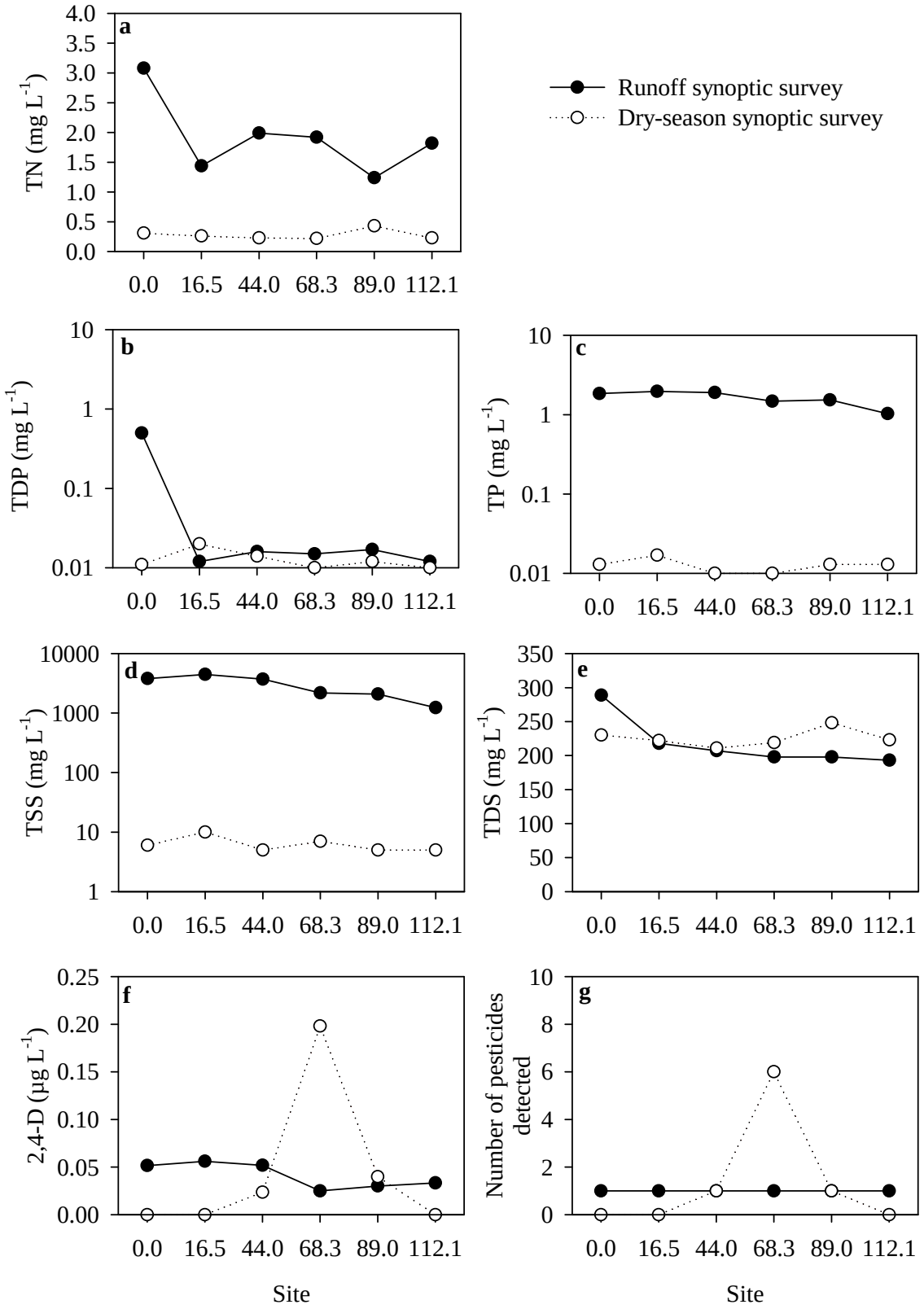


**Figure 4.9. Oldman River concentrations of total nitrogen (TN), total dissolved phosphorus (TDP), total phosphorus (TP), total suspended solids (TSS), total dissolved solids (TDS), 2,4-D, and number of pesticides detected during runoff and dry-season surveys in 2014.**

#### 4.3.2.2 Coulee Sites

Concentrations varied among the coulee sites during the runoff survey, and this likely reflected the individual coulee characteristics and land use in their drainage area. For example, TN ranged from 0.6 to 10.7 mg $L^{-1}$ and TP ranged from 0.03 to 1.86 mg $L^{-1}$ (Table 4.4). In particular, one coulee, OS-38.1 (Bountiful Coulee), had TSS concentration several orders of magnitude higher than the other coulee sites during the runoff survey. This was likely due to the much higher flow and erosion that occurred in this coulee compared to the other coulees (Figure 4.6, Table 4.4).

The three largest TDS concentrations during the runoff survey were from coulee sites (OS-3.4, OS-62.7, and OS-76.9). These coulees were likely influenced by soil salinity in the drainage areas and the high degree of interaction between soil and surface runoff. Two coulees (OS-76.9 and OS-4.5) had no detection of 2,4-D or any other pesticides during the runoff survey. Bountiful Coulee (OS-38.1) had the most pesticides detected (10) of all the coulees and compared to most other contribution sites (Tables 4.4). This was likely also related to the higher flow of runoff in this coulee.

The coulee sites had the highest FWMC of TP and TSS compared to the other contributing sources during the runoff survey (Table 4.6). Although the flow in the tributary (OS-13.9) was 19-fold greater than compared to the coulees (Table 4.6), the FWMC of TSS from the coulees was about four-fold greater than compared to the tributary. As discussed previously, the coulee FWMC was greatly influenced by one particular coulee (OS-38.1).

Since only one coulee (OS-38.1) flowed during the dry-season survey, few comparisons could be made between the two surveys. Concentrations of all parameters at Site OS-38.1 (Bountiful Coulee) during the dry-season survey were less than during the runoff survey (Tables 4.4 and 4.5). However, this coulee site had the greatest FWMC of TP and TDP when compared to the other source types during the dry-season survey (Table 4.6).

#### 4.3.2.3 Tributary Site

The Little Bow River tributary (OS-13.9) had the smallest concentrations of TN, TDP, TP, TDS, and 2,4-D when compared to the FWMC of other source types during the runoff survey (Table 4.6). There was no detection of 2,4-D in the tributary during runoff. Although pesticide concentrations could be reduced by dilution during precipitation events, it is unusual for a commonly detected pesticide such as 2,4-D to be absent during a runoff event.

During the dry-season survey, the Little Bow River tributary continued to have the smallest concentration of TN, TDP, and TDS when compared to the FWMCs of the other contribution

source types (Table 4.6). Only one pesticide was detected at the tributary site, and this pesticide was 2,4-D, which was not detected during the runoff survey. The Little Bow River tributary had the greatest concentration of TSS compared to other contribution source types during the dry-season survey (Table 4.6). Although reduced by more than half from the runoff survey, Little Bow River flows were still the greatest of all contribution sources during the dry-season survey. It also had the highest TSS concentration compared to other source types. The concentrations of most parameters, except for 2,4-D, were less during the dry-season survey compared to the runoff survey.

#### 4.3.2.4 Irrigation Sites

Among the 12 irrigation return sites, concentrations varied by more than an order magnitude (Table 4.4) during the runoff survey, and concentrations tended to be higher at sites influenced by surface runoff. Irrigation returns influenced by surface runoff included sites already identified as sharing flow with coulee runoff (OS-39.4 and OS-68.4) and irrigation sites designed to function as drains (OS-1.9 and OS-85.0) (Figure 4.10, only TSS shown as an example). Other irrigation returns that were less influenced by surface runoff had similar concentrations to each other and similar concentrations when comparing the runoff and dry-season survey. Variability was generally less among the irrigation sites during the dry-season survey than during the runoff survey (Tables 4.4 and 4.5).

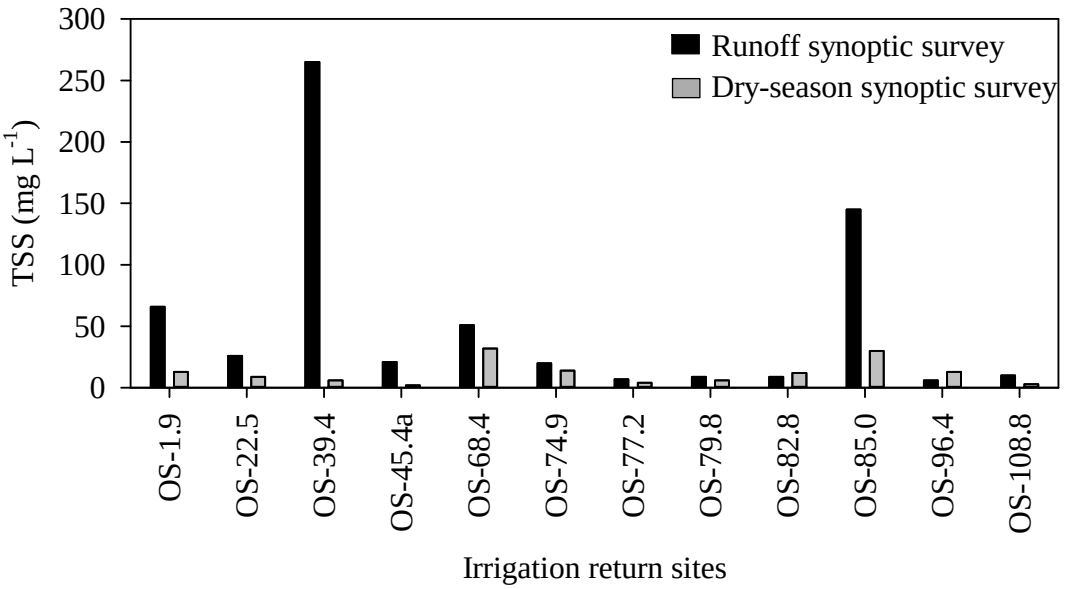


**Figure 4.10. Concentration of total suspended solids (TSS) at the irrigation sites during the runoff and dry-season surveys in 2014.**

No irrigation site consistently had the highest or the lowest concentrations for all parameters during both surveys. However, it was interesting that Site OS-39.4 had the highest concentration of TN and TDP during the runoff survey, but the lowest concentration of these two parameters during the dry-season survey. This was a site that in addition to irrigation return water, had surface runoff contributions (i.e., coulee) during the runoff survey; whereas, during the dry-season survey, there was no coulee runoff.

The FWMCs of the irrigation sites often ranked third highest of the five contribution source types (Table 4.6). One exception was during the runoff survey, when the irrigation sites had the smallest average number of pesticides detected compared to the averages of other contribution site types. The FWMC of irrigation sites were consistently higher during the runoff survey compared to the dry-season survey.

#### 4.3.2.5 Municipal Sites

Of the three municipal sites, concentrations at the Taber Wastewater Treatment plant (OS-45.1) were most similar between the runoff and dry-season synoptic surveys (Figure 4.11, only TP shown as an example). This was likely because this site was sampled inside the treatment plant and the runoff event had minimal effect. The other two municipal sites were affected by the runoff event as observed in higher flow, and higher concentrations of TDP, TP, TSS, and 2,4-D during the runoff survey compared to the dry-season survey (Tables 4.4 and 4.5). This was expected as OS-43.1 and OS-45.4c drained urban runoff, and Site OS-43.1 was specifically identified to have coulee runoff contributions.

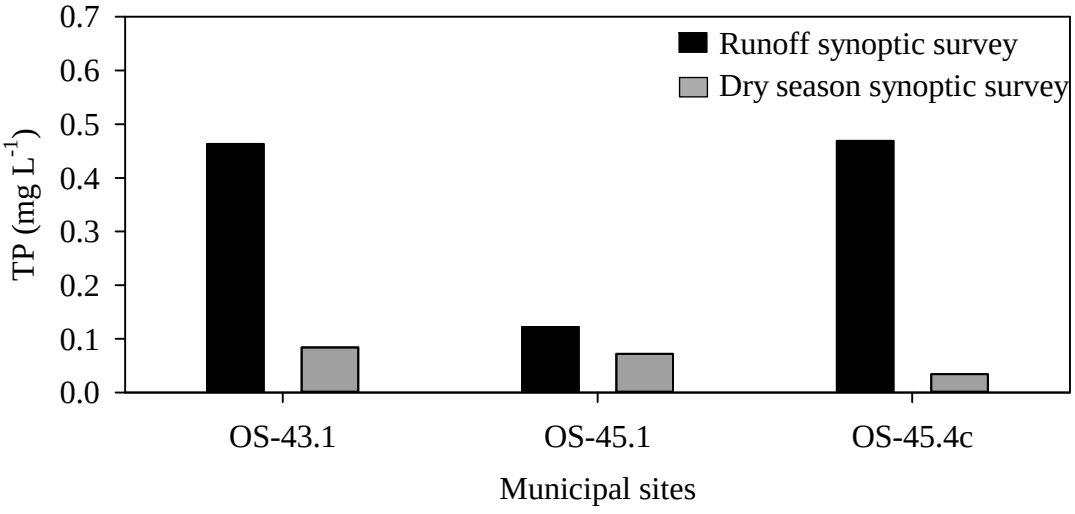


**Figure 4.11. Concentration of total phosphorus (TP) at the municipal sites during the runoff and dry-season surveys in 2014.**

Flow weighted mean concentrations of the municipal sites were generally moderate when compared to other source types, except for 2,4-D and number of pesticides detected (Table 4.6). The FWMC of 2,4-D at municipal sites was the highest for all source types for both surveys. The average number of pesticides detected at the municipal sites was second greatest after the industrial site and was more than double the other remaining source types during the runoff survey. Average number of pesticides detected during the dry-season survey was greatest compared to the other source types. The FWMC for all parameters was greatest during the runoff survey compared to the dry-season survey.

#### 4.3.2.6 Industrial Site

Industrial site OS-45.4b had the highest FWMC of TN and TDP and the smallest FWMC of TSS when compared to other source types during the runoff survey (Table 4.6). This site had the highest FWMC of TN and TDS and the lowest FWMC of TP, TSS, and 2,4-D compared to other site types during the dry-season survey. The number of pesticides detected at the industrial site was the greatest of all source type averages during the runoff survey and one of the smallest during the dry-season survey. Although the source of the nitrogen and pesticides in the industrial discharge was unknown, the source was not the industrial operations on site. It is more likely that the pesticides were pre-existing in the industry's source water and that the nitrogen was from groundwater seepage. The pesticide signature matches a municipal discharge into Taber Lake (see Chapter 5, Site T-LU2) that is near the pump station of the industrial source water. Almost all the TN was in the nitrate form ($NO_3$-N) which is indicative of groundwater influence.

The concentrations for most parameters, except for TN and TDS, were greater during the runoff survey compared to the dry-season survey. Unlike other source types, where the differences between the runoff and dry-season surveys could be attributed to runoff caused by the precipitation event, this site was sampled directly at the discharge pipe before water was influenced by external conditions. The concentration differences at the industrial site during the runoff survey compared to the dry-season survey were likely due to changes in source water quality and a shift in industrial operations. The industry was operating on the date of the runoff survey, and during the dry-season survey, water use was only for non-contact cooling of equipment (personal communication). Nitrogen from groundwater seepage would be more easily observed during the dry-season survey than the wet-season because of dilution from the operating water during the wet-season survey.

### 4.3.3 Loads

#### 4.3.3.1 Comparison of Contribution Source Loads (Contribution Ratio)

During the runoff survey, coulee, irrigation, and tributary sources contributed the greatest TN, TDP, TP, and TDS loads to the river (Figure 4.12, Table 4.8). Coulee and tributary sources contributed the most TSS load, and coulee and irrigation sources contributed the most 2,4-D load to the river. Irrigation sources contributed a relatively small TSS load and the tributary source contributed no 2,4-D load to the river as it was not detected during the runoff survey. Industrial and municipal sources consistently contributed the smallest loads to the river for all parameters. As discussed in Section 4.3.1, irrigation, tributary, and coulee sources were the greatest contributors of flow to the river, and municipal and industrial sources were the smallest. Therefore, flow had a large influence on load contributions. Loads from the coulee sources were dominated by Bountiful Coulee (OS-38.1), which had flow and TSS concentration that were much higher than the other coulees (Table 4.4).

During the dry-season survey, irrigation sources generally contributed the greatest load for most parameters, followed by the tributary source (Figure 4.12, Table 4.9). The only exception was for TSS, for which the tributary contributed the greatest load followed by irrigation sources. Municipal, coulee, and industrial sources were much less prevalent. It was expected that irrigation sources would be the greatest contributors to the river during the dry-season survey based on flow alone, as irrigation sources contributed the greatest flow to the river during the dry-season survey compared to other contribution sources. The flow of the tributary source was about half of the irrigation sources, and although the municipal, industrial, and one coulee contributed, the flows of these three sources were several orders of magnitude less than the irrigation and tributary sources.

The loads of most sources were less during the dry-season survey than during the runoff survey (except for the tributary load of 2,4-D) because of smaller flows and lower concentrations. River loads were also less during the dry-season survey (Table 4.10) due to smaller flows and lower concentrations.

Kromrey et al. (2011) found that the size of tributary flow was not equal to loading effect (i.e. proportional to their load) during the high flow synoptic survey in 2005. Although the runoff synoptic survey in 2014 only included one tributary (Little Bow River) on the monitored river stretch, the size of other contribution sources were generally representative of loading contributions, except for TSS. High TSS concentrations from Bountiful Coulee (OS-38.1) resulted in disportionate loading compared to volume contributed by the coulee sources. Interestingly, during the dry-season survey, the TSS loading of the tributary contribution was also disportionately higher compared to volume contribution because of higher TSS concentrations compared to other sources.

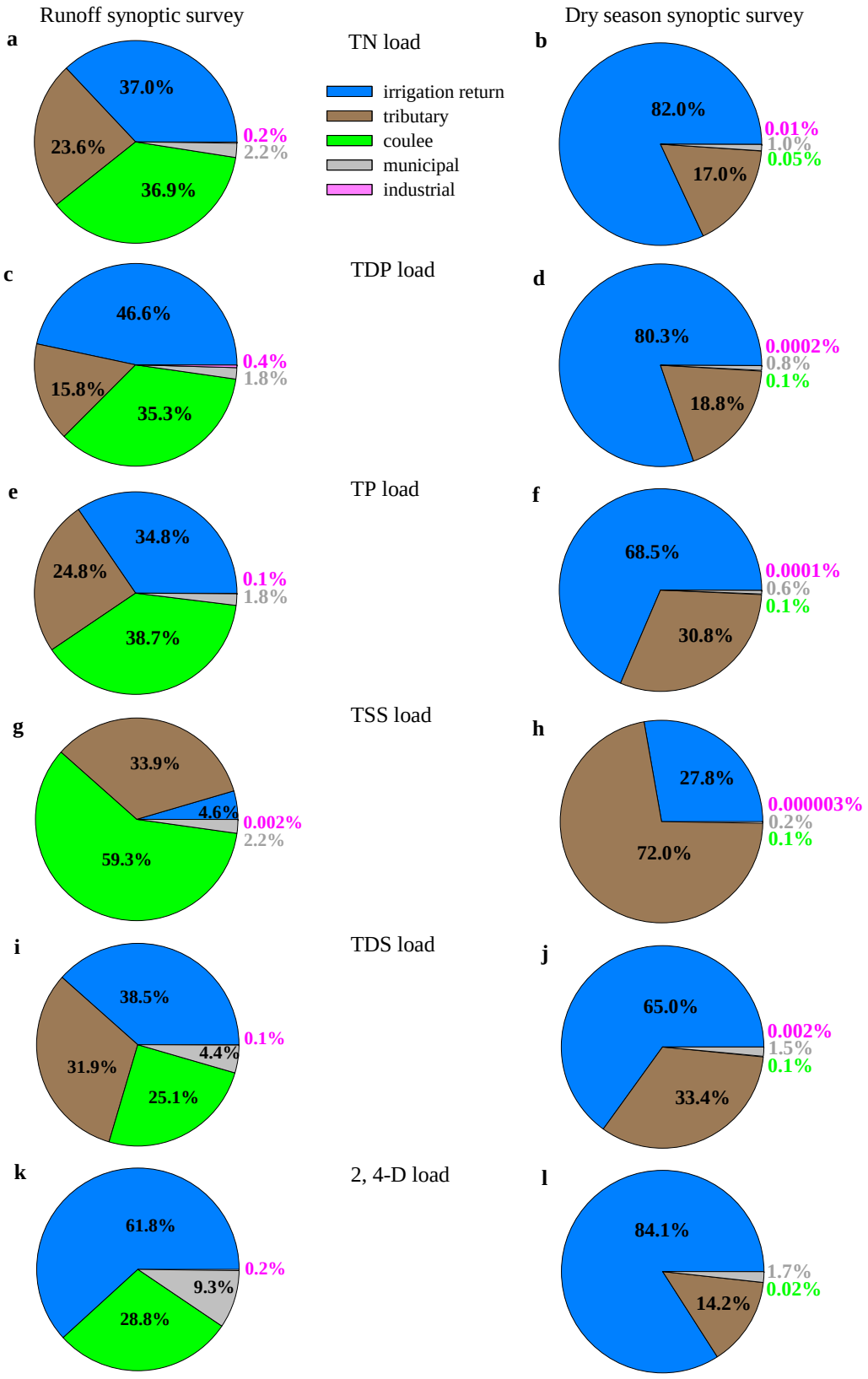


**Figure 4.12. Contribution ratios of loads during the synoptic surveys on the Oldman River in 2014.**

**Table 4.8. Water quality daily loads measured at contribution sources during the 2014 Oldman River runoff survey.**

| Site | TN | TDP | TP | TSS | TDS | 2,4-D |
|---|---|---|---|---|---|---|
| | ---------- (kg $d^{-1}$) ---------- | | | | | |
| | | | *Coulee* | | | |
| OS-3.4 | 14 | 0.2 | 0.4 | 117 | 1,555 | 0.00009 |
| OS-4.5 | 0.09 | 0.002 | 0.004 | 1.3 | 67 | 0.00 |
| OS-19.1 | 0.05 | 0.01 | 0.02 | 0.3 | 5.0 | 0.00001 |
| OS-38.1 | 1,040 | 36 | 362 | 505,440 | 100,505 | 0.26 |
| OS-39.4[z] | 98 | 16 | 24 | 5878 | 16837 | 0.06 |
| OS-43.1[y] | 65 | 2.3 | 12 | 10584 | 24,949 | 0.04 |
| OS-62.7 | 0.002 | 0.00005 | 0.0001 | 0.05 | 4.6 | 0.0000001 |
| OS-68.4[z] | 205 | 5.1 | 12 | 3018 | 57,468 | 0.05 |
| OS-76.9 | 0.03 | 0.0001 | 0.0005 | 0.3 | 13 | 0.00 |
| *Total*[x] | *1,421* | *60* | *410* | *525,039* | *201,403* | *0.46* |
| | | | *Tributary* | | | |
| OS-13.9 | 908 | 27 | 263 | 300,499 | 255,744 | 0.00 |
| | | | *Irrigation* | | | |
| OS-1.9 | 677 | 17 | 268 | 12,177 | 72,138 | 0.7 |
| OS-22.5 | 42 | 3.5 | 4.8 | 1,223 | 6,536 | 0.03 |
| OS-39.4[z] | 98 | 16 | 24 | 5878 | 16,837 | 0.06 |
| OS-45.4a | 14 | 0.2 | 0.7 | 274 | 6,158 | 0.002 |
| OS-68.4[z] | 205 | 5 | 12 | 3019 | 57,478 | 0.05 |
| OS-74.9 | 37 | 3.5 | 6.0 | 1,125 | 17,943 | 0.01 |
| OS-77.2 | 76 | 7.1 | 9.2 | 655 | 35,089 | 0.01 |
| OS-79.8 | 84 | 6.2 | 7.3 | 482 | 29,462 | 0.01 |
| OS-82.8 | 36 | 2.4 | 3.6 | 617 | 14,525 | 0.01 |
| OS-85.0 | 121 | 14 | 26 | 14,482 | 33,359 | 0.04 |
| OS-96.4 | 14 | 3.4 | 3.7 | 173 | 6,406 | 0.004 |
| OS-108.8 | 1.9 | 1.3 | 1.9 | 320 | 12,308 | 0.003 |
| *Total*[x] | *1,425* | *79* | *366* | *40,424* | *308,230* | *0.98* |
| | | | *Municipal* | | | |
| OS-43.1[y] | 65 | 2.3 | 12 | 10,584 | 24,949 | 0.04 |
| OS-45.1 | 4.7 | 0.2 | 0.5 | 25 | 3,671 | 0.01 |
| OS-45.4c | 17 | 0.6 | 7.2 | 9,120 | 6,890 | 0.10 |
| *Total*[x] | *86* | *3.1* | *19* | *19,728* | *35,509* | *0.15* |
| | | | *Industrial* | | | |
| OS-45.4b | 6.7 | 0.7 | 0.8 | 21 | 519 | 0.003 |
| | | | *Combination* | | | |
| OS-45.4[w] | 177 | 2.0 | 18 | 12,131 | 35,785 | 0.2 |

[z] Site OS-39.4 and OS-68.4 loads were equally split between irrigation and coulee contributions.
[y] Site OS-43.1 loads were equally split between municipal and coulee contributions.
[x] Values presented in table may not sum to equal total because of rounding.
[w] Site OS-45.4 was used for calculation of total load of contribution sources and Sites 45.4a, b, and c were used for calculation of contribution source type totals.

**Table 4.9. Water quality daily loads measured at contribution sources during the 2014 Oldman River dry-season survey.**

| Site | TN | TDP | TP | TSS | TDS | 2,4-D |
|---|---|---|---|---|---|---|
| | ----------(kg $d^{-1}$)---------- | | | | | |
| | | | *Coulee* | | | |
| OS-38.1 | 0.28 | 0.05 | 0.07 | 22 | 247 | 0.00002 |
| | | | *Tributary* | | | |
| OS-13.9 | 99 | 7.0 | 21 | 19,130 | 79,050 | 0.02 |
| | | | *Irrigation* | | | |
| OS-1.9 | 34 | 3.2 | 3.9 | 816 | 12,176 | 0.006 |
| OS-22.5 | 18 | 1.9 | 2.5 | 443 | 6,589 | 0.02 |
| OS-39.4 | 3.5 | 0.3 | 0.4 | 77 | 2,040 | 0.001 |
| OS-45.4a | 18 | 0.1 | 0.1 | 7.3 | 3,819 | 0.0009 |
| OS-68.4 | 36 | 4.7 | 6.2 | 1,504 | 21,010 | 0.01 |
| OS-74.9 | 23 | 1.6 | 2.1 | 336 | 6,841 | 0.003 |
| OS-77.2 | 42 | 3.1 | 3.6 | 176 | 13,327 | 0.003 |
| OS-79.8 | 59 | 5.2 | 6.2 | 362 | 17,664 | 0.01 |
| OS-82.8 | 167 | 6.1 | 16 | 1,344 | 24,424 | 0.03 |
| OS-85.0 | 63 | 2.9 | 5.3 | 2,232 | 39,800 | 0.006 |
| OS-96.4 | 2.4 | 0.1 | 0.2 | 32 | 502 | 0.007 |
| OS-108.8 | 9.6 | 0.9 | 0.2 | 46 | 5,741 | 0 |
| *Total*[z] | *475* | *30* | *48* | *7,375* | *153,934* | *0.09* |
| | | | *Municipal* | | | |
| OS-43.1 | 2.2 | 0.2 | 0.2 | 38 | 1,249 | 0.0006 |
| OS-45.1 | 3.6 | 0.09 | 0.2 | 7.2 | 2,266 | 0.001 |
| OS-45.4c | 0.03 | 0.0004 | 0.0005 | 0.04 | 21 | 0.0000005 |
| *Total*[z] | *5.9* | *0.3* | *0.4* | *45* | *3,536* | *0.002* |
| | | | *Industrial* | | | |
| OS-45.4b | 0.07 | 0.00008 | 0.00008 | 0.0009 | 3.8 | 0 |
| | | | *Combination* | | | |
| OS-45.4[y] | 7.6 | 0.1 | 0.1 | 17 | 1,768 | 0.0003 |

[z] Values presented in table may not sum to equal total because of rounding

[y] Site 45.4 was used for calculation of total load of contribution sources and Sites 45.4a, b, and c were used for calculation of contribution source type totals.

### 4.3.3.2 Comparison of Contribution Source Loads to the River (River Ratio)

The loads from all contributions varied from 1 to 74% relative to the river during the runoff survey and from 22 to 112% during the dry-season survey, depending on the parameter (Table 4.7). The five individual contribution source types, among all parameters, ranged from less than 0.1 to 46% during the runoff survey and from less than 0.1 to 80% during the dry-season survey relative to the river (Table 4.7). Ratios during the dry-season survey were greater than during the runoff survey because, as with flow, the river loads were reduced by a greater proportion than the contribution source loads compared to the runoff survey. This was in part because irrigation

loads were a dominant contribution source and their loads remained similar during both surveys. Increased ratios with decreased river flow was also observed in 2011 and 2012 as river flows decreased through the summer and irrigation inputs remained consistent (Villeneuve 2013). Overall, ratios were greater during the synoptic surveys in 2014 than in 2011 and 2012, and this was expected as all contributions to the river were included in 2014.

**Table 4.10. Water quality loads measured at river sites during 2014 Oldman river synoptic surveys.**

| Site | TN | TDP | TP | TSS | TDS | 2,4-D |
|---|---|---|---|---|---|---|
| | | | ($kg\ d^{-1}$) | | | |
| | | | *Runoff survey* | | | |
| OS-0.0 | 193,996 | 31,493 | 116,523 | 239,975,136 | 18,202,838 | 3.2 |
| OS-16.5 | 91,888 | 766 | 125,708 | 285,872,948 | 13,910,782 | 3.6 |
| OS-44.0 | 128,040 | 1,029 | 122,250 | 239,351,964 | 13,318,779 | 3.3 |
| OS-68.3 | 123,603 | 966 | 95,277 | 140,984,527 | 12,746,546 | 1.6 |
| OS-89.0 | 80,435 | 1,103 | 99,895 | 136,219,966 | 12,843,597 | 1.9 |
| OS-112.1 | 117,522 | 775 | 66,510 | 79,424,505 | 12,462,544 | 2.2 |
| | | | *Dry-season survey* | | | |
| OS-0.0 | 1,243 | 44 | 52 | 24,054 | 922,061 | 0.0 |
| OS-16.5 | 1,132 | 87 | 74 | 43,530 | 966,375 | 0.0 |
| OS-44.0 | 1,016 | 62 | 44 | 22,091 | 932,260 | 0.1 |
| OS-68.3 | 973 | 44 | 44 | 30,956 | 968,496 | 0.9 |
| OS-89.0 | 2,057 | 57 | 62 | 23,920 | 1,186,448 | 0.2 |
| OS-112.1 | 1,097 | 48 | 62 | 23,846 | 1,063,549 | 0.0 |

During the runoff survey, irrigation, tributary, and coulee sources had the greatest loads relative to the river (Table 4.7). The loads from the coulees were heavily influenced by Bountiful Coulee, which was not representative of the other coulees (Table 4.4). During the dry-season survey, irrigation sites had the greatest loads relative to the river of all contribution types for most parameters, except for TSS.

#### 4.3.3.3 Instream Load Comparison and Cumulative Loads

From the upstream to downstream river sites (OS-0.0 and OS-112.1, respectively), loads decreased for all parameters in the runoff survey and either increased (TDP, TP, and TDS) or decreased (TN and TSS) in the dry-season survey (Tables 4.10). The load increases during the dry-season survey were solely attributed to an increase in flow because concentrations either decreased or remained similar from upstream to downstream (Table 4.3).

Although concentration of contribution sources was often higher than river concentrations, the influence of these sources was not measurable in the river. More than half (65%) of contribution source concentrations of TN, TDP, TP, TSS, TDS, and 2,4-D were higher than their nearest downstream river site during the runoff survey, and 92% were higher during the dry-season survey.

As water moved from upstream to downstream in the river, it was hypothesized that loading would be cumulative and changes in concentrations and loads would be proportional to the contribution source inputs. However, this was not observed. For example, during the dry-season survey, TSS load from all contribution sources was 111% of the downstream river load at OS-112.1 (Table 4.7). Similarly, TP load from all contribution sources was 112% of the downstream river load. This indicated that the river load at OS-112.1 was less than the total amount of all the contribution sources. The river TSS load actually decreased by 0.9% from OS-0.0 to OS-112.1 (Table 4.11). Similar river dynamics were observed by Saffran (2005). All measured loads at OS-112.1 were smaller than the predicted cumulative loads calculated from the contribution sources added to the upstream river site (OS-0.0) (Table 4.11). The predicted cumulative change in river loading was lower during the runoff survey than during the dry-season survey because of the larger dilution effect of the river during the runoff survey.

During both synoptic surveys, because river flows were fairly constant, the changes in load from one river site to the next were mainly caused by changes of instream concentrations. As mentioned previously, decreasing or no consistent trends of parameter concentrations in the river were observed (Figure 4.9). During the runoff survey, the calculated cumulative loads (adding contribution sources to the upstream river sites per stretch) showed that source contributions were often so small that cumulative loads mirrored the previous river site's measured load (Figure 4.13a, only TP shown as an example). During the dry-season survey, although source contributions were greater relative to river volume, proportionate cumulative change in the river was not consistently observed (Figure 4.13b).

Several factors can explain why the river loads were not cumulative and the variability of concentration among the six river sites. Dynamic and complex river processes including sedimentation, re-suspension of sediments, biological, and chemical activities can affect measured concentrations. Variability across the river is likely a factor as well. The sample of water collected at each river site was assumed representative of the entire parcel of flowing water across the river; however, concentration can differ across the river. Even for duplicate samples, a relative percent difference of up to 20 to 30% is to be expected, and this type of variation is acceptable for measurement quality objectives of several monitoring programs (Hutchinson Environmental Science Ltd. 2015). This degree of variability alone could be greater than the cumulative load change expected in the runoff survey and for most of the measured load change in the dry-season synoptic survey (Table 4.11).

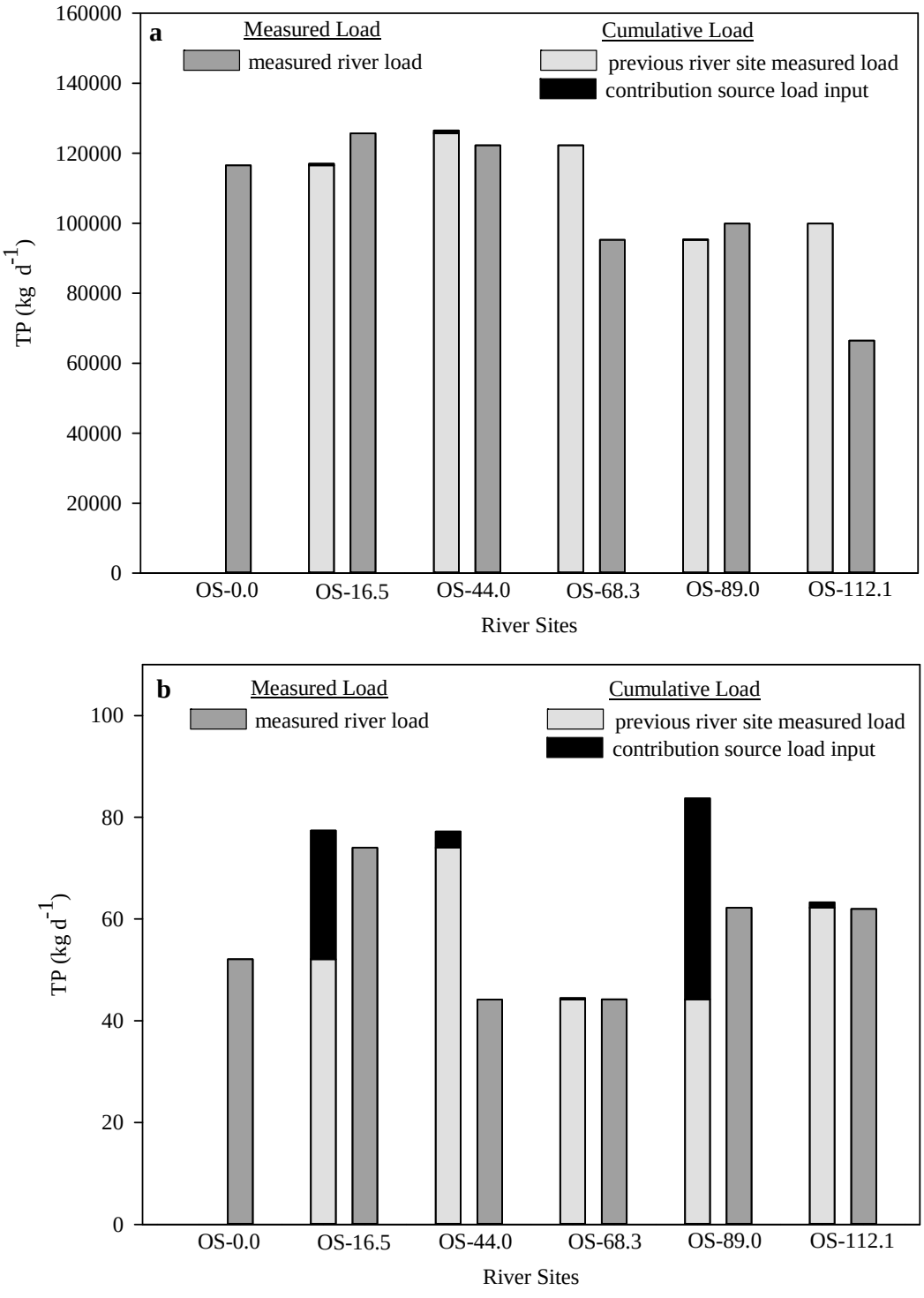


**Figure 4.13. Measured total phosphorus (TP) load compared to cumulative TP load at river sites during the (a) runoff and (b) dry-season surveys in 2014.**

**Table 4.11. Change in loads from the upstream (OS-0.0) to downstream (OS-112.1) Oldman River sites based on measured upstream and downstream loads and calculated cumulative load from contribution sources during the runoff and dry-season synoptic surveys in 2014.**

| | TN | TDP | TP | TSS | TDS | 2,4-D |
|---|---|---|---|---|---|---|
| | ---------- (%) ---------- | | | | | |
| *Runoff survey* | | | | | | |
| Measured load change[z] | -39 | -98 | -43 | -67 | -32 | -34 |
| Cumulative load change[y] | 2.1 | 0.5 | 0.9 | 0.4 | 4.5 | 52 |
| *Dry-season survey* | | | | | | |
| Measured load change | -12 | 8.2 | 19 | -0.9 | 15 | nd[x] |
| Cumulative load change | 46 | 85 | 133 | 111 | 26 | nd |

[z] Difference between Sites OS-0.0 (upstream) and OS-112.1 (downstream) based on field measurements at the two sites.
[y] Difference between Sites OS-0.0 (upstream, based on field measurement) and OS-112.1 (downstream, based on cumulative source contribution calculations as described in Sub-section 4.2.5.3).
[x] nd = no detection of 2,4-D at the upstream and downstream sites.

In spite of the comprehensive sampling during these synoptic surveys, the loading from the contribution sources, including irrigation returns, to the river had no measureable effect on river water quality. This supports the previous work by Villeneuve (2013). The dynamic, natural processes of the river may have more important effects on water quality than the contribution sources, including irrigation returns. Additionally, or alternatively, our ability to measure water quality is not sensitive enough to capture the small changes that may occur.

### 4.4 Summary and Future Work

The synoptic surveys measured all major contributions to the river and allowed for the comparison among different types of contribution sources (tributary, coulee, municipal, industrial, and irrigation return). Irrigation returns were often the dominant contribution source of flow and loads to the river during the runoff and dry-season surveys compared to other contribution types. Measuring water quality in the river at various locations along the stretch helped determine when and where degradation occurred and if it could be related to any particular loading contributions. With fairly constant flows (i.e., slowly increasing from upstream to downstream), the river loads were driven by concentrations that were not largely influenced by any contribution source to the river, including irrigation returns. During the runoff survey, river volume was orders of magnitude larger than input volumes and the effects of inputs were negligible. During the dry-season survey, localized variability in the river concentration, as well as dynamic physical, chemical, biological processes of the river likely had more effects on river water quality than the contribution sources. Although cumulative effects of contributions to

the river were not measurable, the buffering capacity of natural river processes remains unknown and these results should not be interpreted as an opportunity to release higher loads. These data will serve as a baseline against which future work may be compared.

Synoptic surveys on the lower stretch of the Bow River are planned for 2015. Because the high river flows during runoff events make it difficult to detect water quality changes caused by contribution sources, a runoff survey on the Bow River will not be conducted. Instead, two dry-season surveys will be conducted. An additional dry-season survey will also be carried out on the Oldman River in 2015 for comparison to the 2014 dry-season survey.

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# 5 Factors Affecting Irrigation Water Quality

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## 5.1 Introduction

Without question, the conditions of freshwater resources are largely a result of landscape processes and influences. Water quality degradation is generally observed as water flows from the primary sites at the entrance of an irrigation district to the return sites where water leaves the district and returns to the natural drainage system (Little et al. 2008; Charest et al. 2014). Complex relationships exist between agricultural land use and water resources within watersheds.

One of the objectives of the current Irrigation District Water Quality (IDWQ) study was to assess relationships between land use and irrigation water quality. A previous literature review (Charest et al. 2014) outlined how to assess relationships between land use and irrigation water quality, as well as a proposed field study. This chapter summarizes the results of the field study completed in 2014.

### 5.1.1 Study Objectives

The main objective of the study was to better understand the effects of the land use on changes in irrigation water quality.
More specifically, the study objectives were to examine irrigation water quality throughout the season and the influence of:

- irrigation reservoirs,
- municipal stormwater, and
- canal and landscape characteristics in selected irrigation canal segments.

### 5.1.2 Study Design

The study was carried out within the Taber Irrigation District (TID). There are several characteristics of the TID that were conducive for this type of study. The TID is a relatively small district with approximately 343 km of conveyance works (AARD 2014). About 90% of the land base is used to grow crops, which are mainly composed of cereal, forage, and specialty crops. Among the 13 irrigation districts in Alberta, TID has the largest proportion of specialty crops representing 37.5% of the irrigated land area (AARD 2014). Potatoes and sugar beets are the primary specialty crops in the district. The TID also includes the Town of Taber of 8000

residents, industrial food-processing facilities, and two in-stream reservoirs. The irrigation water quality, land use, and agriculture practices in the TID are generally representative of a large proportion of Alberta's irrigation districts.

The study was designed to utilize the previously established water quality monitoring sites in the TID. An upstream-downstream sampling design was selected to evaluate the change in water quality attributed to reservoirs, municipal storm water, and land use. This design type has been used to monitor the effects of nonpoint sources on stream water quality (Spooner et al. 1985).

### 5.1.3 Hypotheses

The hypothesis was that certain land-use characteristics, defined by the irrigation canal and landscape parameters, as well as the presence of in-stream reservoirs and municipal stormwater flow, would have a significant effect on water quality as water flowed from upstream to downstream. It was hypothesized that the strengths and direction of the relationships between specific land-use and water quality parameters would vary with the different sampling event types.

More specifically, it was hypothesized that (1) the in-stream reservoirs would reduce the concentration of total suspended solids (TSS) and total phosphorus (TP) by sedimentation, (2) the municipal stormwater contribution would increase the concentration of several parameters and diversity of pesticides detected, and (3) the change of water quality within the canal segments would be more apparent during runoff and infrastructure flushing events than during the irrigation season.

## 5.2 Methods

The sampling design for this study was developed in conjunction with the main IDWQ study. The same grab-sampling methodology was used as described in Sub-section 2.2.1, and the study included several of the same sampling sites and dates used for the main IDWQ study. This was done in order to reduce sampling and laboratory analytical costs and maintain comparability between the different project components. The differences in this study compared to the main IDWQ study were that this study had higher sampling frequency, a longer sampling season, and flow data collection at all sites. A total of 135 water quality parameters including nutrients, salts, pesticides, and physical and bacterial parameters were analyzed using the same laboratories and methods as for the main IDWQ study (Chapter 2). Samples were not analyzed for metals, pathogens, pharmaceuticals, or glyphosate.

### 5.2.1 Sampling Sites

Seventeen water quality sampling sites were used to assess land-use effects on irrigation water quality. Of these sites, six were part of the main IDWQ study and were sampled annually since 2011. In addition, 11 new sites were established in 2014 specifically for the land-use study. These 11 new sites were selected based on existing information about irrigation conveyance.

The six main IDWQ sites and nine of the new sites were used to isolate nine canal segments (Figure 5.1) for the upstream-downstream sampling design (Table 5.1 and Figure 5.1). The sites were selected to isolate canal segments ensuring there was minimal flow contribution between the upstream and downstream sampling sites. The only potential flow contributions within the canal segments were the drainage points that were identified and characterized as part of the land-use assessment described in Sub-section 5.2.4. The canal segments were all located directly upstream, downstream, or in between the two reservoirs.

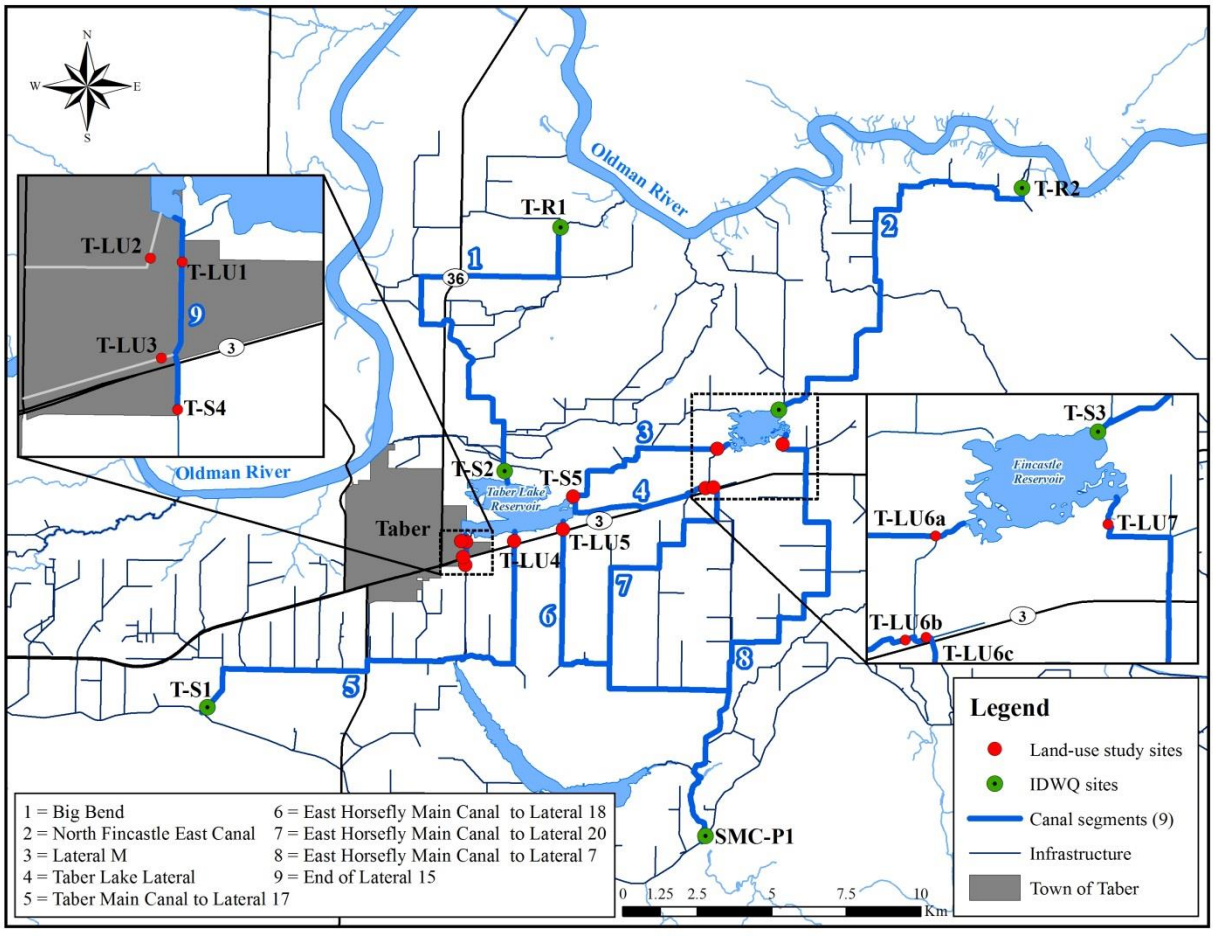


**Figure 5.1. Selected land-use study canal segments and sampling sites in the Taber Irrigation District.**

The remaining two new sites were used to sample municipal stormwater contributions: one (T-LU3) contributed to the Lateral 15 canal segment and the other (T-LU2) contributed directly into Taber Lake Reservoir (Figure 5.1). Lateral 15 was used to assess the effects of municipal stormwater, and it was not included in the land-use segment analysis. The sampling sites at each reservoir inlet and outlet were used to assess the influence of the reservoirs on water quality (Table 5.2).

**Table 5.1. Land-use canal segments sampling sites.**

| Segment name | Abbreviation | Upstream sampling site | Downstream sampling site |
|---|---|---|---|
| 1. Big Bend Canal | BB | T-S2[z] | T-R1[z] |
| 2. North Fincastle East Canal | NFEC | T-S3[z] | T-R2[z] |
| 3. Lateral M | LatM | T-S5 | T-LU6a |
| 4. Taber Lake Lateral | TLL | T-S5 | T-LU6b |
| 5. Taber Main Canal to Lateral 17 | TMC_17 | T-S1[z] | T-LU4 |
| 6. East Horsefly Main Canal to Lateral 18 | EHMC_18 | SMC-P1[z] | T-LU5 |
| 7. East Horsefly Main Canal to Lateral 20 | EHMC_20 | SMC-P1[z] | T-LU6c |
| 8. East Horsefly Main Canal to Lateral 7 | EHMC_7 | SMC-P1[z] | T-LU7 |
| 9. End of Lateral 15 | Lat15 | T-S4 | T-LU1 |

[z] Sites also used for the main Irrigation District Water Quality Study. All other sites were established in 2014 specifically for the land-use study.

**Table 5.2. Water quality sampling sites of the inlet and outlet canals for Taber Lake and Fincastle reservoirs.**

| Taber Lake Reservoir | | Fincastle Reservoir | |
|---|---|---|---|
| Canal | Sample site | Canal | Sample site |
| *Inlet* | | *Inlet* [z] | |
| Lateral 15 | T-LU1 | Lateral M | T-LU6a |
| Lateral 17 | T-LU4 | Taber Lake Lateral | T-LU6b |
| Lateral 18 | T-LU5 | Lateral 20 | T-LU6c |
| | | Lateral 7 | T-LU7 |
| *Outlet* | | *Outlet* | |
| Big Bend | T-S2 | North Fincastle Lateral | T-S3 |
| Lateral M and Taber Lake Lateral | T-S5 | | |

[z] The sampling site T-LU6 was sampled on March 12, 2015 and was then replaced by the three sites (T-LU6a, T-LU6b and T-LU6c) located on canals that join together just upstream of the site.

All sampling sites were marked with a sign and their coordinates recorded. Detailed descriptions of the sampling sites are in Appendix A. The 17 sites were grouped into two sampling areas (6a and 6b) for logistical reasons as indicated in Chapter 2 (Table 5.3). The new sampling sites were

named by following a similar naming convention as used for the main IDWQ sampling sites, with the first letter of the irrigation district (T for TID), followed by a dash and the site type designated with the letters "LU" to indicate land-use study sites, and a number to further differentiate sites. In some cases, a lower-case letter was added to further delineate the sites converging to a single canal (Figure 5.1). The six main IDWQ study sampling sites retained their names when sampled for the land-use study. Early in the study design, two sites were added (T-S4 and T-S5) with the same nomenclature used in the main study as they were going to be added to the main IDWQ study, but in the end were not.

**Table 5.3. Sites within sampling Areas 6a and 6b used for the land-use study in 2014.**

| Area 6a | | Area 6b | |
|---|---|---|---|
| T-S1[z] | T-LU1 | SMC-P1[z] | T-LU6a |
| T-S2[z] | T-LU2 | T-S3[z] | T-LU6b |
| T-S4 | T-LU3 | T-S5 | T-LU6c |
| T-R1[z] | T-LU4 | | T-LU7 |
| T-R2[z] | T-LU5 | | |

[z] Sites also used in the main IDWQ study in 2014.

### 5.2.2 Sampling Events

In 2014, there were 16 sampling events from March to November (Table 5.4). These events covered the entire flow seasons and were divided into five different event types reflecting expected differences in water quality and flow. The pre-irrigation sampling events monitored water quality and flow in the spring before irrigation water was released by the irrigation district in their canal system. Flows in the canal were generally very low. The flush event was a single sampling event that captured the water quality of the initial flow released by the irrigation district in preparation for the growing season. The irrigation season events occurred every two weeks during the period when irrigators can utilize the water for their cultures. The post-irrigation event occurred after the district turned off the irrigation water source. Finally, the runoff events were any events during the season where rain or snowmelt could have generated runoff.

The first sampling event was conducted in mid-March to collect preliminary data to aid in the study design. The samples from this event were processed by the Alberta Agriculture and Forestry (AF) lab as opposed to the Exova Lab for the remaining sampling events. As well, for this sampling event, sites T-LU6a, T-LU6b, and T-LU6c were not yet established and were not sampled. The sampling events occurred approximately every two weeks. However, extra sampling events were scheduled in order to collect samples that occurred during specific events including the infrastructure flushing event at the beginning of the irrigation season, and runoff events in response to snowmelt or rainfall.

**Table 5.4. Land-use study sampling event type dates in 2014.**

| Sampling event | Date | Pre-irrigation | Flush | Irrigation season | Post-irrigation | Runoff | Sampling event | Date | Pre-irrigation | Flush | Irrigation season | Post-irrigation | Runoff |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | March 12 | x | | | | x | 9 | July 21 | | | x | | |
| 2 | April 4 | x | | | | | 10[z] | August 5 | | | x | | |
| 3 | April 14 | x | | | | | 11 | August 19 | | | x | | |
| 4 | May 7 | x | | | | | 12[z] | September 2 | | | x | | |
| 5 | May 15, 20, and 21 | | x | | | | 13 | September 4 | | | x | | x |
| 6[z] | June 10 | | | x | | | 14 | September 22 | | | x | | |
| 7 | June 17 | | | x | | x | 15 | October 9 | | | x | | |
| 8[z] | July 7 | | | x | | | 16 | November 3 and 7 | | | | x | |

[z] Events sampled in conjunction with the main IDWQ sampling.

The initial infrastructure flushing event occurred from May 15 to 21 to capture the first irrigation water that reached the sampling sites (Table 5.4). This event was collected on three different dates because not all canal segments were flushed on the same date. Sampling at the downstream site of each segment occurred within minutes or hours from the time the flush water reached the site. Four sampling events occurred in conjunction with the IDWQ main study sampling dates for TID (June 10, July 7, August 5, and September 2). Three sampling events (March 12, June 17, and September 4) were scheduled during periods of runoff contribution. The March 12 sampling event occurred after a period of 10 days with average daily temperatures above 0°C at the Fincastle Irrigation Management Climate Information Network (IMCIN) weather station, and snowmelt runoff was observed. The June 17 sampling event occurred during a period of rainfall runoff. The Fincastle IMCIN station recorded 42 mm that day in addition to the 22 mm that fell in the previous three days. The third runoff sampling event was sampled the day after 54 mm of rainfall. Ten sampling events occurred during the irrigation season from June 10 to October 9. The October 9 sampling event occurred just before the end of the irrigation season at the end of a flushing event, which caused increased flow in the district infrastructure. The November 3 sampling event occurred after the irrigation season when there was very little flow in the canals, similar to the pre-season sampling events. However, the three sites at the outlets of the reservoirs (T-S2, T-S3, and T-S5) were not flowing. Therefore, samples were collected from within the reservoirs, in close proximity to the outlet sampling sites, on November 7.

### 5.2.3 Flow Measurement

Water flow was obtained or calculated for each sampling site. Most flow data were collected at each sampling site or at a nearby location where a check structure or other device allowed for flow measurement (Appendix A). The only sampling site that was located more than 2 km from

the flow measurement site was SMC-P1. Water samples collected at SMC-P1 in the St. Mary River Irrigation District (SMRID) main canal (just downstream from the Horsefly diversion), represented the water diverted to the East Horsefly main canal. Flow for this site was measured on East Horsefly main canal, just downstream of the diversion to Horsefly Reservoir. One site, T-S5, had two flow measurements; flow for water exiting Taber Lake at T-S5 was measured on Lateral M (flowing north) and Taber Lake Lateral (flowing east).

Most flow data were collected as water stage and converted to flow using the contracted rectangular weir formula, a rating curve, or a slope gauge table (Table 5.5). Water stage was manually measured at the time of sampling using a portable staff gauge. The staff gauge was inserted into the water on the most upstream edge of the crest or boards of the check structure. Boards are inserted into check structures by the irrigation district to raise the height of water upstream. The manual stage measurement could be compared to a static staff gauge attached to the structure for determination of an offset created by inserted boards. Manual measurements were used for flow calculations instead of static gauge measurements as this ensured an accurate measurement of the height of flowing water at the time of sampling. Water stage measurements were not taken at T-S1 and SMC-P1 because they were instrumented by TID with Acoustic Doppler Current Profilers (ADCPs) for flow measurement.

**Table 5.5. Flow measurement methods and weir lengths.**

| Site name | Description | Flow measurement | Weir length (m) |
|---|---|---|---|
| T-S2 | Big Bend Canal | Slope gauge table | na |
| T-R1 | Lateral G7 Spill | Weir formula | 1.96 |
| T-S3 | North Fincastle East Canal | Weir formula | 1.83, 1.83[x] |
| T-R2 | North Fincastle East Canal Spill | Weir formula | 1.97 |
| T-S5 north | Lateral M | Weir formula | 1.70 |
| T-LU6a | Lateral M Tailout | Weir formula | 1.40 |
| T-S5 east | Taber Lake Lateral | Weir formula | 1.22 |
| T-LU6b | Taber Lake Lateral Tailout | Rating curve | na |
| T-S1 | Taber Main Canal | ADCP[z] | na[y] |
| T-LU4 | Lateral 17 Tailout | Weir formula | 1.45 |
| SMC-P1 | East Horsefly Main | ADCP | na |
| T-LU5 | Lateral 18 Tailout | Weir formula | 1.82 |
| T-LU6c | Lateral 20 Tailout | Weir formula | 1.93, 1.70[x] |
| T-LU7 | Lateral 7 Tailout | Weir formula | 2.41 |
| T-S4 | Lateral 15 | Weir formula | 1.80, 1.61, 1.83[x] |
| T-LU3 | Taber town drain 14 | Rating curve | na |
| T-LU1 | Lateral 15 Tailout | Addition of T-S4 and T-LU3 | na |
| T-LU2 | Taber town drain | Rating curve | na |

[z] ADCP = Acoustic Doppler Current Profiler.
[y] na = not applicable.
[x] Check structure had two or three gates with lengths listed west to east.

#### 5.2.3.1 Weir Formula

Eleven sites (Table 5.5) were at or near check structures and the contracted rectangular weir formula (Equation 5.1) was used to convert water stage to flow. Although not true weirs, the check structures were used as weirs and Equation 5.1 gave a reasonable estimate of flow.

$$Q = 1838LH^{1.5} \quad \text{Equation 5.1}$$

where:
Q = flow (L $s^{-1}$)
L = length of weir (m)
H = water stage (m)

#### 5.2.3.2 Rating Curve

Three sites were not near check structures (Table 5.5) and these sites were flow metered and rating curves were built. Flow metering was done using an acoustic Doppler velocity meter (FlowTracker, Teledyne RD Instruments, Poway, California, United States). It was attempted to fit a power curve (Equation 5.2) to the flow metering and water stage data to generate a rating curve. Unfortunately, T-LU2 and T-LU3 were only metered once and data for T-LU6b were too scattered for curve fitting. Instead, a straight line (Equation 5.3) was used to estimate flow for T-LU2 and T-LU3. Data from T-S5 were used for T-LU6b.

$$\boldsymbol{x = \left(\frac{y}{a}\right)^{\frac{1}{b}}} \quad \text{Equation 5.2}$$

where:
*x* = flow ($m^3$ $s^{-1}$)
*y* = stage (m)
a and b = coefficients

$$\boldsymbol{x = (y - b)/m} \quad \text{Equation 5.3}$$

where:
*x* = flow ($m^3$ $s^{-1}$)
*y* = stage (m)
m = slope
b = stage offset

#### 5.2.3.3 Slope Gauge Table and Addition of Upstream Sites

Flow for T-S2 was calculated using TID's slope gauge in the Big Bend main canal just downstream of the sampling site. The TID provided a flow rating table specific for this gauge, and the table was used to convert water-stage measurements to flows. Since T-LU3 was the only input into Lateral 15 between T-S4 and T-LU1, the addition of T-LU3 flow to T-S4 flow was used to calculate the flow for T-LU1.

#### 5.2.3.4 Acoustic Doppler Current Profiler

For two sites, an ADCP (Argonaut SW, SonTek/YSI, San Diego, California, United States) was used to monitor flow (Table 5.5). The ADCP uses acoustic Doppler technology to measure and calculate water height and velocity. The units were programmed with the cross-sectional information of the canals where they were installed. Flow was calculated and recorded every 15 min and the data were provided by TID. Flows were estimated based on field notes and photos for times before and after the irrigation season when the ADCPs were not installed.

#### 5.2.3.5 Other TID Flow Data

Other flow data were available from TID for eight of the 18 land-use flow metering sites. These data were in the form of daily flows recorded by the ditch-riders or data loggers at check structures. Instantaneous flows calculated from stage measurements or read from ADCP displays at the time of sampling were used as often as possible as they were more representative of the sample time. However, the other TID data were used if the instantaneous flows were unavailable or thought to be unreliable.

### 5.2.4 Canal and Landscape Assessment

An assessment was done for each canal segment to identify characteristics that could potentially explain a change in water quality. The parameters used for the assessment were categorized into two types: canal and landscape parameters (Table 5.6). The canal parameters are related to the irrigation infrastructure characteristics and the landscape parameters are related to characteristics of the land surrounding the canals. All parameters were selected for their potential to influence irrigation water quality.

In order to accurately assess the transport of water from the landscape into open irrigation channels, a field survey and a Geographic Information System (GIS) exercise were conducted. The purpose of the field survey was to locate all direct flow contributions from the landscape to irrigation canals along the eight segments. Each segment was surveyed along its length, and Global Positioning System (GPS) points were recorded for all instances where potential contributions from the surrounding landscape were identified. These included direct overland runoff, subsurface drains, and infrastructure draining road ditches, borrow pits, and toe drains. These drains consisted of culverts or pipes. The drain pipe diameters, as well as the material, such as corrugated steel or polyvinyl chloride (PVC), were recorded for each culvert and pipe, and later verified using AF's Irrigation District Infrastructure Information System (IDIIS). The field survey also identified the crop type and the presence or absence of irrigation systems on adjacent fields. Drainage infrastructure is referred to as drain inlets in this study, and includes culverts and pipes. Further, the drainage infrastructure, or drainage pipes, was considered to be nonpoint sources, as they have the potential to drain water from adjacent fields, which may include water from a few kilometres away. These observations were used to develop several parameters for the analysis (Table 5.6).

**Table 5.6. Canal and landscape parameters and units used for analysis.**

| Parameters | Units |
|---|---|
| *Canal parameters* | |
| Segment length | km |
| Canal flow capacity (length weighted average) | $m^3 s^{-1}$ |
| Length of lined canal | km |
| Length of earth canal | km |
| Proportion of earth canal | % |
| *Landscape parameters* | |
| Number of drainage points | No. |
| Drainage point density | No. $km^{-1}$ of canal |
| Drainage inlet flow potential (cumulative culvert cross section area) | $m^2$ |
| Average land slope | degrees |
| Annual crops | % |
| Irrigated crops | % |
| Road length | km |
| Road density | km $km^{-2}$ |

Initially, a GIS exercise was conducted using ArcMap 10.1 (Environmental Systems Research Institute, Redlands, California, United States) to determine the contributing area for each landscape drain inlet contribution. However, errors of omission and commission between field observations and the GIS model were numerous, as is common in areas with flat relief (Galzki et al. 2011), and this resulted in unreliable delineation of drainage areas. Instead, it was assumed that landscape contributions to the open canals in each segment would come from the land within

an 805-m (one quarter section) wide area along both sides of each segment. This was defined as the segment area. ArcMap has the ability to create areas around lines at a fixed distance, and this allowed for the description and analysis of edge effects (Johnson and Gage 1997). The 'buffer' tool in ArcMap 10.1 was used to determine the segment area, or the area around each canal segment within an 805m radius, for which the landscape parameters were calculated for the analysis (Table 5.6).

### 5.2.4.1 Canal Parameters

**Segment Length**

The canal segment length is described as the length of the canal between the upstream and downstream water sampling sites. It was quantified by taking the sum of the canal section lengths for each of the nine segments using IDIIS, an AF database on irrigation infrastructure.

**Canal Flow Capacity**

The canal flow capacity represents the flow for which the canals were designed. Since canals are typically built of sections that get smaller as the water gets utilized along the way, the length weighted mean of the canal capacity of each section was calculated from IDIIS (Equation 5.4).

$$LWCC = \frac{\sum(Q \cdot l)}{L} \qquad \text{Equation 5.4}$$

Where:
LWCC = length weighted canal capacity ($m^3\ s^{-1}$)
$Q$ = design capacity ($m^3\ s^{-1}$) of canal section
$l$ = length of canal section (km)
$L$ = total length of canal segment (km)

**Length and Proportion of Earth and Lined Canal**

Under the assumption that the physical properties of the canal banks and beds could influence water quality, the canals were characterized as earth or lined. Earth refers to unlined open conveyance works, which typically consisted of natural soil. Lined refers to any type of open canal conveyance work that is lined with a synthetic or manufactured material, typically concrete or PVC. TID lining methods have almost exclusively been buried liner, with approximately 0.6m of earth cover material. The exposed earth may still contribute to TSS with scour, and also biological processes. Lining, even buried lining will likely prevent infiltration/leaching from the adjacent land. The total length of lined canal and total length of earth canal were determined for each canal segment, as well as their relative proportions. Only the proportion of earth canal was presented because the proportion of lined canal is the remaining portion of the total length (100%).

### 5.2.4.2 Landscape Parameters

**Number of Drainage Points**
The number of drainage points refers to the total number of instances where water can enter a canal segment, as documented by the field survey. This includes low spots, as well as drainage infrastructure such as culverts, pipes, and tile drains.

**Drainage Point Density**
The drainage point density was calculated by dividing the total number of drainage points along a canal segment by the total length of the canal segment (number per kilometre).

**Drainage Inlet Flow Potential**
The drain inlet flow potential is an indicator of the cumulative potential flow contribution from the landscape that can enter the canal segment from drainage infrastructure such as culverts and pipes. Since runoff flow could not be easily measured, the size of drainage inlet was used as a surrogate of the potential flow that can enter irrigation canal segments. It was assumed that larger culverts would likely contribute more flow to the canal than smaller culverts. The drain inlet flow potential was calculated as the cumulative culvert cross section area ($m^2$) for each canal segment using Equation 5.5. All culverts on a segment were used for the calculation but subsurface drains and low spots where runoff could enter canal were not considered reliable surrogates for flow potential.

$$\mathrm{CCA} = \sum_{i=1}^{n} \pi r^2{}_i \qquad \text{Equation 5.5}$$

Where:
CCA= cumulative culvert area ($m^2$)
$\pi r_i^2$= the area of a the cross section of each culvert *i* ($m^2$)

**Slope**
Catchment and channel slope elevation are physical landscape properties that have the potential to influence drainage patterns and intensity and aid in predicting contaminant losses from the landscape (Johnson and Gage 1997; White et al. 2009). The characterization of the slope for each of the segment area was done using a digital elevation model created from a Light Detection and Ranging (LiDAR) dataset provided by the TID. The zonal statistics tool in ArcMap was used to determine the average slope (degrees) for each segment area.

**Crop Type and Irrigation Presence**
Observations of crop type and presence of irrigation systems were recorded for quarter sections of land adjacent to the canal segments during the field survey. Agricultural practices including soil tillage and fertilizer and pesticide application are dictated by the type of crop grown. Crop

types were assigned to one of two categories: annual or perennial. The proportion of annual crops for each segment area was quantified as a percentage of the total area.

The presence or absence of irrigation systems can influence soil moisture conditions, which dictates runoff potential. The proportions of irrigated crops in a segment area were determined by dividing the number of irrigated quarter sections of land by the total number of cropped quarter sections within the segment areas.

**Road Length and Density**

The density of impervious surface area can have an impact on drainage systems by altering natural flow (Stanfield and Kilgour 2006). Thus, a road network database for the study area was used to determine parameters representing impervious surface area. In ArcMap, the 'clip' tool was used to extract the road network for each segment area. The sum of road lengths in each segment area was taken to determine the total road length (km). The road density (km $km^{-2}$) was determined by dividing the total road length by the segment area.

### 5.2.5 Data Analysis

From the 135 water quality parameters analyzed (Sub-section 5.2), nine parameters were selected to represent different parameter classes for the data analysis in the land-use study, including nutrients, dissolved salts, sediment, bacteria, and pesticides (Table 5.7).

**Table 5.7. Selected parameters and abbreviations utilized for data analysis from the main water quality parameter types.**

| | | | |
|---|---|---|---|
| *Nutrients* | | *Turbidity (sediments)* | |
| Total nitrogen | TN | Total suspended solids | TSS |
| Nitrate-nitrogen | $NO_3$-N | *Bacteria* | |
| Total phosphorus | TP | *Escherichia coli* | *E. coli* |
| Total dissolved phosphorus | TDP | *Pesticides* | |
| *Salts* | | 2,4-Dichlorophenoxyacetic acid | 2,4-D |
| Total dissolved solids | TDS | Number of different pesticides[z] | # pest. |

[z] Parameter only used in some analysis.

There were a total of 16 sampling events in 2014, and these were grouped into five types of events for data analysis (Table 5.4). Average values for each sampling site were calculated for the entire season (March to November) without the flush event (n = 15) because this event had high variability, was not representative of the season, and would bias the average. Further, the shared upstream site (SMC-P1) for the three East Horsefly Main Canal segments located on the SMRID main canal did not have connective flow with the downstream sites for the pre- and post-

irrigation dates. Therefore, these samples were not included in the average values for these three canals (n = 10). This is described in further detail in the following sections.

#### 5.2.5.1 Influence of Reservoirs

Each reservoir inlet and outlet was monitored at a water quality sampling site on an associated irrigation canal segment (Figure 5.1; Table 5.2). Taber Lake Reservoir had three inlets (Lateral 15, 17, and 18) and two outlets (Big Bend, and Lateral M/Taber Lake Lateral). The Fincastle Reservoir had two inlets; one was a combination of three canals (Taber Lake Lateral, Lateral M, and Lateral 20), and the other one was Lateral 7. This reservoir has a single outlet serving two canals for the North Fincastle area.

The effects of the reservoirs on the irrigation water quality was analyzed by calculating the percentage change in concentration of water quality parameters between the average concentration of the inlets and the outlets for each specific sampling event types (Equation 5.6). The sample size was too small to complete statistical analysis but trends were described.

$$\%\,[change] = \frac{\overline{[O]} - \overline{[I]}}{\overline{[I]}} \times 100 \qquad \text{Equation 5.6}$$

Where:

% [change] = percentage change (increase or decrease) in concentration of a water quality parameter from the reservoir inlets to the outlets.

$\overline{[I]}$ = average inlet concentration of a specific water quality parameter.

$\overline{[O]}$ = average outlet concentration of a specific water quality parameter.

#### 5.2.5.2 Influence of Municipal Stormwater

A total of four sampling sites were used to assess the influence of municipal stormwater on irrigation water quality. Two sampling sites were established to monitor the water quality of stormwater ditches draining an area immediately east (T-LU2) and south east (T-LU3) of the Town of Taber (Figure 5.1). The water quality sampling site T-LU2 flowed directly into Taber Lake and site T-LU3 flowed into Lateral 15. Two sampling sites were used to monitor the change in the quality of water in Lateral 15 flowing to Taber Lake Reservoir. One site (T-S4) was located south of Highway 3 and upstream from where T-LU3 flowed into Lateral 15. The Lateral 15 downstream site (T-LU1) was located just north of the catch basin of Lantic's sugar beet processing facility (Roger's Sugar) before the water reached Taber Lake Reservoir. The

segment of canal between T-S4 and T-LU1 on Lateral 15 was 600 m long and the stormwater ditch monitored at T-LU3 was the main potential flow contributor to this canal segment.

Seasonal averages were calculated, but results from the samples collected during the flushing event (May 15–21) were excluded from the analysis since this event did not affect the stormwater sites. The stormwater sites had intermittent flow; and therefore, paired seasonal averages were also calculated for events when all four sites were flowing.

#### 5.2.5.3 Influence of Land Use

Water quality change was quantified as the difference between upstream and downstream concentrations in each segment. Eight of the nine segments were used in the land-use segment analysis. The ninth segment, Lateral 15, was not included in the land-use segment analysis because it was only used to assess the effects of municipal stormwater, as described above.

Averages of the differences in concentration were calculated for each sampling event type, including the pre-irrigation season (n = 4), the irrigation flush (n = 1), the main irrigation season (n = 10), runoff (n = 3), and for the entire season, not including the flush event (n = 15) (Table 5.4). The post-irrigation (n=1) event in November was not analyzed as there was a lack of flow connectivity between the sampling sites for several canal segments. During the flush event, the water quality at the downstream site changed rapidly after the flow first reached it. The rapid change in water quality made comparison between segments impossible for this event. The flush event was not included in the season average as the high concentrations measured and the variable results would have biased the comparison between segments.

Significant differences between the upstream and downstream sites for each segment for the entire season were then determined. The paired samples t-test compares the means between two related groups (i.e., upstream vs. downstream), and requires the differences between upstream and downstream values to be normally distributed (Zar 1999). For each canal segment, there were 15 or less sample pairs ($n \leq 15$). Since the sample pairs per segment was less than 50, the Shapiro-Wilk (S-W) test for normality was performed on the differences of the water quality parameters with $p<0.05$ used to determine if data were normally distributed (i.e., if $p<0.05$, reject the null hypothesis that the data were not normally distributed). If the distributions of differences for any water quality parameter did not show normality after the S-W test, those variables' original data were then log transformed, and the S-W test was performed on the differences of the log-transformed data.

A paired samples t-test was performed on water quality data with differences that were normally distributed (originally or after being log transformed) with $p<0.05$ used to determine test significance (i.e., there is a difference in the average water quality concentrations between the upstream and downstream sites).

For data with differences that were not normally distributed, either originally or after being log transformed, a different test was applied. Ideally, a non-parametric Wilcoxon signed-rank test would have been performed next, but this test requires the distribution of the differences to be symmetrical (Helsel and Hirsch 2002). After examining the shape and skewness of the differences of the data that could not be analyzed with the paired samples t-test, it was determined that none of the distributions of the differences were symmetrical (from original or transformed data), thus the Wilcoxon signed-rank test could not be performed. Alternatively, the sign test is typically used to determine if there is a median difference between paired observations, and is the alternative to the Wilcoxon signed-rank test, and does not require an assumption of symmetry or normality (Helsel and Hirsch 2002). Thus, a sign test was performed on all data with differences that were neither normally distributed nor symmetrical, with $p<0.05$ used to determine test significance (i.e., there is a median difference in water quality concentrations for the upstream and downstream sites). The types of tests performed on the data are shown in Table 5.8.

The canal and landscape parameters (Table 5.6) were used as independent variables in the statistical analyses since they do not change. The dependent variables were the nine water quality parameters listed in Table 5.7.

Correlation analyses were performed to identify potential relationships between canal or landscape characteristics and water quality. Specifically, correlations were performed on the average upstream-downstream differences of water quality for the eight segments for the irrigation, runoff, and entire season (except flush) sampling events. Correlation analysis is a statistical test that also requires the data to be normally distributed. The S-W test was first performed on the canal and landscape parameter data with $p<0.05$ used to determine normality. If the data were found to be not normally distributed, a log transformation was performed, and the S-W test was run on the newly transformed data. An S-W test ($p<0.05$) was then performed on the average differences of the water quality parameters. However, because the analysis was performed on differences, this introduced some negative values. A log-transformation cannot be applied to negative values. To account for negative values, a cube-root transformation was applied to any water quality variables that were found to be not normally distributed from the initial S-W test. Only those canal and landscape parameters, as well as water quality parameters that had normal distributions (originally or after transformation) were included in the correlation analysis. A correlation matrix was created, and significant correlations were determined at $p<0.05$ and $p<0.01$.

**Table 5.8. Type of statistical tests performed on the upstream and downstream season averages[z] of parameter concentrations for each canal segment.**

| Segment | TSS | TDS | TP | TDP | TN | $NO_3$-N | *E. coli* | 2,4-D |
|---|---|---|---|---|---|---|---|---|
| BB | P-S[y] | Sign[x] | Sign | Sign | Sign | Sign | P-S | P-S |
| NFEC | P-S | Sign | P-S | P-S | P-S | P-S | Sign | Sign |
| LatM | P-S | Sign | Sign | Sign | Sign | Sign | P-S | P-S |
| TLL | P-S | Sign | P-S | P-S | P-S | P-S | P-S | Sign |
| TMC_17 | P-S | P-S | P-S | P-S | Sign | P-S | P-S | Sign |
| EHMC_18 | P-S | Sign | P-S | Sign | Sign | P-S | P-S | Sign |
| EHMC_20 | P-S | P-S | Sign | P-S | P-S | P-S | P-S | P-S |
| EHMC_7 | P-S | P-S | P-S | P-S | P-S | Sign | P-S | Sign |

[z] Seasonal average does not include the flush event.
[y] P-S = paired-samples t-test.
[x] Sign = sign test.

## 5.3 Results and Discussion

### 5.3.1 Influence of Reservoirs on Irrigation Water Quality

There was a general decrease in concentration of all water quality parameters from the inlets to the outlets in Taber Lake Reservoir and of most parameters in Fincastle Reservoir (Tables 5.9 and 5.10). The decrease can likely be attributed to sedimentation, dilution, and chemical and biological processes in the reservoirs. The decrease was especially evident during periods when lower water quality flowed into the reservoirs including the spring flush event, runoff events, and the pre- and post-irrigation season sampling events. During the irrigation season when the incoming water quality was good, a slight increase in total dissolved solids (TDS), total dissolved phosphorus (TDP), and total nitrogen (TN) was observed at the outlet from the Taber Lake Reservoir. Similarly, during the irrigation season, Fincastle Reservoir had an increase in total suspended solids (TSS), total phosphorus (TP), TN, and *Escherichia coli* (*E. coli*) between the inlets and the outlet. Other parameters, such as 2,4-D, the number of pesticides per sample, and nitrate nitrogen ($NO_3$-N) were always at lower concentrations in the reservoir outlets as compared to the inlets. These results show that reservoirs generally act as sinks, absorbing suspended solids, nutrients, and pesticides during periods of runoff. However, during the dry season, when water quality is good, the reservoirs can become a small source of water quality contamination.

**Table 5.9. Water quality concentration change and percent difference from the inlet to outlet canals of Taber Lake Reservoir in 2014.**

| Water quality parameter | Pre-irrigation season | Flush event | Irrigation season | Post-irrigation season | Runoff events | Seasonal average[z] |
|---|---|---|---|---|---|---|
| | *Concentration difference (outlets – inlets)* | | | | | |
| Total suspended solids (mg $L^{-1}$) | -8.65 | -296 | -2.29 | -6.50 | -5.74 | -4.03 |
| Total dissolved solids (mg $L^{-1}$) | -570 | -1206 | 69.4 | -273 | -157 | -130 |
| Total phosphorus (mg $L^{-1}$) | -0.141 | -0.543 | -0.004 | 0.018 | -0.173 | -0.040 |
| Total dissolved phosphorus (mg $L^{-1}$) | -0.108 | -0.018 | 0.001 | 0.010 | -0.140 | -0.027 |
| Total nitrogen (mg $L^{-1}$) | -0.938 | -3.20 | 0.211 | -0.162 | -0.541 | -0.113 |
| Nitrate nitrogen (mg $L^{-1}$) | -0.289 | -0.334 | -0.029 | -0.375 | -0.132 | -0.131 |
| *Escherichia coli* (counts 100 $mL^{-1}$) | -7.60 | -3245 | -81.4 | -122 | -218 | -66.0 |
| 2,4-D (µg $L^{-1}$) | -0.327 | -0.238 | -0.633 | -0.291 | -2.46 | -0.539 |
| Number of different pesticides (#/sample) | -1.4 | -1.5 | -0.1 | -0.8 | -2.2 | -0.5 |
| | *Relative difference (difference ÷ inlets)* (%) | | | | | |
| Total suspended solids | -74 | -98 | -44 | -59 | -69 | -56 |
| Total dissolved solids | -73 | -85 | 33 | -51 | -40 | -33 |
| Total phosphorus | -73 | -96 | -6 | 33 | -71 | -41 |
| Total dissolved phosphorus | -79 | -48 | 2 | 35 | -74 | -42 |
| Total nitrogen | -49 | -84 | 41 | -14 | -41 | -12 |
| Nitrate nitrogen | -59 | -98 | -71 | -80 | -62 | -68 |
| *Escherichia coli* | -87 | -100 | -94 | -98 | -97 | -95 |
| 2,4-D | -100 | -88 | -79 | -100 | -98 | -83 |
| Number of different pesticides (#/sample) | -58 | -50 | -4 | -36 | -65 | -19 |
| Sampling events (n) | 4 | 1 | 10 | 1 | 3 | 15 |

[z] Seasonal average does not include the flush event.

**Table 5.10. Water quality concentration change and percent difference from the inlet to outlet canals of Fincastle Reservoir in 2014.**

| Water quality parameter | Pre-irrigation season | Flush event | Irrigation season | Post-irrigation season | Runoff events | Seasonal average[z] |
|---|---|---|---|---|---|---|
| | *Concentration difference (outlet – inlets)* | | | | | |
| Total suspended solids (mg $L^{-1}$) | 6.34 | -112 | 4.68 | -1.75 | -1.81 | -1.49 |
| Total dissolved solids (mg $L^{-1}$) | -516 | -553 | -18.7 | -553 | -85.2 | -221 |
| Total phosphorus (mg $L^{-1}$) | -0.292 | na[y] | 0.079 | -0.030 | -0.242 | -0.040 |
| Total dissolved phosphorus (mg $L^{-1}$) | -0.273 | -0.023 | -0.000 | -0.025 | -0.235 | -0.071 |
| Total nitrogen (mg $L^{-1}$) | -0.975 | -1.44 | 1.09 | -2.00 | -0.327 | 0.200 |
| Nitrate nitrogen (mg $L^{-1}$) | -0.377 | -0.093 | -0.010 | -1.97 | -0.104 | -0.260 |
| *Escherichia coli* (counts 100$mL^{-1}$) | -4.32 | -327 | 164 | -5.25 | -112 | 78.2 |
| 2,4-D (µg $L^{-1}$) | -0.050 | -0.005 | -0.269 | -0.106 | -0.265 | -0.200 |
| Number of different pesticides (#/sample) | -1.2 | -0.7 | -0.4 | 0.5 | -1.5 | -0.6 |
| | *Relative difference (difference ÷ inlets)* (%) | | | | | |
| Total suspended solids | 102 | -99 | 124 | -78 | -38 | -15 |
| Total dissolved solids | -77 | -75 | -8 | -70 | -29 | -53 |
| Total phosphorus | -88 | na[z] | 151 | -62 | -82 | -30 |
| Total dissolved phosphorus | -95 | -64 | -1 | -64 | -87 | -71 |
| Total nitrogen | -57 | -72 | 208 | -77 | -30 | 19 |
| Nitrate nitrogen | -87 | -95 | -26 | -95 | -47 | -87 |
| *Escherichia coli* | -61 | -98 | 261 | -64 | -92 | 131 |
| 2,4-D | -83 | -1 | -41 | -72 | -84 | -46 |
| Number of different pesticides (#/sample) | -55 | -40 | -14 | 20 | -60 | -23 |
| Sampling events (n) | 4 | 1 | 10 | 1 | 3 | 15 |

[z] Seasonal average does not include the flush event.

[y] na = not available.

Improvement of water quality was better in Taber Lake Reservoir than in Fincastle Reservoir for TSS, TP, TN, *E. coli* and 2,4-D but not for TDS, TDP, $NO_3$-N and pesticide diversity. On average for the season, there was a reduction of 12 to 95% for all parameters at the outlets compared to the inlets in Taber Lake Reservoir (Table 5.9). For Fincastle Reservoir, the concentrations of six parameters decreased by 15 to 87% (Table 5.10). The concentration increased by 19% for TN and by 131% for *E. coli* (Table 5.10). On average during the irrigation season, TSS, TP, TN, and *E. coli* concentrations were higher at the Fincastle Reservoir outlet sampling site (Site T-S3) than at the inlet canals (Sites T-LU6a, b, and c, and T-LU7). The source of bacterial contamination is currently being investigated in a separate study by Jokinen (2014).

### 5.3.2 Influence of Municipal Stormwater on Irrigation Water Quality

The concentrations of the two stormwater sampling sites, T-LU2 and T-LU3 (Figure 5.1), were generally greater than the concentration in the irrigation canal for most water quality parameters and for most sampling events. The average concentrations for most parameters at T-LU2 were higher than at T-LU3, except for TDS (Table 5.11). Compared to the downstream site on Lateral 15 (T-LU1), T-LU2 had seasonal average concentrations that were 1.4 to 44 fold higher depending on the parameter, with 2,4-D 36 fold higher and *E. coli* 44 fold higher. The average concentrations for $NO_3$-N, *E. coli*, and 2,4-D at T-LU2 were more than 100 fold higher than at T-LU1 during the irrigation season (data not shown). The concentrations at T-LU3 and T-LU1 were more comparable for TSS and nutrients in particular. The average number of pesticides detected per sample in the stormwater drains (T-LU2 and T-LU3) was higher than in Lateral 15 (T-S4 and T-LU1). There was an average of about 12 pesticides detected per sample at T-LU2 as compared to about three for the upstream site on Lateral 15 (Table 5.12).

There was an increase of water quality parameter concentrations from the upstream (T-S4) to the downstream (T-LU1) sampling sites on Lateral 15 (Table 5.11). Seasonal average concentrations among the parameters were 1.2 to 3.8 fold higher at T-LU1. The higher concentrations of the stormwater site T-LU3, which flowed into Lateral 15, may explain some of the increase in the concentrations. However, increase from upstream to downstream cannot be explained by contributions from T-LU3 for three of the parameters (TSS, TN, $NO_3$-N), since the concentration of these parameters in the storm drain were less than the upstream site. Furthermore, slight increase in salinity and nutrient concentrations from T-S4 to T-LU1 was also observed when T-LU3 was not flowing. Therefore, the increase in concentration observed in the short segment of Lateral 15 cannot solely be attributed to the stormwater quality from T-LU3. The mass contribution from T-LU3 can only explain 1 to 7% of the increase in concentration from T-S4 to T-LU1 for most parameters except 2,4-D with 18%. The average number of pesticides detected increased from 2.8 to 3.8 from site T-S4 to T-LU1 on Lateral 15. This increase may be explained by the stormwater drain T-LU3, which had an average of about five pesticides per sample.

It is difficult to identify the source of the increase in concentration not explained by the stormwater contribution (T-LU3), considering the short distance between the sites and the absence of other known contributions. However, the flow was observed to be a lot more turbulent at the downstream site, T-LU1, than the upstream site (T-S4) which could potentially disturb bottom sediments and increase turbidity. The results suggest that stormwater only represented a fraction of the contamination measured. The most important impact was the increase of pesticide concentration and diversity.

**Table 5.11. Average seasonal and paired seasonal water quality concentrations from municipal stormwater and Lateral 15 in 2014.**

| | Seasonal average[z] | | | | Paired seasonal average[y] | | | |
|---|---|---|---|---|---|---|---|---|
| | Lat15 upstream T-S4 | Storm-water T-LU3 | Lat15 downstream T-LU1 | Storm-water T-LU2 | Lat15 upstream T-S4 | Storm-water T-LU3 | Lat15 downstream T-LU1 | Storm-water T-LU2 |
| Flow ($m^3s^{-1}$) | 1.28 | 0.0057 | 1.29 | 0.0036 | 0.560 | 0.0078 | 0.568 | 0.0036 |
| Total suspended solids (mg $L^{-1}$) | 6.9 | 9.6 | 10.7 | 22.9 | 7.3 | 5.9 | 14.2 | 22.9 |
| Total dissolved solids (mg $L^{-1}$) | 509 | 2010 | 667 | 982 | 712 | 1334 | 983 | 982 |
| Total phosphorus (mg $L^{-1}$) | 0.08 | 0.18 | 0.14 | 1.37 | 0.08 | 0.21 | 0.20 | 1.37 |
| Total dissolved phosphorus (mg $L^{-1}$) | 0.04 | 0.13 | 0.09 | 1.24 | 0.04 | 0.17 | 0.13 | 1.24 |
| Total nitrogen (mg $L^{-1}$) | 1.03 | 1.43 | 1.27 | 21.7 | 1.38 | 1.34 | 1.78 | 21.7 |
| Nitrate nitrogen (mg $L^{-1}$) | 0.26 | 0.22 | 0.36 | 10.4 | 0.47 | 0.28 | 0.62 | 10.4 |
| *Escherichia coli* (CFU 100 $mL^{-1}$) | 19 | 324 | 72 | 3190 | 22 | 386 | 114 | 3190 |
| 2,4-D (µg $L^{-1}$) | 0.14 | 2.58 | 0.24 | 8.69 | 0.20 | 2.66 | 0.40 | 8.69 |
| Pesticides detected per sample (count) | 2.5 | 4.9 | 2.6 | 11.6 | 2.8 | 4.8 | 3.8 | 11.6 |

[z] This seasonal average includes all samples collected except during the flush event (n=8 to15)
[y] The paired seasonal average only include samples on dates when all four sites were flowing (n=8).

Both T-LU1 and T-LU2 sites flowed directly and independently into Taber Lake Reservoir but the concentrations from T-LU2 were up to 44 fold higher. In contrast, the average flows of the two stormwater sites were more than 200 fold smaller than the average flow in Lateral 15 at T-LU1. The stormwater site T-LU2 had a small flow and it only flowed during eight of the 15 sampling events. Therefore, the overall loads from the stormwater sites were smaller than the loads from Lateral 15. Outside of the irrigation season however, when the flow in Lateral 15 was only 6.5 fold higher than the stormwater site T-LU2, the loads of T-LU2 and T-LU1 were more comparable with 3 to 151% difference between them (data not shown). Conversely, the export coefficient or load per unit of contributing area would likely be higher for the stormwater than

the irrigation water given the small size of the town versus the large area of agricultural land base that may contribute to runoff into the canals. The actual drainage areas of agricultural land were not delineated due to the flat topography, as described in Sub-section 5.2.4.

### 5.3.3 Influence of Canal and Landscape Characteristics on Irrigation Water Quality

#### 5.3.3.1 Canal and Landscape Characteristics

The three longest canal segments began as the first part of the East Horsefly Main Canal, sharing an upstream site (SMC-P1) (Figure 5.1). The lengths of these canals were 17.6, 19.7, and 20.2 km, respectively, for EHMC_18, EHMC_7, and EHMC_20 (Table 5.12). These canals along with TMC_17 were all immediately downstream of the SMRID main canal, which served as source water. The shortest canal segments were between the two reservoirs, with lengths of 5.2 km and 6.7 km for TLL and LatM, respectively, and these two canals shared T-S5 as an upstream site. The canal flow capacities were generally proportional to the canal length. The proportion of each segment that was constructed of earth material was more variable, ranging from 11 (NFEC) to 100% (TLL and EHMC_18).

Longer canals were generally observed to have more drainage inlets than the shorter canals, with the exception of TLL, which was only 5.2 km long, but had 24 drainage inlets; whereas, BB was 16.2 km long and had 23 drainage inlets, for example (Table 5.12). The drainage point density was highest for TLL with 4.6 drain inlets per kilometre and lowest for EHMC_7 with 0.71 drain inlets per kilometre. Potential flow contribution (i.e., cumulative culvert cross section area) from drain inlets was generally higher for the longer canal segments. Slope was fairly uniform for each segment area, with mean slope ranging from 0.8 degrees (TMC_17) to 1.8 degrees (LatM). Road density was the lowest (0.7 km $km^{-2}$) for the three EHMC and the highest (1.2 km $km^{-2}$) for the TLL.

Annual crops represented the majority of crops grown for nearly all canal segment areas except for LatM, which only had 36% of the crops as annuals (Table 5.12). The majority of the land adjacent to LatM was used as pasture for livestock and horses. The majority of crops in all eight segment areas were irrigated ranging from 71 to 90%. Along the four southern canals (TMC_17, EHMC_7, EHMC_18, and EHMC_20), crops included mainly cereal and specialty crops. Compared to the southern segments, there was less annual crop land surrounding LatM and TLL between the two reservoirs. There was more pasture land along LatM compared to TLL, and a main highway and train tracks were near TLL. Finally, canal segments BB and NFEC, located downstream of the reservoirs, had slightly higher proportions of irrigated crops, which include specialty (potatoes, corn) and cereal crops, as well as some pasture.

**Table 5.12. Canal and landscape parameter values for each of the eight canal segments.**

| | Canal segment[z] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | BB | NFEC | LatM | TLL | TMC_17 | EHMC_18 | EHMC_20 | EHMC_7 |
| *Canal parameters* | | | | | | | | |
| Segment length (km) | 16.2 | 16.0 | 6.7 | 5.2 | 16.6 | 17.6 | 20.2 | 19.7 |
| Canal flow capacity ($m^3$ $s^{-1}$) | 4.3 | 2.0 | 1.1 | 0.3 | 3.7 | 8.9 | 7.7 | 10.3 |
| Length of lined canal (km) | 8.1 | 14.3 | 3.6 | 0.0 | 7.6 | 0.0 | 2.0 | 3.6 |
| Length of earth canal (km) | 8.2 | 1.8 | 3.1 | 5.2 | 9.0 | 17.6 | 18.1 | 16.2 |
| Proportion of earth canal (%) | 50 | 11 | 46 | 100 | 54 | 100 | 90 | 82 |
| *Landscape parameters* | | | | | | | | |
| Number of drainage points (No.) | 23 | 21 | 7 | 24 | 22 | 33 | 32 | 14 |
| Drainage point density (No. per $km^{-1}$ of canal) | 1.4 | 1.3 | 1.0 | 4.6 | 1.3 | 1.9 | 1.6 | 0.7 |
| Drain inlet flow potential (cumulative culvert cross section area) ($m^2$) | 0.5 | 0.9 | 0.3 | 2.6 | 1.4 | 4.5 | 4.1 | 3.0 |
| Average land slope (°) | 1.1 | 1.5 | 1.8 | 1.0 | 0.8 | 0.9 | 0.9 | 1.1 |
| Proportion of crops that are annual (%) | 58 | 74 | 36 | 73 | 87 | 80 | 87 | 78 |
| Proportion of crops that are irrigated (%) | 84 | 90 | 71 | 88 | 83 | 76 | 83 | 71 |
| Road length (km) | 26.4 | 23.4 | 10.2 | 12.4 | 32.5 | 19.3 | 23.1 | 22.6 |
| Road density (km $km^{-2}$) | 1.0 | 0.9 | 0.8 | 1.2 | 1.2 | 0.7 | 0.7 | 0.7 |

[z] BB = Big Bend Canal, NFEC = North Fincastle East Canal, LatM = Lateral M, TLL = Taber Lake Lateral, EHMC_7 = East Horsefly Main Canal to Lateral 7, EHMC_18 = East Horsefly Main Canal to Lateral 18, EHMC_20 = East Horsefly Main Canal, Lateral 2, and Lateral 20.

### 5.3.3.2 Effects on Water Quality

### Sampling Event Types

The highest average concentrations were observed during the flush event for TSS, TDS, TP, TN, and *E.coli* compared to other event types (Table 5.13). The highest average concentration for TDP and $NO_3$-N was for the pre-irrigation events, but the highest average concentration for 2,4-D was during runoff events. Sediments at the bottom of canal got stirred up during the flush, dissolved nutrients could have leached from the soil in the early spring and pesticides were more likely coming from surface runoff of adjacent land. Lowest average concentrations were mainly observed during the irrigation events. Lower concentrations of *E. coli* during the pre-irrigation events were likely attributed to cooler temperatures that were not favorable for bacterial growth.

On average among all eight canal segments, there was an increase in concentration from the upstream to downstream sites for nearly all parameters except TSS for the pre-irrigation, flush, and runoff events, and TN for the irrigation season (Table 5.13). Of the eight parameters, six parameters (TSS, TDS, TP, TN, $NO_3$-N, and *E. coli*) increased the most during the flush event, and six parameters (TSS, TDS, TP, TDP, TN, $NO_3$-N) changed the least during the irrigation event. Generally, percent increases were intermediate for pre-irrigation and runoff events, with the latter tending to have larger percentage increases than the former.

During the pre-irrigation sampling event, the average percentage change in concentration from upstream to downstream ranged from -11 to 703% (Table 5.13). The larger changes occurred for dissolved in comparison to total nutrients. TDP increased 8 fold and TP by 4 fold followed by *E.* coli and 2,4-D that increased by 250 and 144% respectively. The only parameter with an average concentration that decreased was TSS by -11%. The concentration of TSS was often higher at the upstream sites, T-S1, T-S3 and SMC-P1, and there were likely some opportunities for sediment to settle in the canal segments which counteracts the potential contamination as observed with other parameters. The pre-irrigation sampling events were mainly representative of water that remained in the canals after the irrigation water was shut off the previous fall, as well as water from snowmelt, rainfall and groundwater seepage. Irrigation canals are subject to significant snow drifting that occurs in southern Alberta throughout the winter, but small flow remained in the canal well after the snow melt period. Groundwater was observed to maintain flow in the irrigation canals and groundwater in other irrigated areas was typically high in $NO_3$-N concentration (AARD 2014b).

The highest average increase in concentration, compared to the other event types, occurred during the flush event for TSS, TDS, TP, TN, $NO_3$-N, and *E. coli*. For TDP and $NO_3$-N, the largest increase was measured for the pre-irrigation season event type. The flush event included any pre-irrigation water still residing in the canals along with the initial water released from reservoirs and the SMRID main canal in the early spring. The flush water contained wind-blown debris accumulated in the canals during the fall, winter, and early spring. The turbidity was very high when the initial flow reached the downstream sampling sites and visually improved in the minutes and hours after. Since the time elapsed between the arrival of water at the downstream site and the collection of sample varied for the different canal segments, comparison of parameter concentrations between canal segments was biased by the rapid change in water quality observed and limited analysis could be performed on the flush event. Time series sampling during the flush would be helpful to understand how water quality changes after water reaches the downstream site.

The results suggest that the poorest quality water, for most parameters, was present in irrigation canals in the pre-irrigation and flush events. However, irrigation does not occur during the pre-irrigation and flush events, though water flow during these events will enter reservoirs or enter the natural drainage through returns.

**Table 5.13. Average concentration of water quality parameters among all sites (upstream and downstream) and average change in concentrations (absolute and percent) from upstream to downstream among the canal segments for each sampling event type in 2014.**

| | TSS | TDS | TP | TDP | TN | $NO_3$-N | *E. coli* | 2,4-D |
|---|---|---|---|---|---|---|---|---|
| | *Average concentration (all sites)* | | | | | | | |
| | ---------- (mg $L^{-1}$) ---------- | | | | | | ($CFU\ 100\ mL^{-1}$) | ($\mu g\ L^{-1}$) |
| Pre-irrigation | 9.0 | 620 | 0.184 | 0.131 | 1.80 | 0.37 | 6 | 0.15 |
| Flush | 112.3 | 876 | 0.265 | 0.026 | 1.89 | 0.15 | 725 | 0.10 |
| Irrigation season | 15.5 | 300 | 0.079 | 0.037 | 0.82 | 0.04 | 127 | 0.42 |
| Runoff | 6.4 | 285 | 0.149 | 0.106 | 1.19 | 0.15 | 113 | 0.72 |
| Season average[z] | 6.0 | 342 | 0.088 | 0.058 | 1.03 | 0.17 | 50 | 0.38 |
| | *Average concentration difference (downstream – upstream)*[y] | | | | | | | |
| | ---------- (mg $L^{-1}$) ---------- | | | | | | ($CFU\ 100\ mL^{-1}$) | ($\mu g\ L^{-1}$) |
| Pre-irrigation | -1.0 | 473 | 0.232 | 0.232 | 0.44 | 0.30 | 5 | 0.13 |
| Flush | 186.7 | 848 | 0.452 | 0.021 | 2.27 | 0.22 | 1540 | 0.07 |
| Irrigation season | -1.7 | 13 | 0.001 | 0.009 | -0.19 | 0.02 | 19 | 0.53 |
| Runoff | -0.0 | 77 | 0.145 | 0.152 | 0.10 | 0.15 | 98 | 1.11 |
| Season average[z] | -1.6 | 136 | 0.046 | 0.051 | 0.00 | 0.17 | 17 | 0.45 |
| | *Average percent difference (difference ÷ upstream)*[y] | | | | | | | |
| | ---------- (%) ---------- | | | | | | | |
| Pre-irrigation (n=18) | -11 | 130 | 270 | 703 | 27 | 125 | 250 | 144 |
| Flush (n=7) | 153 | 101 | 191[x] | 91 | 128 | 129 | 142 | 58 |
| Irrigation season (n=74) | -20 | 5[w] | 2[v] | 26 | -21 | 67[w] | 37 | 331 |
| Runoff (n= 21) | 0 | 33 | 161 | 411 | 8 | 136 | 185 | 854 |
| Season average[z] (n= 95) | -25 | 49[u] | 65[t] | 146 | 0 | 189[u] | 40 | 300 |

[z] Season average does not include the flush event that occurred from May 15 to 21.
[y] Positive values indicate an increase in concentration from upstream to downstream.
[x] n = 6 for TP during the flush.
[w] n = 68 for TDS and $NO_3$-N during irrigation.
[v] n = 73 for TP during irrigation.
[u] n = 89 for TDS and $NO_3$-N for the season.
[t] n = 92 for TP for the season.

During the runoff events, an increase in water quality concentration was measured from the upstream to downstream sites for nearly all parameters except TSS (Table 5.13). The increase in concentration was less than during the pre-irrigation season, except for *E. coli* and 2,4-D. The largest increase of 2,4-D concentration was observed during runoff events. The concentration of 2,4-D among the canal segments peaked on June 17 (runoff event) or July 7 for most sampling sites (data not shown). Interestingly, the peak was observed on June 17 for sites located upstream

of the Taber Lake Reservoir. For nearly all other sites, except T-R1, the highest concentration of 2,4-D was measured on July 7. The largest concentrations were measured on July 7 at the stormwater sites (T-LU2 and T-LU3) as well, suggesting that there was a delay between the runoff event and its effect on water quality, in particular downstream of the reservoirs.

There were three separate runoff events and their effect on water quality differed depending on parameters. A more important increase in TDS concentration was observed during the June and September runoff events as compared to the other irrigation sampling events. The increase was smaller for the March runoff event, as compared to the other pre-irrigation events. This could be explained by a lower salinity concentration in the snowmelt runoff as compared to the water in the canal. Similar results were observed for $NO_3$-N. The TP and TDP concentration increased for all runoff events but was larger in the first runoff event in March and least in the June runoff events. Similar to 2,4-D, a larger increase in TDP concentration was observed in the sampling event following the June runoff sampling event. The concentration of *E. coli* increased more during the June and September runoff events than the other irrigation sampling events. However, no increase in concentration was measured during the runoff event of the pre-irrigation period.

Runoff volumes were not measured during this study; however, based on field observations, runoff entering the canals from the landscape was very small as compared to the volume of water flowing in the canals. This likely resulted in a large dilution effect of runoff water entering the canals in particular during the irrigation events. Larger runoff events could have more effect on water quality.

Direct measurement of runoff volume and quality would be useful to study the effect of runoff on water quality in the irrigation canal. To really understand the relationship between water quality and land use, the drainage contributing area of each runoff drainage point would need to be characterized. This was tried (Sub-section 5.2.4), but in a flat and artificially drained landscape where road ditches and culverts create a complex drainage network, as in the current study, contributing areas are difficult to define (Duke et al. 2006).

During the irrigation sampling events, average concentration for most parameters increased, except for TSS and TN (Table 5.13). However, the average percent changes were smaller than 30%, for most parameters, except for $NO_3$-N, *E. coli*, and 2,4-D, which all showed larger average percent changes in concentration, ranging from 37 to 331%. A larger increase for 2,4-D was expected during the irrigation season since it coincided with the period when pesticides are applied to crops and along canal banks. At the end of the irrigation season, the flow was increased to flush the infrastructure before shutting flow down. Samples collected at the end of this event on Oct 9, revealed parameter concentrations among the lowest of the entire irrigation season but only slightly lower than the previous irrigation sampling event.

## Canal Segments

Six of the eight segments showed statistically significant increases in concentration from upstream to downstream for seven of the water quality parameters (Tables 5.14 and 5.15). There were no significant differences for any of the water quality parameters within TMC_17 and NFEC, and no significant differences for average TP concentrations within any of the segments. There was only one instance of a significant decrease in concentration, and this was for TSS in EHMC_20.

**Table 5.14. Average concentration of total suspended solids (TSS), total dissolved solids (TDS), total phosphorus (TP), and total dissolved phosphorus (TDP) for paired samples at the upstream (US) and downstream (DS) sites for the canal segments for the whole sampling season (except the flush event) in 2014.**

| | TSS | | TDS | | TP | | TDP | |
|---|---|---|---|---|---|---|---|---|
| | US | DS | US | DS | US | DS | US | DS |
| Segment | ---------- (mg $L^{-1}$)[z] ---------- | | | | | | | |
| BB | 2.75 | 4.74 | 298 | 673b | 0.071 | 0.095 | 0.045 | 0.076 |
| NFEC | 9.94 | 5.15 | 195 | 260 | 0.107 | 0.067 | 0.033 | 0.032 |
| LatM | 3.28 | 3.54 | 231 | 365b | 0.050 | 0.244 | 0.033 | 0.208 |
| TLL | 3.28 | 5.04 | 231 | 515b | 0.050 | 0.164 | 0.033 | 0.130a |
| TMC_17 | 8.54 | 5.09 | 190 | 211 | 0.079 | 0.076 | 0.030 | 0.054 |
| EHMC_18 | 8.72 | 5.78 | 172 | 185b | 0.038 | 0.072 | 0.020 | 0.043b |
| EHMC_20 | 8.72 | 3.61a | 172 | 196a | 0.038 | 0.043 | 0.020 | 0.032a |
| EHMC_7 | 8.72 | 5.67 | 172 | 176 | 0.038 | 0.037 | 0.020 | 0.024a |

[z] Averages for each parameter per segment followed by letters are significantly different ($p \leq 0.05$), with 'a' indicating a significant paired-samples test (parametric), and 'b' indicating a significant sign test (non-parametric).

**Table 5.15. Average concentration of total nitrogen (TN), nitrate nitrogen ($NO_3$-N), *Escherichia coli* (*E. coli*), and 2,4-D herbicide for paired samples at the upstream (US) and downstream (DS) sites for the canal segments for the whole sampling season (except the flush event) in 2014.**

| | TN | | $NO_3$-N | | *E. coli* | | 2,4-D | |
|---|---|---|---|---|---|---|---|---|
| | US | DS | US | DS | US | DS | US | DS |
| Segment | ---------- (mg $L^{-1}$)[z] ---------- | | | | (CFU 100 $mL^{-1}$)[z] | | ----- (µg $L^{-1}$)[z] ----- | |
| BB | 0.89 | 1.12 | 0.11 | 0.31a | 3 | 40a | 0.12 | 0.29a |
| NFEC | 1.40 | 1.09 | 0.04 | 0.06 | 171 | 28 | 0.29 | 0.26 |
| LatM | 0.77 | 0.92 | 0.05 | 0.12 | 4 | 28a | 0.12 | 0.14 |
| TLL | 0.77 | 1.73a | 0.05 | 0.84a | 4 | 71a | 0.12 | 0.24a |
| TMC_17 | 1.91 | 0.77 | 0.05 | 0.09 | 30 | 58 | 0.14 | 0.92 |
| EHMC_18 | 0.30 | 0.36 | 0.02 | 0.03 | 37 | 126 | 0.10 | 1.25 |
| EHMC_20 | 0.30 | 0.37 | 0.02 | 0.04 | 37 | 54 | 0.10 | 1.22a |
| EHMC_7 | 0.30 | 0.31 | 0.02 | 0.02 | 37 | 55 | 0.10 | 0.88a |

[z] Downstream averages for each parameter per segment followed by 'a' are significantly different from the corresponding upstream averages ($p \leq 0.05$).

Specifically, there were significant increases from upstream to downstream in BB for TDS, $NO_3$-N, *E. coli*, and 2,4-D; in LatM for TDS and *E. coli*; in TLL for TDS, TDP, TN, $NO_3$-N, *E. coli* and 2,4-D; in EHMC_18 for TDS, and TDP; in EHMC_20 for TDS, TDP and 2,4-D; and in EHMC_7 for TDP and 2,4-D (Tables 5.14 and 5.15). The increase in concentrations of TDS, TDP, *E. coli*, and 2,4-D occurred most often among the canals (three or four out of eight canals).

Of the comparisons between upstream and downstream that were not significantly different, a majority tended to have higher values at the downstream sites for nearly all parameters (Tables 5.14 and 5.15). The only exception was for TSS, which had higher concentrations at the upstream sites, for the NFEC and the four southern segments (TMC_17, EHMC_18, EHMC_20, and EHMC_7) though only EHMC_20 was significantly different.

Average concentrations for all water quality parameters increased in the BB canal, especially for TDS and TSS, which showed the largest increases among all segments. Aside from the flush event, the increase in TSS was more prevalent during the irrigation season compared to the other segments (Table 5.16). Notably, the water quality from the upstream site exiting Taber Lake at T-S2 had low suspended solids. Apart from the stormwater sites, the highest concentration TDS was generally observed at T-R1. The BB segment had the second-highest increase in TN and $NO_3$-N among all segments for the entire season but the increase was only significant for $NO_3$-N.

The two canal segments in the north half of TID (NFEC and BB) shared similar characteristics (Table 5.12) such as length, proportion of irrigated crops, number of drainage points, and upstream sites start immediately downstream of a reservoir. However, the NFEC had the lowest proportion of earth canal (11%) among all segments compared to 50% for BB, and the highest proportion of irrigated crops. Water quality tended to improve from upstream to downstream for most parameters in NFEC, except for TDS and $NO_3$-N (Tables 5.14 and 5.15). This is the only canal segment that showed decreases in concentrations for most parameters. However, these upstream-downstream differences in NFEC were not significantly different for any of the parameters. In contrast, as indicated above, the average concentration for four of the eight parameters were significantly greater at the downstream site in BB. The other four parameters also had lower concentrations at the downstream sites, but were not significantly different from the upstream site. One likely reason for the differences in upstream-to-downstream changes in water quality between these two canals is that NFEC had a low proportion of earth structure and resulted in no significant differences; whereas, the higher proportion of earth structure in BB caused water quality degradation. Another reason could be the difference in water quality at the upstream site. Higher concentrations of TSS, TN, TP, *E. coli*, and 2,4-D were observed at the Fincastle Reservoir outlet (T-S3) compared to the Taber Lake Reservoir outlet (T-R2). Visual observation revealed high concentration of blue-green algae, poor odor and high turbidity in water collected from T-S3 site. Large populations of waterfowl were typically observed on the

Fincastle Reservoir throughout the season. Degradation of water quality along a canal segment could have been offset by different physical, chemical and biological processes. For example, sedimentation or filtering could occur when the source water is high in suspended solids. This would reduce the concentration of TSS, and total nutrients. Other processes could have reduced the concentration of *E. coli* and 2,4-D along the NFEC considering the relatively high concentrations at the upstream site.

The two segments that flowed from Taber Lake Reservoir to Fincastle Reservoir, LatM and TLL, showed an increase in concentration for all parameters (Tables 5.14 and 5.15). Two parameters in LatM and six parameters in TLL were significantly increased from upstream to downstream. Compared to the other segments, the average increase in concentration for the season for TP and TDP were the largest in LatM and the second largest in the TLL. Further, during runoff events, concentrations for each parameter, including TP and TDP, were slightly higher in the TLL segment than in the LatM segment (Table 5.16). The largest increases in average concentrations for TN and $NO_3$-N among all segments for the season were observed in TLL. Apart from the pre-irrigation event, the largest increase of $NO_3$-N was also measured in TLL during runoff, and over the entire season.

Although not significant, the increases in concentration of TSS on average for the season were only measured in three segments including TLL and LatM. Apart from the flush event, the largest increase in TSS was measured in TLL during the pre-irrigation season. For TDS, the largest significant increase during the entire season, pre-irrigation, and runoff events occurred in BB, while the second and third largest increases in TDS during these events occurred in TLL and LatM, respectively. For *E. coli* during the season, the second highest significant increase was measured in TLL. Significant increases in 2,4-D concentrations were also measured in TLL on average for the season.

The LatM and TLL segments had several characteristics that differed from the other segments. The two segments share the same upstream site, T-S5, at the east outlet of Taber Lake (Figure 5.1). They were the two shortest segments studied (Table 5.12), but despite their short length they were often among the segments that had the largest changes in water quality, especially for TLL. They had the lowest flow volumes, therefore, the lowest dilution effects, potentially contributing to the larger changes in water quality. Taber Lake Lateral was the only segment that has not been rehabilitated and remains entirely as earth canal, compared to LatM, which is more than 50% lined. This could explain the higher increase in nutrients and sediments observed in this segment. The absence of a synthetic liner would allow groundwater to seep into the canal, particularly during the pre-irrigation and irrigation season. This could also explain the observed increases in $NO_3$-N and TN. Groundwater was considered one of the main source of water flowing in the canals outside of the irrigation season. Nitrate-nitrogen has been shown to be associated with subsurface or shallow groundwater drainage. Nitrate in artificially drained areas

travels directly from the landscape into pipe drains and into field-adjacent streams or canals (Billy et al. 2013; Rassam et al. 2006). This earth canal was also not armored with rocks or concrete on the sides, thus the steep canal banks would be more susceptible to erosion especially during periods of runoff. Increases in concentration of TSS, TP, and TN were observed during the runoff events in TLL, and concentrations were usually the highest among all other segments. Taber Lake Lateral also had the largest drainage point density and one of the highest road density values (Table 5.12). There were several drain inlets that allowed the water to enter this segment, explaining why the largest increases in TP, TDP, TN, and $NO_3$-N were observed in this segment during runoff (Table 5.16). The majority of the runoff likely comes from the ditches along Highway 3 and the drains along the Canadian Pacific Railway tracks, which are both near TLL. These results support the hypothesis that the proportion of earth canal, drain inlet density, and road density in the segment influences water quality.

Lateral M had the lowest proportion of annual crops (Table 5.12) and the land-use inventory indicated several pastures used for cattle and horse grazing. Although fences restrict animal access to the canal, as in most of the TID, the pastures were sloped and drained toward the canal. The concentrations of *E. coli* significantly increased from upstream to downstream in LatM and TLL (Table 5.15). Even though LatM had a higher proportion of pasture land than TLL, the latter had a larger increase in *E. coli* concentration. One explanation for this is that the upstream portion of TLL had a pasture occupied by cattle, which had direct access to the channel. This suggests that direct access of cattle to canals causes a high risk for water quality degradation. In addition, to LatM and TLL, BB was the only other canal segment that had a significant increase in *E. coli* concentration as water moved downstream. The BB segment had the second lowest proportion in cropland (58%) further supporting the influence of pasture land.

Water quality along the TMC_17 segment remained relatively constant from the SMRID main canal diversion at T-S1 to Taber Lake Reservoir at T-LU4 with no significant differences for any parameters (Table 5.14 and 5.15). Low degradation and even some improvement for certain water quality parameters (TSS, TP, and TN) were measured. The relatively high turbidity at T-S1 could explain why concentrations of TSS, TN and TP, which are typically linked with turbidity, decreased. Sediments could have settled between the upstream and downstream sampling sites of TMC_17 reducing the concentration of TSS, TP and TN. The other parameters increased. Although not significant, the increase of 2,4-D was comparable to the EHMC segments. This increase was especially important during the runoff events. This can be explained by large proportion of annual crops (>77%) along these canal segments.

**Table 5.16. Average difference in water quality concentrations for each segment in each sampling event.**

| Parameter | Season | BB | NFEC | LatM | TLL | TMC_17 | EHMC_18 | EHMC_20 | EHMC_7 |
|---|---|---|---|---|---|---|---|---|---|
| TSS ($mg\ L^{-1}$) | Pre-irr | 3.6 | -10.8 | 1.3 | 5.5 | -6.0 | --[z] | -- | -- |
| | Flush | 238.0 | 1.0 | 220.0 | 5.0 | 141.0 | 597.0 | -- | 105.0 |
| | Irrigation | 2.0 | -2.8 | 0.2 | 0.5 | -2.5 | -2.9 | -5.1 | -3.1 |
| | Runoff | 2.6 | -11.7 | 3.4 | 4.4 | -3.3 | 5.3 | 1.3 | 0.3 |
| | Season[y] | 2.0 | -4.8 | 0.3 | 1.8 | -3.5 | -2.9 | -5.1 | -3.1 |
| TDS ($mg\ L^{-1}$) | Pre-irr | 1026 | 251 | 366 | 757 | 47 | -- | -- | -- |
| | Flush | 2704 | 16 | 522 | 130 | 634 | 1024 | -- | 904 |
| | Irrigation | 19 | 3 | 11 | 22 | 10 | 12 | 245 | 4 |
| | Runoff | 179 | 42 | 126 | 147 | -15 | 21 | 58 | 8 |
| | Season | 375 | 65 | 134 | 284 | 21 | 12 | 24 | 4 |
| TP ($mg\ L^{-1}$) | Pre-irr | 0.168 | 0.023 | 0.618 | 0.325 | -0.041 | -- | -- | -- |
| | Flush | 0.577 | -- | 0.597 | 0.064 | 0.465 | 0.803 | -- | 0.205 |
| | Irrigation | -0.007 | -0.063 | 0.006 | 0.019 | 0.012 | 0.034 | 0.005 | -0.001 |
| | Runoff | 0.144 | -0.073 | 0.375 | 0.402 | 0.066 | 0.105 | 0.045 | 0.002 |
| | Season | 0.024 | -0.040 | 0.194 | 0.113 | -0.003 | 0.034 | 0.005 | -0.001 |
| TDP ($mg\ L^{-1}$) | Pre-irr | 0.158 | 0.014 | 0.591 | 0.279 | 0.045 | -- | -- | -- |
| | Flush | 0.006 | 0.019 | 0.018 | 0.022 | 0.047 | 0.021 | -- | 0.011 |
| | Irrigation | -0.002 | -0.006 | 0.010 | 0.019 | 0.014 | 0.022 | 0.012 | 0.004 |
| | Runoff | 0.138 | 0.002 | 0.359 | 0.376 | 0.108 | 0.080 | 0.036 | 0.005 |
| | Season | 0.030 | -0.001 | 0.174 | 0.097 | 0.023 | 0.022 | 0.012 | 0.004 |
| TN ($mg\ L^{-1}$) | Pre-irr | 0.81 | 0.83 | 0.60 | 1.79 | -1.63 | -- | -- | -- |
| | Flush | 4.75 | 0.07 | 1.60 | 0.24 | 4.63 | 2.30 | -- | 2.30 |
| | Irrigation | -0.02 | -0.69 | -0.02 | 0.04 | -0.94 | 0.06 | 0.07 | 0.01 |
| | Runoff | 0.60 | -0.55 | 0.67 | 0.89 | -1.19 | 0.24 | 0.24 | 0.00 |
| | Season | 0.23 | -0.31 | 0.15 | 0.96 | -1.14 | 0.06 | 0.07 | 0.01 |
| $NO_3$-N ($mg\ L^{-1}$) | Pre-irr | 0.25 | 0.08 | 0.20 | 0.84 | 0.07 | -- | -- | -- |
| | Flush | 0.28 | 0.04 | 0.02 | 0.03 | 0.54 | 0.42 | -- | 0.23 |
| | Irrigation | 0.02 | 0.00 | 0.00 | 0.07 | 0.03 | 0.01 | 0.02 | 0.00 |
| | Runoff | 0.16 | 0.05 | 0.26 | 0.40 | 0.09 | 0.08 | 0.10 | 0.00 |
| | Season | 0.19 | 0.02 | 0.07 | 0.79 | 0.04 | 0.01 | 0.02 | 0.00 |
| *E. coli* (CFU $100\ mL^{-1}$) | Pre-irr | -1 | 4 | 1 | 18 | 2 | -- | -- | -- |
| | Flush | 90 | 4 | 100 | 86 | 8595 | 1100 | -- | 810 |
| | Irrigation | 48 | -191 | 37 | 95 | 39 | 89 | 17 | 17 |
| | Runoff | 82 | -55 | 42 | 184 | 148 | 366 | 36 | 26 |
| | Season | 37 | -143 | 24 | 67 | 28 | 89 | 17 | 17 |
| 2,4-D ($\mu g\ L^{-1}$) | Pre-irr | 0.13 | 0.16 | 0.04 | 0.04 | 0.30 | -- | -- | -- |
| | Flush | 0.08 | 0.00 | -0.02 | 0.00 | 0.15 | 0.25 | -- | 0.04 |
| | Irrigation | 0.17 | -0.09 | 0.01 | 0.14 | 0.97 | 1.15 | 1.13 | 0.78 |
| | Runoff | 0.14 | 0.10 | 0.03 | 0.07 | 3.39 | 5.01 | 1.06 | 0.02 |
| | Season | 0.16 | -0.03 | 0.02 | 0.12 | 0.78 | 1.15 | 1.13 | 0.78 |

[z] Missing data can be explained by the lack of connective flow between sites during the pre-irrigation events or missing sample during the flush event.

[y] Season refers to the average of all sampling events except for the flush.

The three canal segments, EHMC_18, EHMC_20, and EHMC_7, shared the same diversion site (SMC-P1) from the SMRID main canal. Source water for SMC-P1 and T-S1 was the SMRID main canal and were about 20 kilometres apart. The water quality from these sites was very similar except during the pre-irrigation events (data not shown). The samples from the pre-irrigation events were not included in the season average for SMC-P1 as the flow was not connective with the downstream sites.

The change in water quality in the three EHMC canal segments was generally comparable to the TMC_17 segment. The average concentration for most parameters, except for TSS, tended to be higher at the downstream sites; however, most were not significantly different (Tables 5.14 and 5.15). The concentration of TDS and 2,4-D significantly increased in EHMC_20 and EHMC_7 canals and TDP significantly increased in all there EHMC canals. After the flush, largest concentration increases were measured with the runoff and were generally more important in EHMC_18 followed by EHMC_20 and EHMC_7 (Table 5.16). During runoff, the largest increase of TSS, *E. coli*, 2,4-D were measured in EHMC_18. The EHMC segments had the highest drain inlet flow potential, and this supports the hypothesis that drain inlet flow potential would affect water quality during runoff.

Similarly to the TMC_17, the EHMC canal segments had high increases in 2,4-D concentration during the runoff and irrigation season. This could be explained by the high proportion of annual crops, mainly cereal and specialty crops, grown along these segments. This supports the hypothesis that concentrations of pesticides would increase with the proportion of annual crops. Interestingly, among all segments, the largest increase in *E. coli* concentration during runoff and all season events was observed in the EHMC_18 segment, despite the fact that no livestock grazing (i.e., pasture land) was observed along Lateral 2 and Lateral 18 during the field survey. However, the upstream reach of Lateral 18 runs through some acreages with septic fields and stockpiled manure was reported along this reach.

Overall, water quality generally degraded along the canal segments, but some specific trends were observed. Increases in concentrations were observed for all parameters along the BB canal and was the highest of all canal segments for TSS and TDS. Source water quality from the Fincastle Reservoir was generally of poorer quality than Taber Lake Reservoir. A decrease in concentrations of several water quality parameters in the NFEC segment was observed possibly because of sedimentation and other processes along this canal segment. Similarly, the upstream water quality from the SMRID main canal was subject to high turbidity, and a reduction in TSS concentrations was measured in the TMC_17 and EHMC segments. However, these same canals showed the largest increase in 2,4-D concentrations likely because of the high proportion of annual crops. The largest increase of nutrient concentrations among all canal segments were observed along the short canal segments (LatM and TLL) between the two reservoirs. These short canal segments had the smallest flows. Taber Lake Lateral was the only segment that had

not been rehabilitated and remained entirely an earth canal. It is also the segment with the highest density of drainage points. A significant increase in *E. coli* concentration was observed along the BB, LatM, and TLL and these canal segments had the highest proportion of pastures (i.e. non-annual crops).

#### 5.3.3.3 Relationships between Land Use and Water Quality

Only about 20% of the resulting correlation tests presented were statistically significant ($p< 0.05$), with about 54% of the significant correlations as positive associations (Table 5.17). During the irrigation season, 2,4-D had the highest number of significant correlations (four) with canal and landscape parameters. The canal flow capacity had the highest number significant correlations with water quality parameters (five), followed by length of lined canal, proportion of earth canal, and total road length with four significant associations for each.

Throughout the irrigation and entire season, 2,4-D was significantly positively correlated with drainage inlet flow potential, canal flow capacity, and length of earth canal. In particular, the total length of earth canal was highly positively correlated with 2,4-D during the irrigation sampling event ($r = 0.90$) and for the entire season ($r = 0.94$) (Table 5.17). The three EHMC segments had high values for these parameters in comparison to other segments had the highest increase in 2,4-D concentration (Table 5.12 and 5.15). These long and larger canals mainly built of earth material could have been more favorable for weed growth and therefore required more 2,4-D herbicide for weed control. However, the herbicide application records were not known.

The canal flow capacity was negatively correlated with TDS ($r = -0.73$) during the entire season, and $NO_3$-N during runoff ($r = -0.72$) and for the entire season ($r = -0.77$) (Table 5.17). These relationships were likely driven by the TLL and LatM. These canals were small segments where larger increase in concentrations were measured. This supports the hypothesis that canal flow capacity had an inverse relationship with salt and $NO_3$-N concentrations. Dilution is directly related to canal flow capacity (i.e. volume of water), and could have been a factor in these relationships.

The proportion of earth canal was strongly positively correlated to TP ($r = 0.83$), TDP ($r = 0.78$), and TN ($r = 0.88$) during the irrigation season and to TSS ($r = 0.77$) during runoff (Table 5.17). All these were also negatively correlated with the length of lined canal ($r > 0.80$). This suggests that the higher the proportion of earth canal in a segment, the larger the increase in nutrient and sediment concentrations. On average, the largest reduction in TP and TDP, and the second largest reduction in TN concentrations were measured in NFEC. This segment had the smallest proportion of earth canal (11 %) (Table 5.12).

**Table 5.17. Correlation matrix showing statistically significant correlation coefficients between land-use variables and water quality variables during runoff (R), the irrigation season (I), and the entire season except the flush (S).[z]**

| | Canal flow capacity | Length of earth canal | Length of lined canal | Proportion of earth canal | Drainage inlet flow potential | Drainage point density | Total road length | Road density | Mean slope | Proportion annual crops |
|---|---|---|---|---|---|---|---|---|---|---|
| TSS (R) | 0.20 | 0.40 | **-0.88**** | **0.77*** | 0.37 | 0.33 | -0.47 | -0.10 | -0.22 | -0.25 |
| TDS (S) | **-0.73*** | -0.65 | 0.11 | -0.21 | -0.58 | 0.49 | -0.33 | 0.59 | 0.27 | -0.59 |
| TP (I) | 0.27 | 0.51 | **-0.89**** | **0.83*** | 0.51 | 0.34 | -0.23 | 0.01 | -0.47 | 0.09 |
| TP (R) | -0.57 | -0.38 | -0.54 | 0.30 | -0.21 | 0.56 | **-0.75*** | 0.43 | 0.28 | -0.61 |
| TP (S) | -0.53 | -0.41 | -0.47 | 0.15 | -0.28 | 0.31 | **-0.83*** | 0.22 | 0.52 | **-0.76*** |
| TDP (I) | 0.10 | 0.38 | **-0.83*** | **0.78*** | 0.59 | 0.53 | -0.32 | 0.08 | -0.41 | 0.24 |
| TN (I) | 0.49 | 0.64 | **-0.86**** | **0.88**** | **0.76*** | 0.34 | -0.48 | -0.44 | -0.27 | 0.12 |
| TN (R) | -0.13 | -0.01 | -0.59 | 0.43 | 0.10 | 0.42 | **-0.77*** | -0.11 | 0.25 | -0.55 |
| TN (S) | -0.16 | -0.04 | -0.54 | 0.47 | 0.19 | 0.59 | **-0.76*** | -0.01 | 0.16 | -0.35 |
| $NO_3$-N (I) | -0.48 | -0.16 | -0.22 | 0.26 | 0.05 | **0.80*** | 0.01 | 0.63 | -0.42 | 0.18 |
| $NO_3$-N (R) | **-0.72*** | -0.50 | -0.39 | 0.22 | -0.24 | **0.75*** | -0.67 | 0.60 | 0.20 | -0.47 |
| $NO_3$-N (S) | **-0.77*** | -0.54 | -0.15 | 0.09 | -0.30 | **0.82*** | -0.36 | **0.76*** | 0.00 | -0.28 |
| 2,4-D (I) | **0.78*** | **0.90**** | -0.46 | 0.61 | **0.78*** | -0.14 | 0.42 | -0.41 | **-0.73*** | 0.70 |
| 2,4-D (S) | **0.83*** | **0.94**** | -0.48 | 0.63 | **0.84**** | -0.14 | 0.37 | -0.51 | -0.69 | 0.69 |

[z] Parameters not included here were either not normally distributed (originally and after transformation), or were not significantly correlated with any other parameters.

* Significant at $p \leq 0.05$

** Significant at $p \leq 0.01$

Nitrate nitrogen was significantly positively correlated with drainage point density during runoff (r = 0.75), irrigation (r = 0.80), and the entire season (r = 0.82), and with road density during the entire season (r = 0.76). This suggests that there may be landscape contributions of $NO_3$-N to the irrigation canals. Higher road density can cause higher flows due to increased impervious surface area, while higher drainage point densities often indicate higher expected runoff flows. With larger volumes of water entering canals during runoff, there is more potential for contaminants to enter canals.

The inverse relationship between total road length and TP (r = -0.75) and TN (r = -0.77) during runoff, and TP (r = -0.83) for the entire season, as well as the positive relationship between $NO_3$-N and road density were likely driven by the TLL and LatM. These had short road length but high road density in their segment area, and had large increases in nutrient concentration. These correlations are difficult to interpret and the road length and density might not be the cause of the water quality change measured.

There were negative relationships between the mean slope and 2,4-D during the irrigation season (r = -0.73), and the proportion of annual crops and TP during the season (r = -0.76). These relationships were likely driven by Lateral M that had the highest slopes and lowest proportion of annual crops, and TMC_17 with the lowest slopes and highest proportion of annual crops among all segments. However, the increased 2,4-D concentration, smallest for Lat M and largest for TMC_17, and change in TP concentration, largest at Lat_M and negative at TMC_17 were likely not caused by the slope or the proportion of annual crops as these results were more logically explained by other factors as previously described. Although not significant, the positive relationship (r = 0.70) between the proportion of annual crops and 2,4-D concentrations could have been a cause and effect as previously hypothesised.

The strongest correlations ($r > 0.85$ or $r < -0.85$) observed were between water quality and canal characteristics, suggesting that the canal characteristic parameters may have more of an effect on water quality than the surrounding landscape over the entire season.

### 5.4 Summary and Future Work

The purpose of this study was to understand changes in irrigation water quality that may be related to land-use. The findings from the first year (2014) are presented. The objectives were to examine the influence of

- shallow irrigation reservoirs on irrigation water quality,
- municipal storm water on irrigation water quality, and
- canal and landscape characteristics on changes in water quality in selected irrigation canal segments.

In regard to the first objective, there was a general improvement in water quality exiting Taber Lake Reservoir and Fincastle Reservoir as compared to water flowing into them. This was especially important during the flush event, periods of runoff and before the irrigation season when water was of lower quality, suggesting the reservoirs acted as sinks or filters. However, during the irrigation season when the water quality was at its best, the difference was not as prevalent. A slight increase in the concentration of several parameters was even observed from the inlets to the outlets of the reservoirs suggesting a slow release of accumulated salts and nutrients. Taber Lake Reservoir outlet water was generally of better quality compared to Fincastle Reservoir, in particular for *E. coli*.

Four sites were used to assess the influence of municipal stormwater on irrigation water quality. Two sites drained directly from the Town of Taber (T-LU2 and T-LU3), with one of the sites draining directly into Taber Lake Reservoir (T-LU2), and the other draining into Lateral 15 (T-LU3) before flowing into Taber Lake Reservoir. Two other sites along Lateral 15 were used to monitor upstream (T-S4) and downstream (T-LU1) of T-LU3 for changes in water quality. In general, concentrations of the two stormwater sampling sites were much greater than concentrations in Lateral 15, with highest concentrations at T-LU2. Increases in concentrations from upstream to downstream were measured in Lateral 15, but only a small portion (<18%) could be attributed to stormwater from T-LU3. Even though the stormwater had higher concentrations and a greater diversity of pesticides, relatively small and intermittent flows of stormwater limited the seasonal loading to Taber Lake Reservoir. However, the high concentrations and diversity of pesticides as well as high concentrations of nutrients and salts from the stormwater sites are undesirable.

It was hypothesised that land-use parameters would influence water quality concentrations from upstream to downstream sites. This was investigated using eight canal segments. The landscape was too flat to determine the drainage contributing area of each drain inlet. Therefore, landscape parameters were based on characteristics of landscape adjacent to the canal segments. Relationships between water quality change and land-use was analyzed using statistical methods.

In general, water quality parameters were most likely to increase from upstream to downstream during the flush and pre-irrigation events, followed by runoff. Water quality was poor in the sampling events leading up to the irrigation season. The pre-irrigation events were likely influenced by groundwater that may be high in $NO_3$-N and TDS, but low in *E. coli* concentrations (AARD 2014b) and reduced dilution as compared to sampling events during the irrigation season. Water quality of irrigation events was generally better than other events and more consistent in time and space, likely because of the large volumes of water flowing in the canals and the dry weather conditions minimizing connectivity between the landscape and the irrigation infrastructure. An increase in concentration for most parameters was associated with runoff events. The highest increase in *E. coli* and 2,4-D concentrations were associated with

runoff events. There was some delay in the degradation of water quality associated with runoff events for canal segments located downstream of reservoirs.

Significant increases in concentrations from upstream to downstream were measured in six of the eight canal segments, and significant increases in concentrations were measured in at least one canal segment for seven of the eight water quality parameters. The two segments that did not show significant water quality degradation had high turbidity measured at their upstream sites. Sedimentation could have occurred along the segment and this could have offset for the input of contaminants. Water quality degradation was more likely to be observed in canal segments with low concentrations at their upstream sites. Canals with smaller flow capacities were more affected by water quality degradation than canals with larger flows, likely because small canals have a higher proportion of landscape runoff compared to good quality irrigation water. The length of canal segments was not proportional to change in water quality. Two short canals with high drain inlet density and made of earth were more affected by water quality change than others. The largest increase of 2,4-D was observed in canal segments associated with the highest proportion of annual crops dominated by cereals. Canal segments with the highest proportion of pasture land had significant increases in *E. coli* concentration.

The following are recommendations for future work.

- A second year of water quality data should be collected in order to increase the replicates (n) for each water quality parameter and to capture more runoff events for more robust statistical testing.
- The upstream site for the three EHMC segments should be relocated from the current site SMC-P1 on the SMRID main canal to the East Horsefly Main Canal to provide better flow connectivity with downstream sites outside of the irrigation season.
- The flush sampling event should be abandoned since the water quality results were highly affected by the timing of sampling after water reaches the downstream sites and had to be excluded from the seasonal analysis and segment comparisons. Time series sampling during the flush would be helpful to understand the rate of water quality changes after water reaches the downstream site.
- Herbicide applications records along canal banks should be integrated in the analysis of 2,4-D.

## 5.5 References

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# Appendix A. Description of Water Quality Sampling Sites.

## A.1 Site Description and Location

A description of each water quality sampling site and each irrigation districts was published in previous progress report (Charest et al. 2012, 2013, and 2014). Site location and maps are presented in this section (Table A.1, Figure A.1 to A10).

### A.1.1 Land-use Sites

In 2014, 11 sites were added for the land-use component of the study in addition to six sites that were already established for the main project (Chapter 5). These sites were located in the Taber Irrigation District (Table A.2). Land-use sites are located on nine specific reach of canal with an upstream and downstream sampling site (Sub-section A.2). Flow data was collected for all sites but for some sites the flow metering station was slightly upstream or downstream from the sampling site where appropriate structure allowed for flow measurement.

**Table A.1. Coordinates of irrigation water sampling sites in 2014.**

| Irrigation district | Site | Latitude (ºN) | Longitude (ºW) | Irrigation district | Site | Latitude (ºN) | Longitude (ºW) |
|---|---|---|---|---|---|---|---|
| AEP canals | AEP-P2 | 51.0087 | -113.8467 | SMRIDE | SME-P1 | 49.9850 | -110.9906 |
| | AEP-P3 | 50.8245 | -113.4260 | | SME-S1 | 49.8234 | -110.9345 |
| | AEP-S2 | 49.3763 | -113.2231 | | SME-R1a | 49.9500 | -110.6380 |
| MVID | MV-P1 | 49.1054 | -113.6307 | | SME-R2 | 49.9920 | -110.7326 |
| | MV-R1 | 49.1839 | -113.6355 | RCID | RC-P1 | 49.9437 | -110.4003 |
| AID | A-R1 | 49.1302 | -113.2706 | BRID | BR-P1 | 50.2080 | -112.6683 |
| UID | U-P1 | 49.2150 | -113.6355 | | BR-S1 | 50.3811 | -112.4397 |
| | U-S1 | 49.3316 | -113.6108 | | BR-S2 | 50.1341 | -112.2950 |
| | U-R2 | 49.4459 | -113.3936 | | BR-S3 | 50.1295 | -112.2542 |
| | U-R3 | 49.4010 | -113.5910 | | BR-S4a | 50.1390 | -111.9364 |
| | U-R4 | 49.4106 | -113.4773 | | BR-S5 | 50.0586 | -111.8028 |
| MID | M-P1 | 49.3481 | -113.0552 | | BR-R1 | 50.4190 | -112.3418 |
| | M-S1 | 49.4067 | -112.9260 | | BR-R2 | 50.2219 | -112.0946 |
| | M-R1 | 49.4945 | -112.9299 | | BR-R3 | 49.9651 | -112.0819 |
| RID | R-P1 | 49.4209 | -112.6756 | | BR-R4 | 49.9245 | -111.7524 |
| | R-R1 | 49.5307 | -112.5114 | | BR-R5 | 50.0439 | -111.5828 |
| | R-R2 | 49.5518 | -112.7728 | | BR-R7 | 50.2574 | -112.2036 |
| LNID | LN-P1 | 49.7275 | -113.5516 | EID | E-P1 | 50.7500 | -112.4748 |
| | LN-S1 | 49.9092 | -113.1807 | | E-S1 | 50.8552 | -112.3585 |
| | LN-S2 | 49.9548 | -112.9501 | | E-S2 | 50.6959 | -112.1485 |
| | LN-S3 | 49.7857 | -112.9251 | | E-S3 | 50.4321 | -112.0866 |
| | LN-S4 | 49.9173 | -112.7996 | | E-S4 | 50.4933 | -111.9017 |
| | LN-S5 | 49.8879 | -112.7715 | | E-S5 | 50.3727 | -111.8824 |
| | LN-R1 | 50.0273 | -112.7341 | | E-S6 | 50.5275 | -111.6568 |
| | LN-R2 | 49.8730 | -112.6001 | | E-S7 | 50.5433 | -111.9720 |
| | LN-R3 | 50.0200 | -112.5866 | | E-S8 | 50.6187 | -111.8286 |
| | LN-R4 | 49.6554 | -112.8427 | | E-R1 | 51.0955 | -112.1070 |
| TID | T-P1a | 49.7854 | -112.4433 | | E-R1a | 50.9213 | -112.1450 |
| | T-S1 | 49.7421 | -112.2351 | | E-R2 | 50.8252 | -111.6809 |
| | T-S2 | 49.8147 | -112.0982 | | E-R2a | 50.8396 | -111.8198 |
| | T-S3 | 49.8344 | -111.9706 | | E-R3 | 50.2223 | -111.9592 |
| | T-R1 | 49.8885 | -112.0736 | | E-R3a | 50.2226 | -112.0095 |
| | T-R2 | 49.9022 | -111.8582 | | E-R4a | 50.6850 | 111.5721 |
| SMRIDW | SMW-P1 | 49.5816 | -112.7125 | | E-R5 | 50.1503 | -111.6874 |
| | SMW-S2 | 49.7559 | -112.6872 | | E-R5a | 50.1494 | -111.6648 |
| | SMW-R1 | 49.7232 | -112.4876 | | E-R6 | 50.3056 | -111.7685 |
| | SMW-R2 | 49.8439 | -112.4257 | | E-R7 | 50.8319 | -112.0797 |
| SMRIDC | SMC-P1 | 49.7055 | -112.0021 | | E-R8a | 50.7340 | -111.6894 |
| | SMC-S1 | 49.7612 | -111.7260 | WID | W-P1 | 50.9109 | -113.6062 |
| | SMC-S2 | 49.7985 | -111.6677 | | W-P2 | 51.0667 | -113.8023 |
| | SMC-S3 | 49.6984 | -111.4277 | | W-S1 | 51.0664 | -113.4117 |
| | SMC-R1 | 49.8879 | -111.6763 | | W-S2 | 50.9178 | -113.0446 |
| | SMC-R3 | 49.9017 | -111.5163 | | W-S3 | 51.0951 | -113.2818 |
| | SMC-R4 | 49.8700 | -111.4498 | | W-S4 | 51.2247 | -113.3307 |
| | | | | | W-R1a | 51.2658 | -113.1681 |
| | | | | | W-R2 | 50.8344 | -112.7627 |

**Table A.2. Coordinates of land-use water sampling and flow metering sites in 2014.**

| Water sampling | | | Flow metering | | |
|---|---|---|---|---|---|
| Site | Latitude (ºN) | Longitude (ºW) | Site | Latitude (ºN) | Longitude (ºW) |
| T-S1 | 49.7421 | -112.2351 | T-S1 | 49.7421 | -112.2351 |
| T-S2 | 49.8147 | -112.0982 | T-S2 | 49.8208 | -112.0989 |
| T-S3 | 49.8344 | -111.9706 | T-S3 (North Fincastle East) | 49.8391 | -111.9574 |
| T-S4 | 49.7877 | -112.1158 | T-S4 | 49.7877 | -112.1158 |
| T-S5 | 49.8075 | -112.0655 | T-S5 (Lateral M) | 49.8137 | -112.0596 |
| T-R1 | 49.8885 | -112.0736 | T-S5 (Taber Lake Lateral) | 49.8045 | -112.0428 |
| T-R2 | 49.9022 | -111.8582 | T-R1 | 49.8885 | -112.0736 |
| SMC-P1 | 49.7055 | -112.0021 | T-R2 | 49.9022 | -111.8582 |
| T-LU1 | 49.7931 | -112.1156 | SMC-P1 | 49.7259 | -112.0072 |
| T-LU2 | 49.7934 | -112.1174 | T-LU1 | 49.7931 | -112.1156 |
| T-LU3 | 49.7883 | -112.1160 | T-LU2 | 49.7934 | -112.1174 |
| T-LU4 | 49.7935 | -112.0932 | T-LU3 | 49.7883 | -112.1160 |
| T-LU5 | 49.7973 | -112.0706 | T-LU4 | 49.7935 | -112.0932 |
| T-LU6a | 49.8221 | -111.9991 | T-LU5 | 49.7973 | -112.0706 |
| T-LU6b | 49.8104 | -112.0032 | T-LU6a | 49.8222 | -112.0119 |
| T-LU6c | 49.8106 | -112.0026 | T-LU6b | 49.8104 | -112.0032 |
| T-LU7 | 49.8239 | -111.9686 | T-LU6c | 49.8106 | -112.0026 |
| | | | T-LU7 | 49.8239 | -111.9686 |

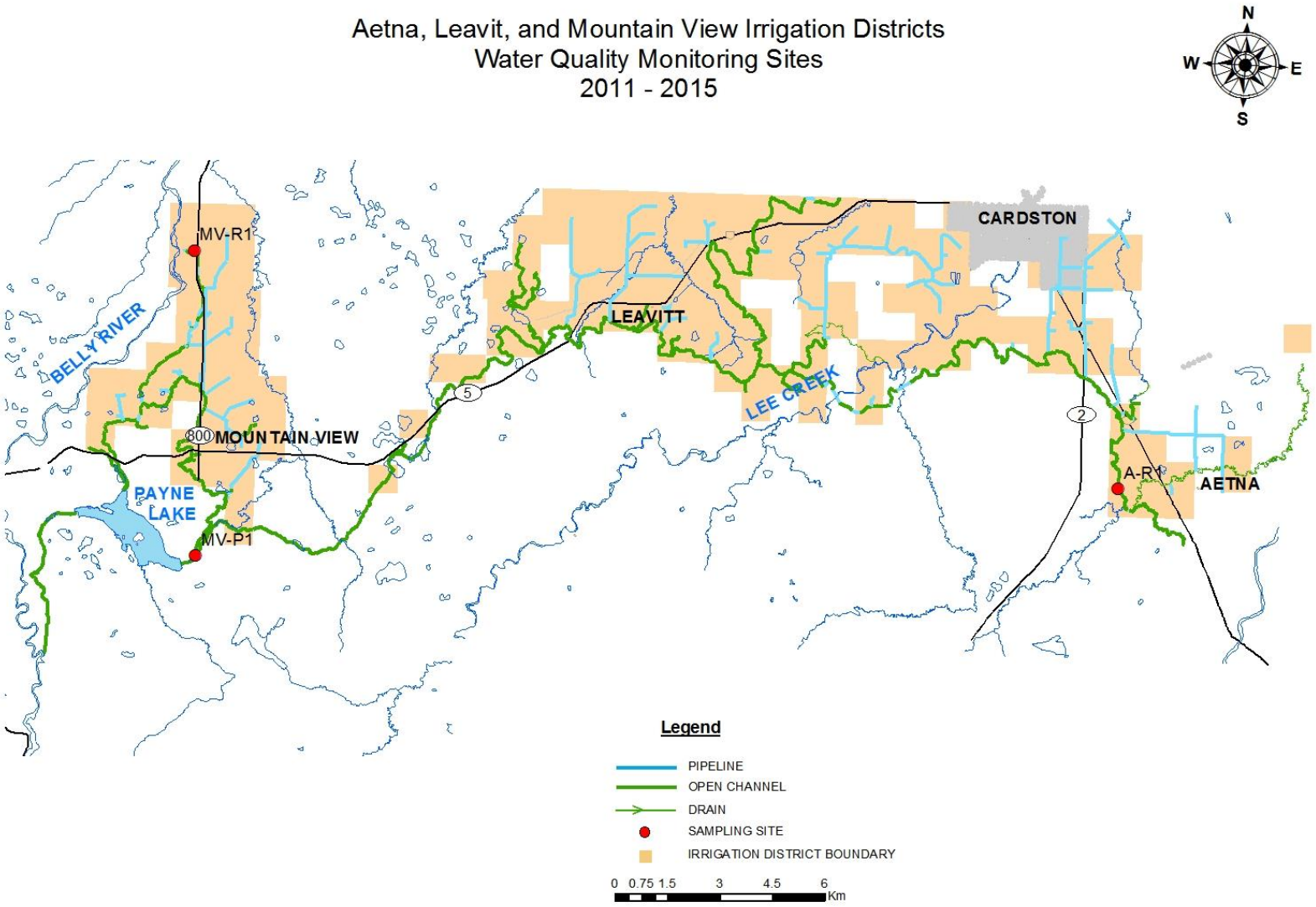



**Figure A.1. Water sampling sites in the Mountain View and Aetna Irrigation Districts.**

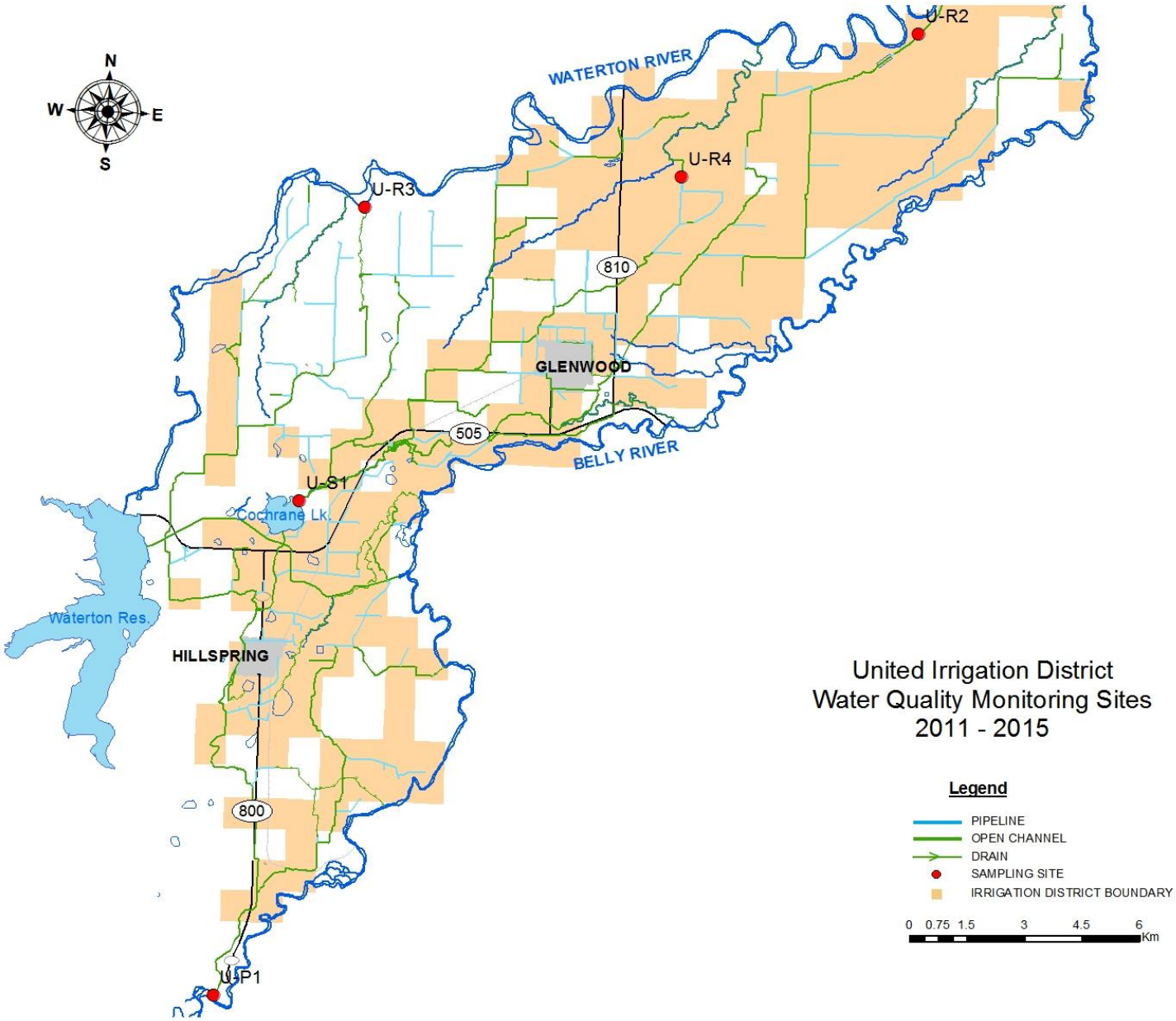



**Figure A.2. Water sampling sites in the United Irrigation District.**

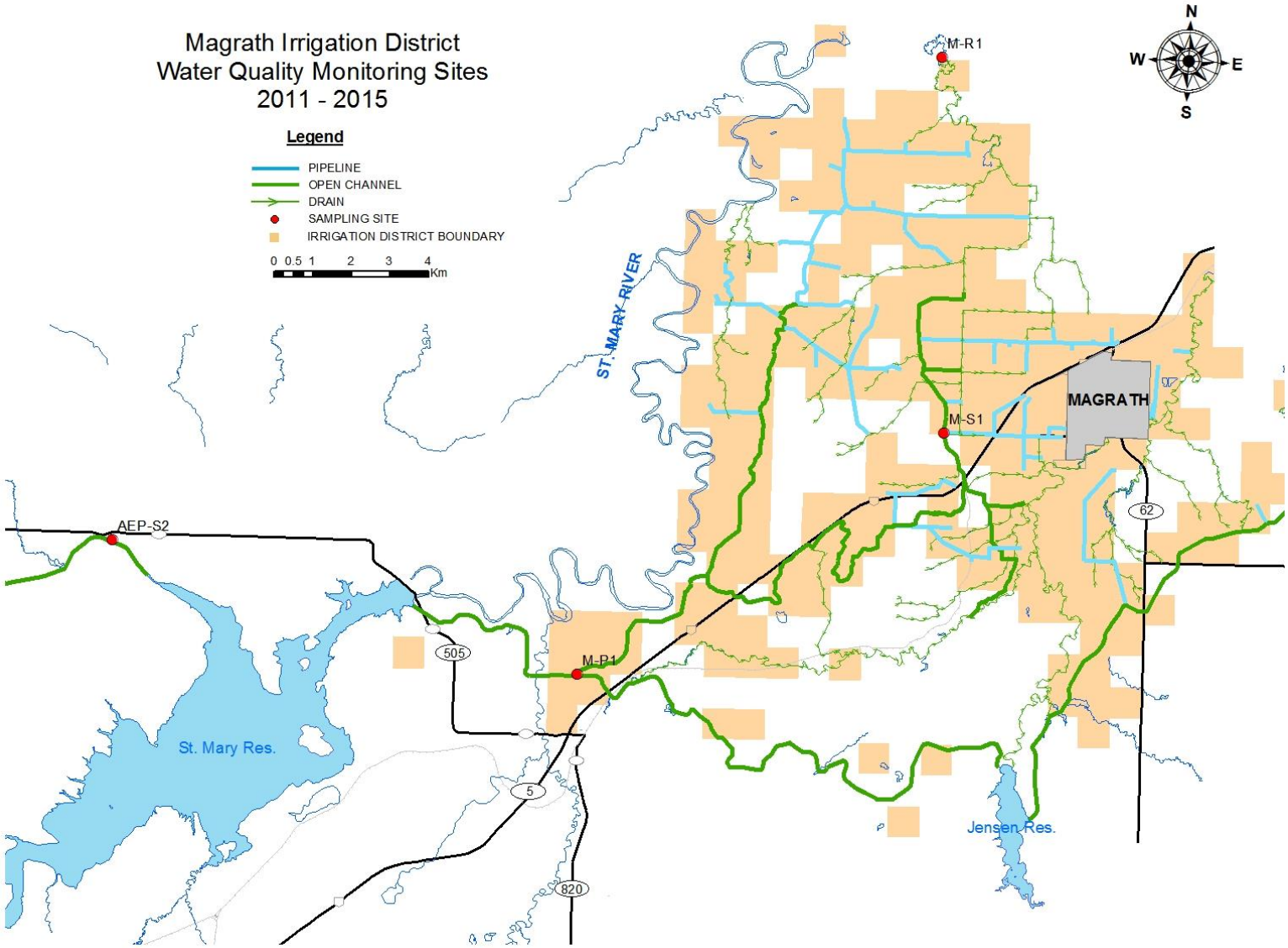



**Figure A.3. Water sampling sites in the Magrath Irrigation District.**

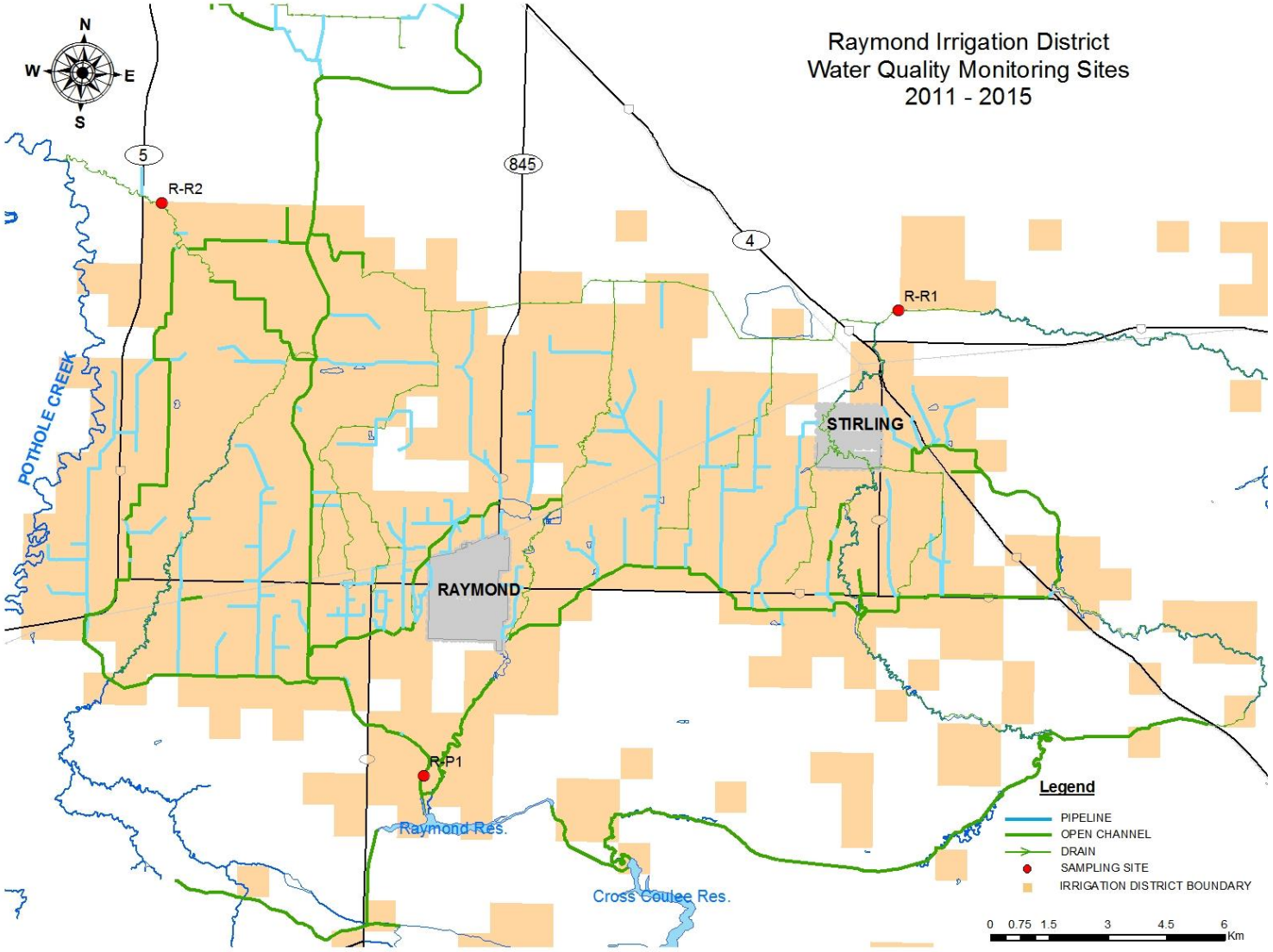



**Figure A.4. Water sampling sites in the Raymond Irrigation District.**

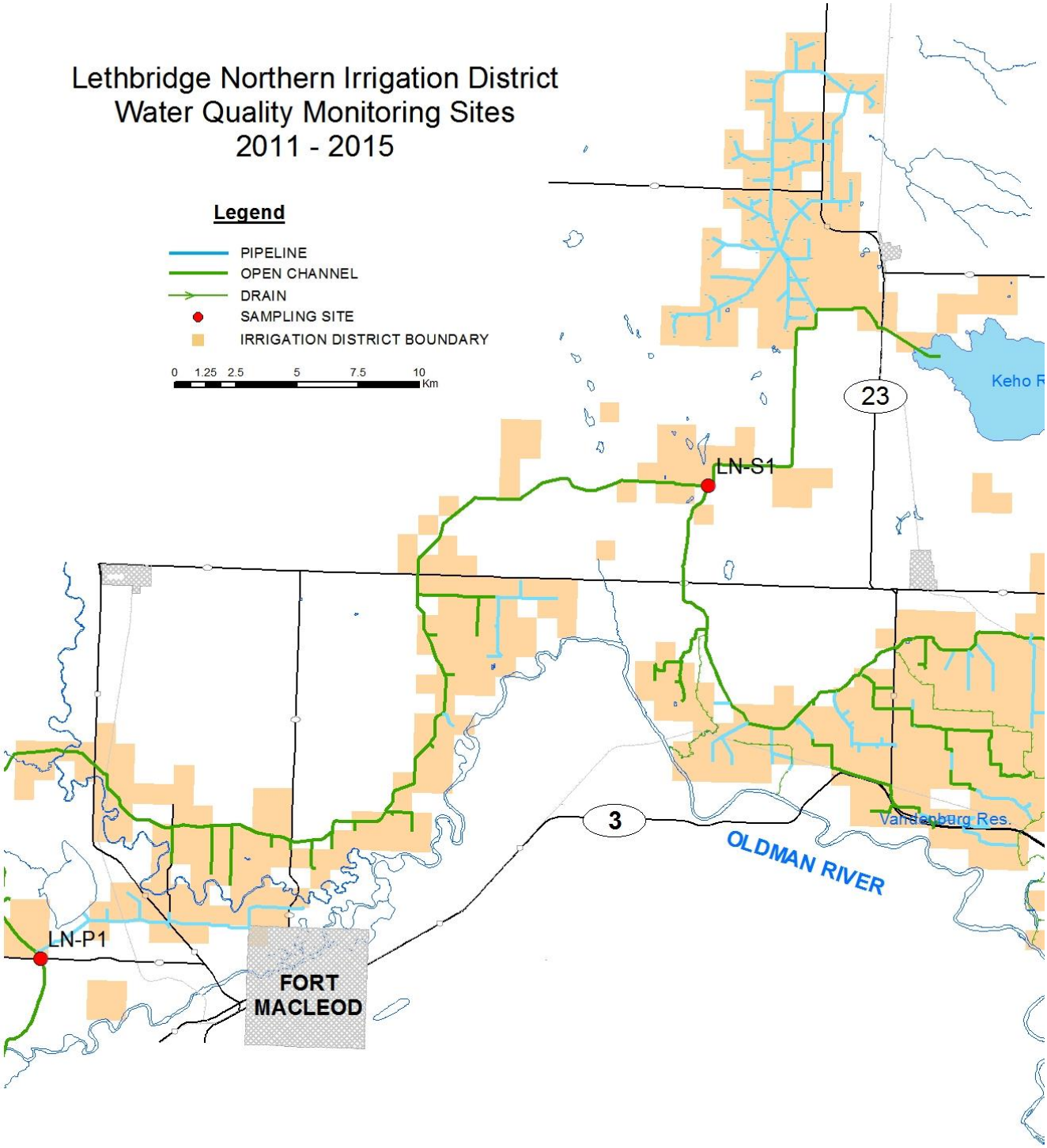
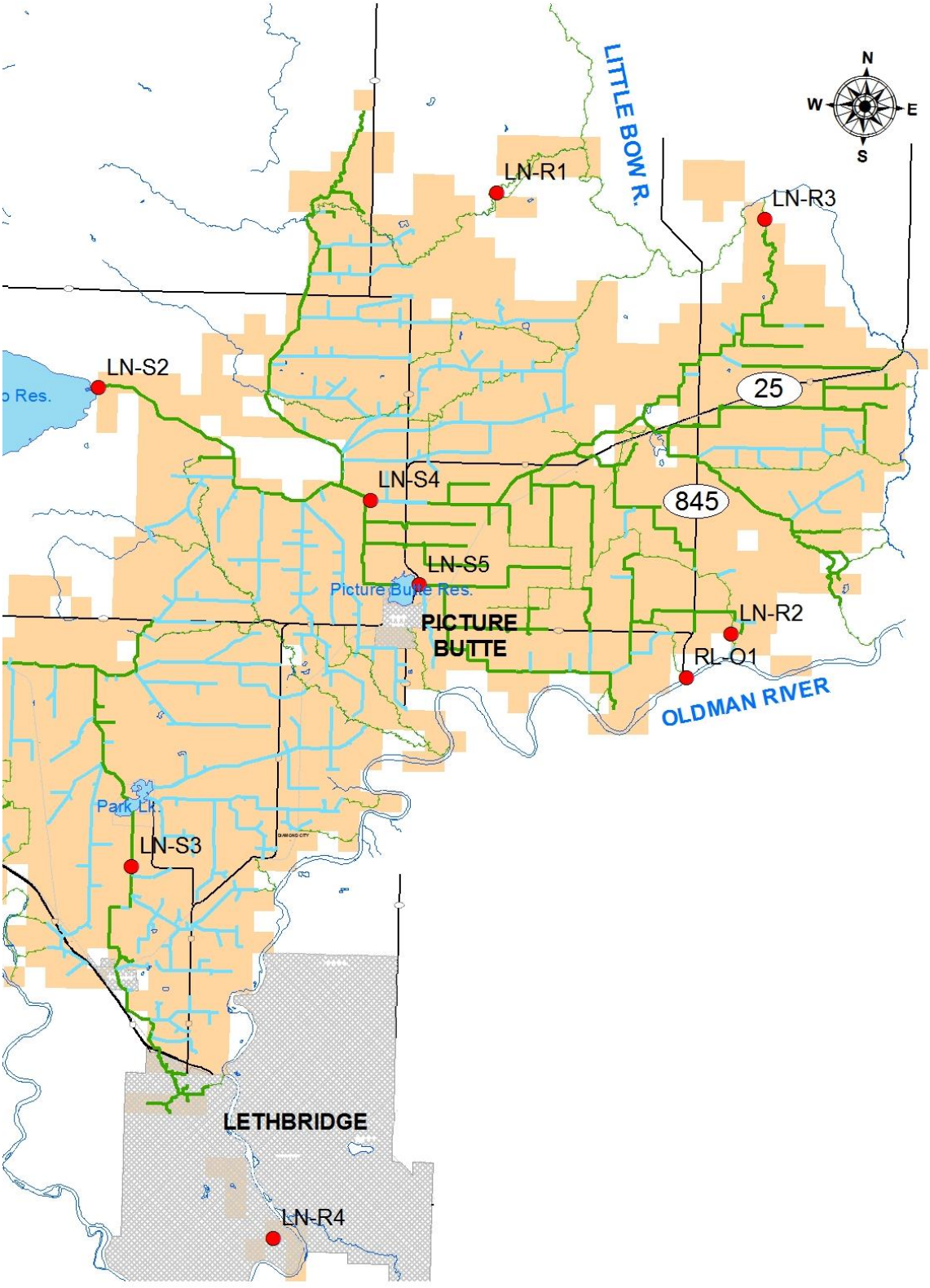



**Figure A.5. Water sampling sites in the Lethbridge Northern Irrigation District.**


LITTLE BOW R.
N
W
E
S
LN-R1
LN-R3
LN-S2
Res.
25
LN-S4
845
LN-S5
Picture Butte Res.
PICTURE BUTTE
LN-R2
RL-O1
OLDMAN RIVER
Park Lk.
LN-S3
LETHBRIDGE
LN-R4

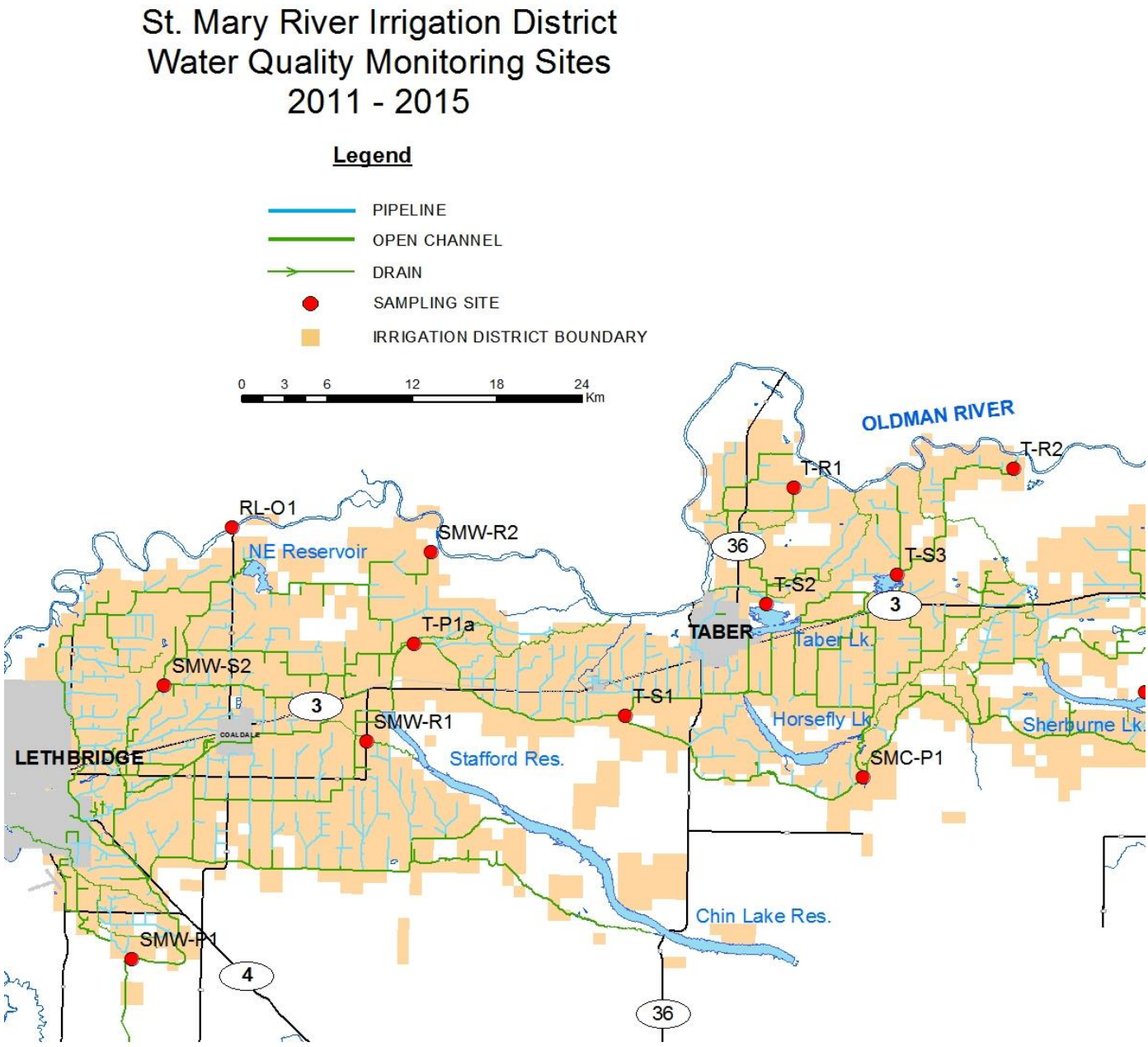
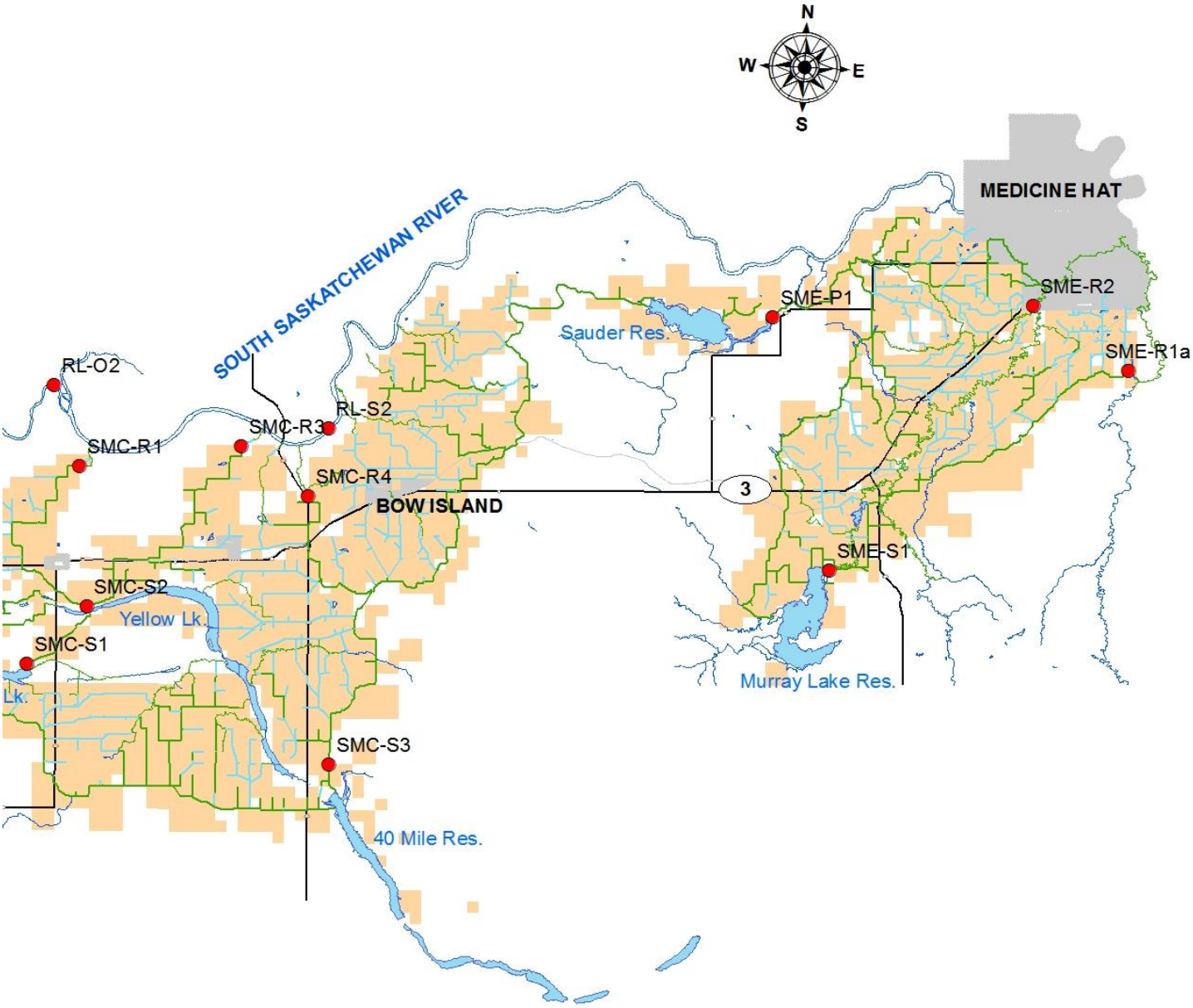



**Figure A.6. Water sampling sites in the Taber and St. Mary River Irrigation Districts.**

Note that Figure A.11 illustrates the location of the land-use sampling site in Taber Irrigation District .


N
W
E
S
MEDICINE HAT
SOUTH SASKATCHEWAN RIVER
SME-P1
SME-R2
Sauder Res.
SME-R1a
RL-O2
SMC-R3
RL-S2
SMC-R1
SMC-R4
BOW ISLAND
3
SME-S1
SMC-S2
Yellow Lk.
SMC-S1
Lk.
Murray Lake Res.
SMC-S3
40 Mile Res.

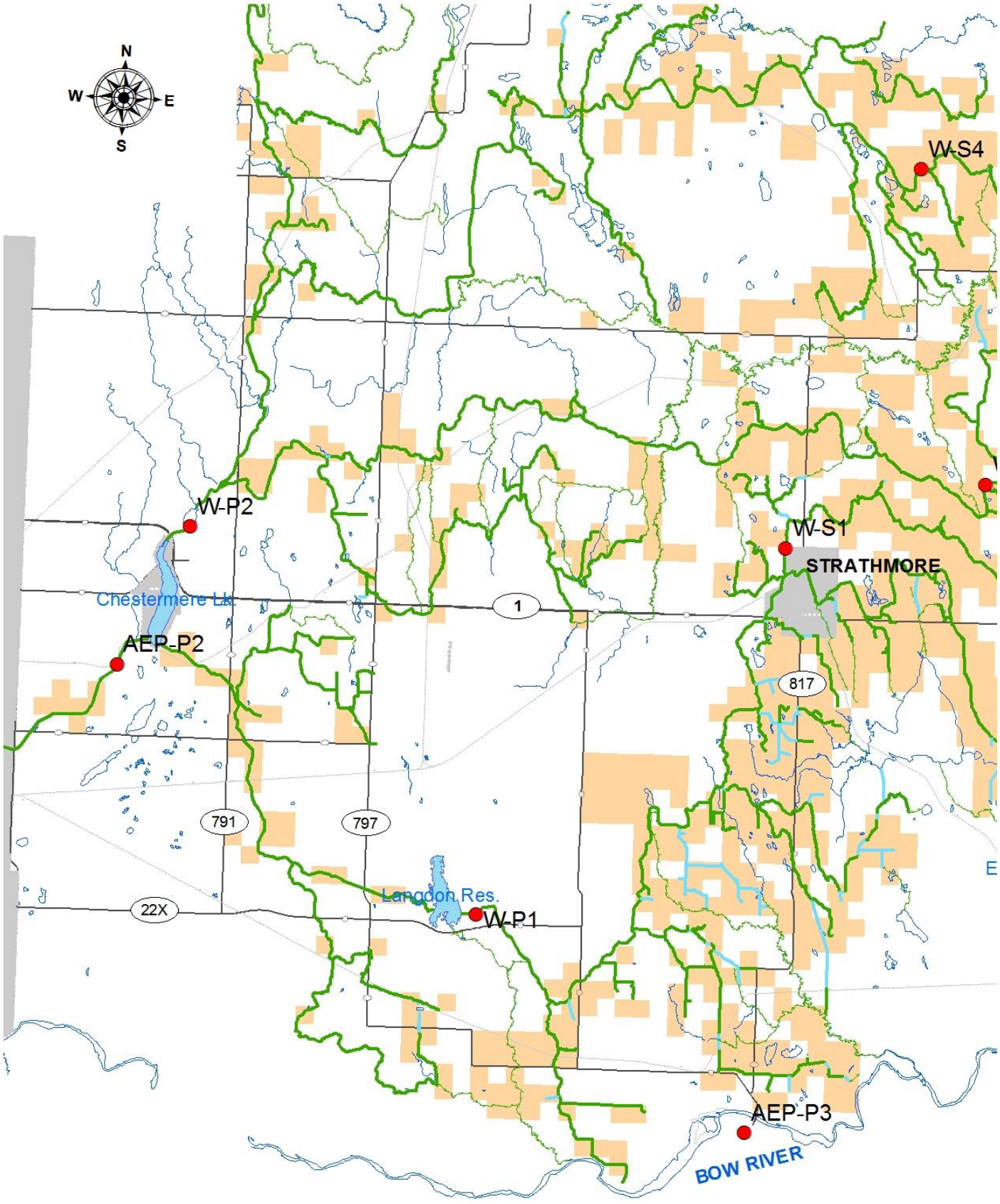
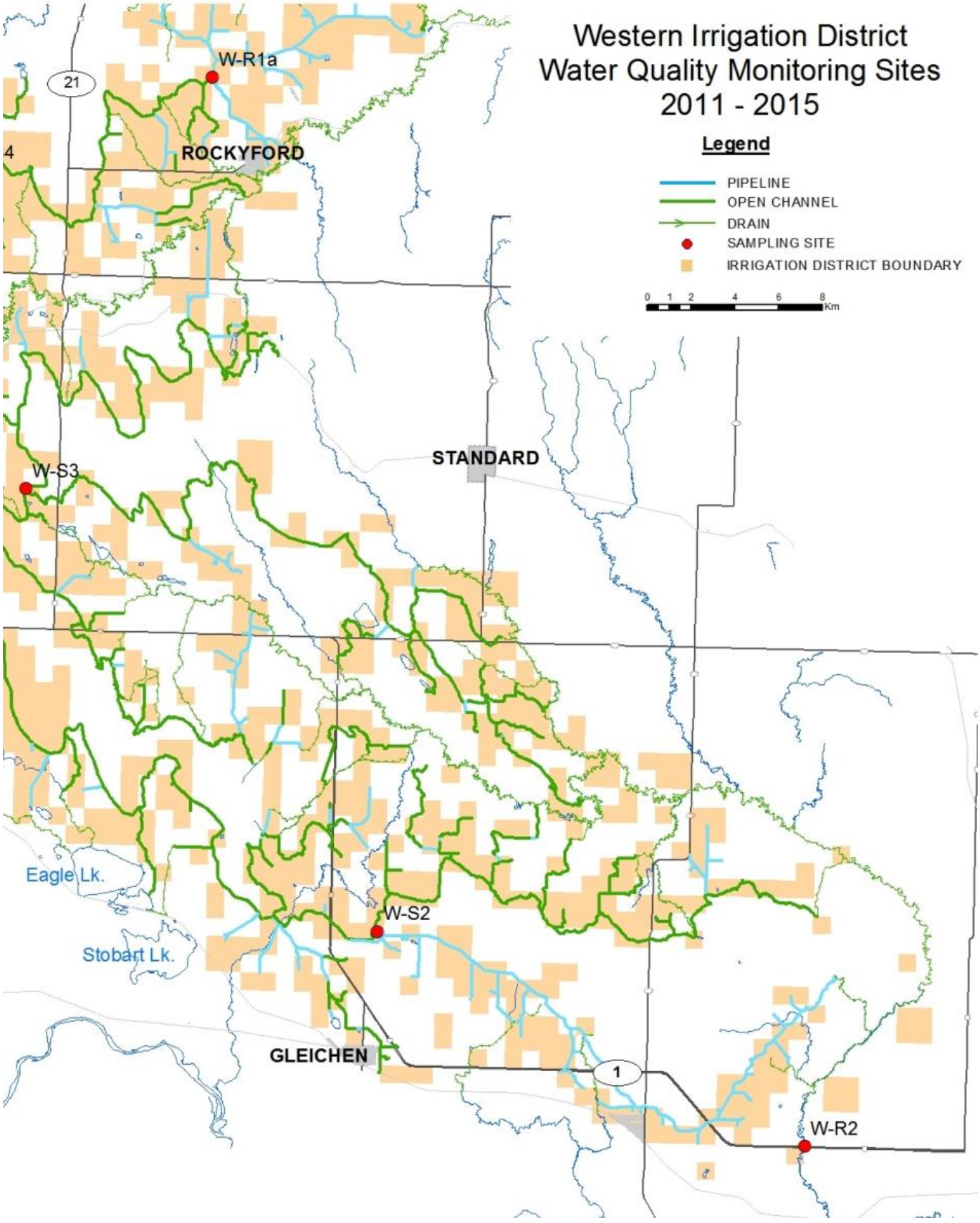



**Figure A.7. Water sampling sites in the Western Irrigation District.**


Western Irrigation District
Water Quality Monitoring Sites
2011 - 2015
Legend
PIPELINE
OPEN CHANNEL
DRAIN
SAMPLING SITE
IRRIGATION DISTRICT BOUNDARY
0 1 2 4 6 8 Km
W-R1a
21
4
ROCKYFORD
STANDARD
W-S3
Eagle Lk.
W-S2
Stobart Lk.
GLEICHEN
1
W-R2

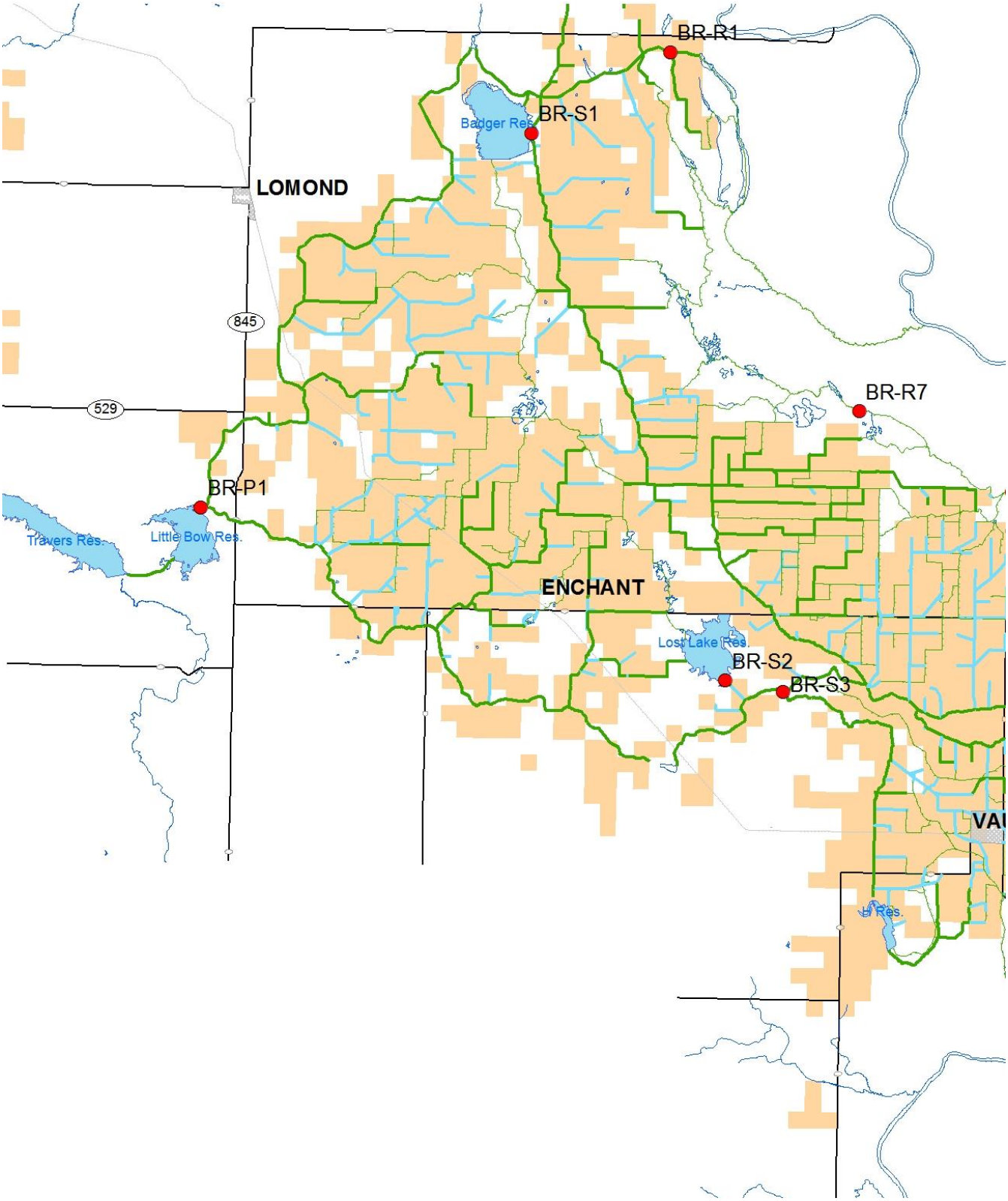
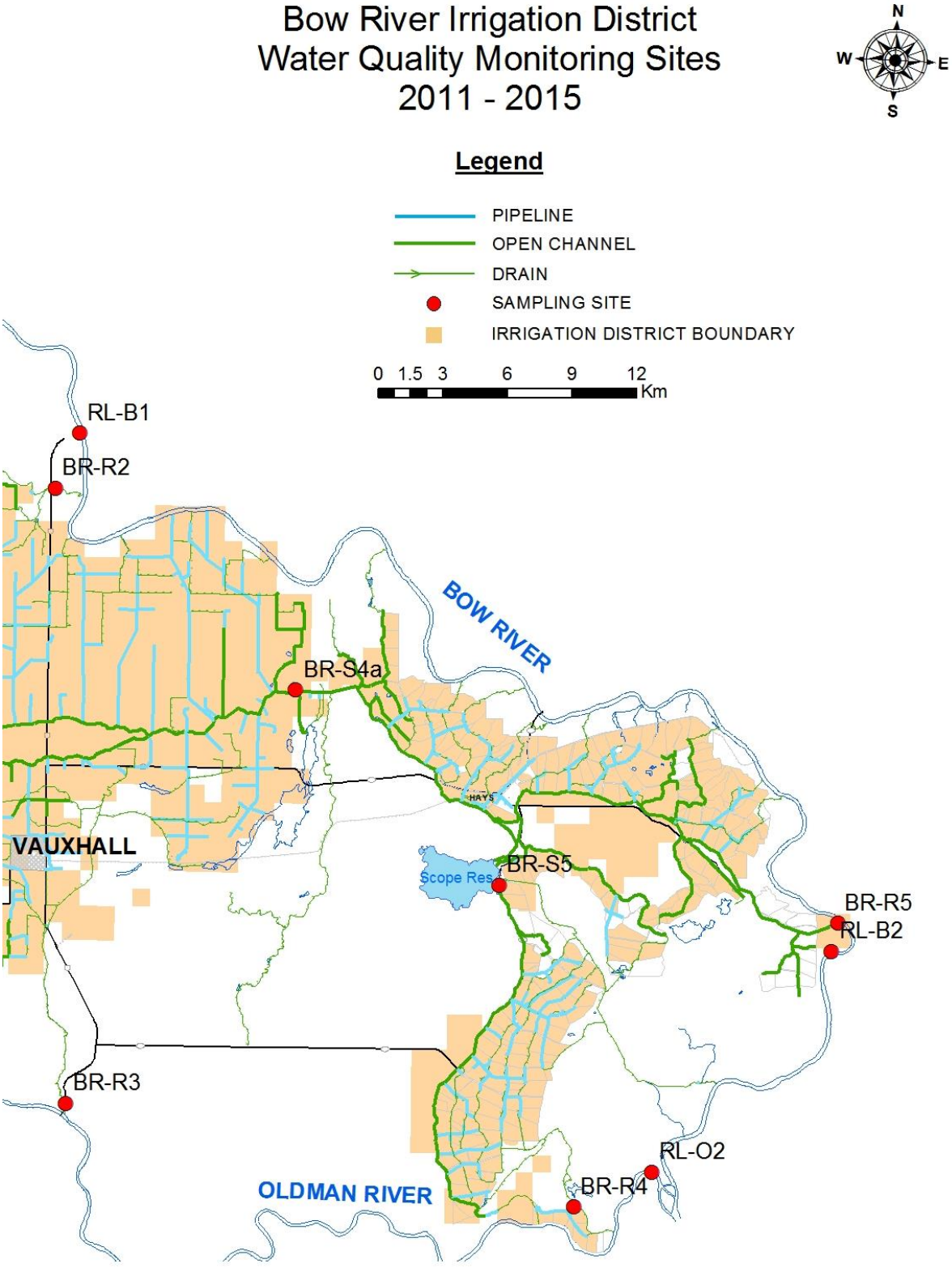
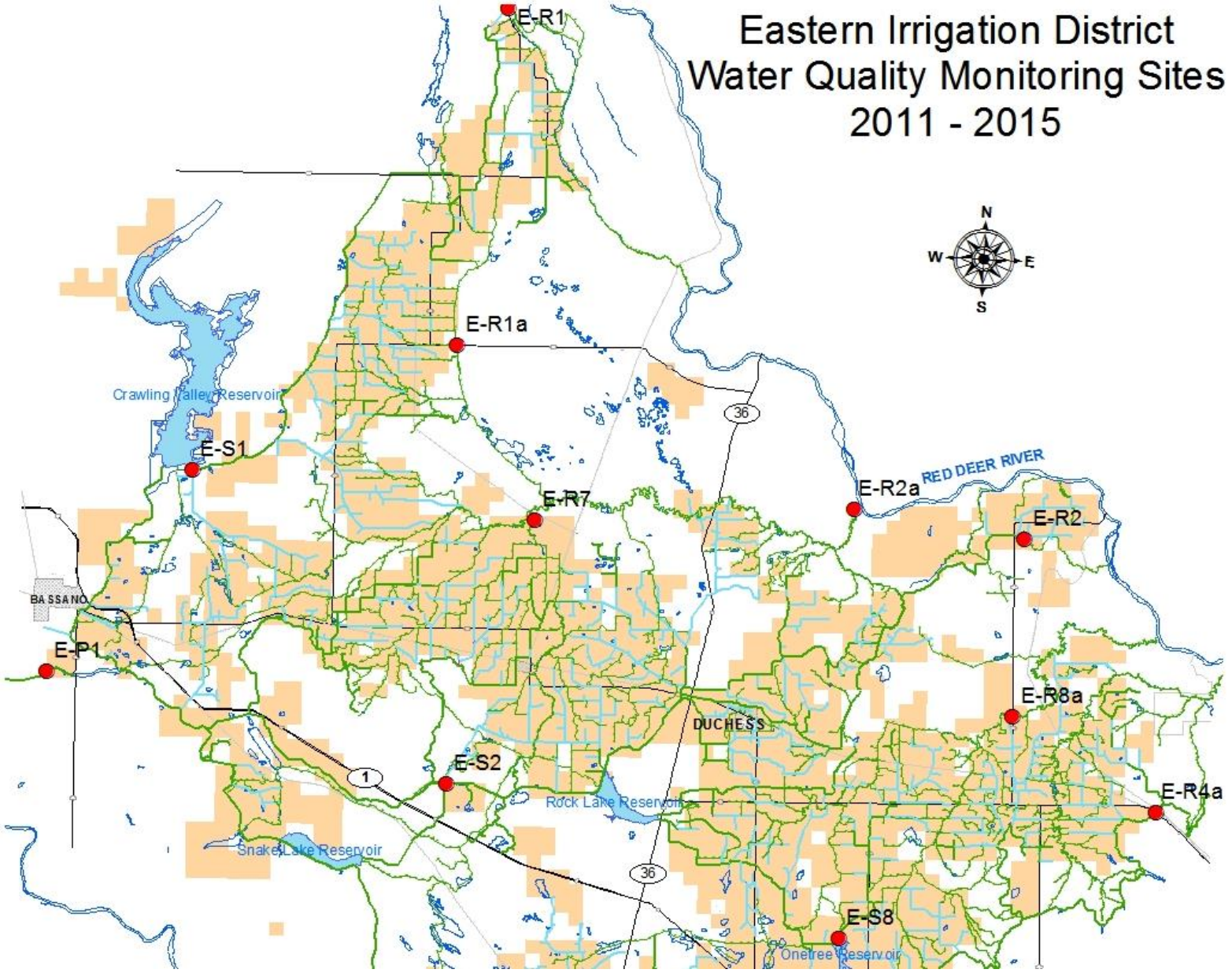



**Figure A.8. Water sampling sites in the Bow River Irrigation District.**

# Bow River Irrigation District
# Water Quality Monitoring Sites
# 2011 - 2015




Eastern Irrigation District
Water Quality Monitoring Sites
2011 - 2015
N
W
E
S
E-R1
E-R1a
Crawling Valley Reservoir
E-S1
E-R7
E-R2a
RED DEER RIVER
E-R2
BASSANO
E-P1
E-R8a
DUCHESS
E-S2
Rock Lake Reservoir
E-R4a
Snake Lake Reservoir
E-S8
Onetree Reservoir
36
1

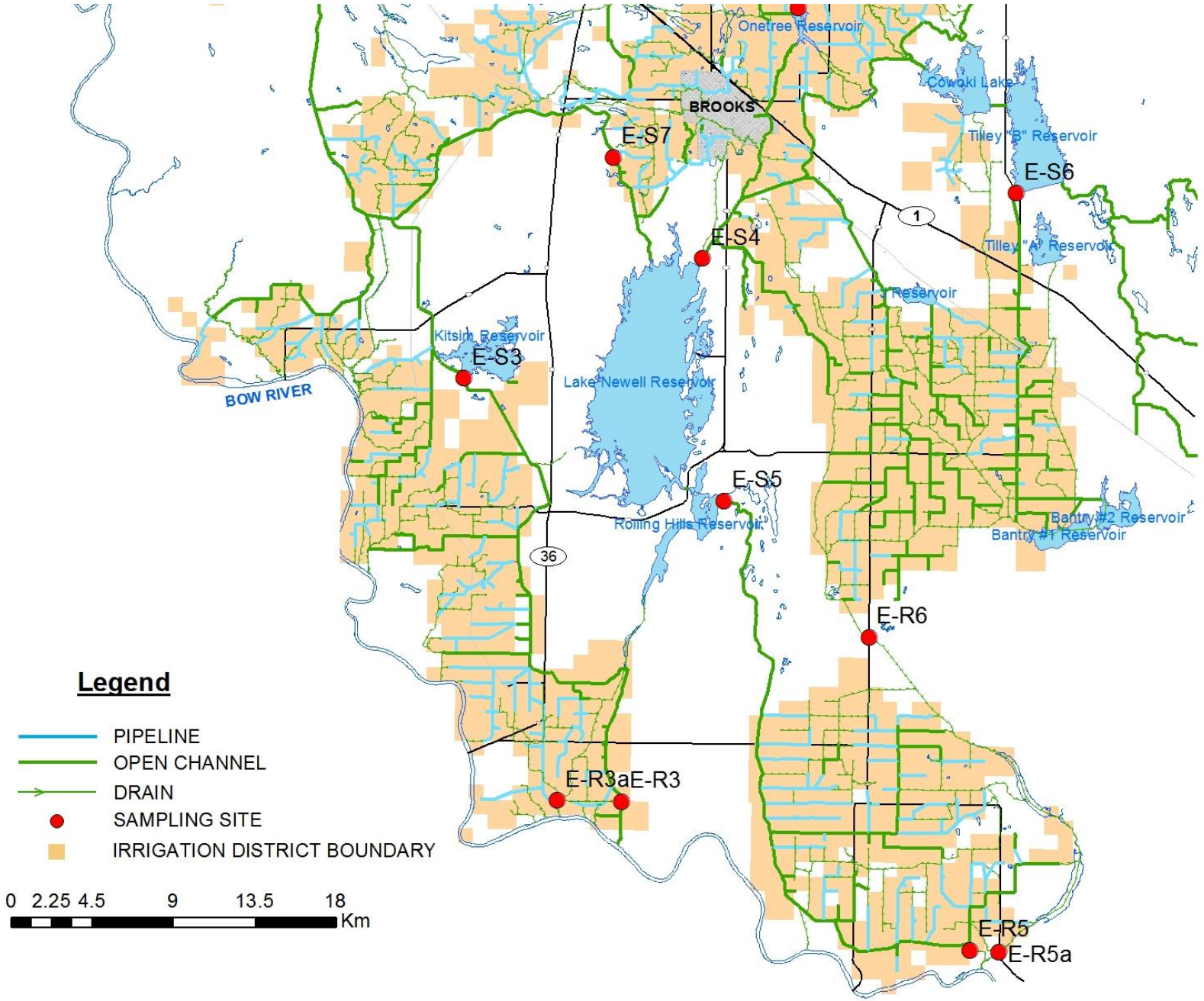



**Figure A.9. Water sampling sites in the Eastern Irrigation District.**

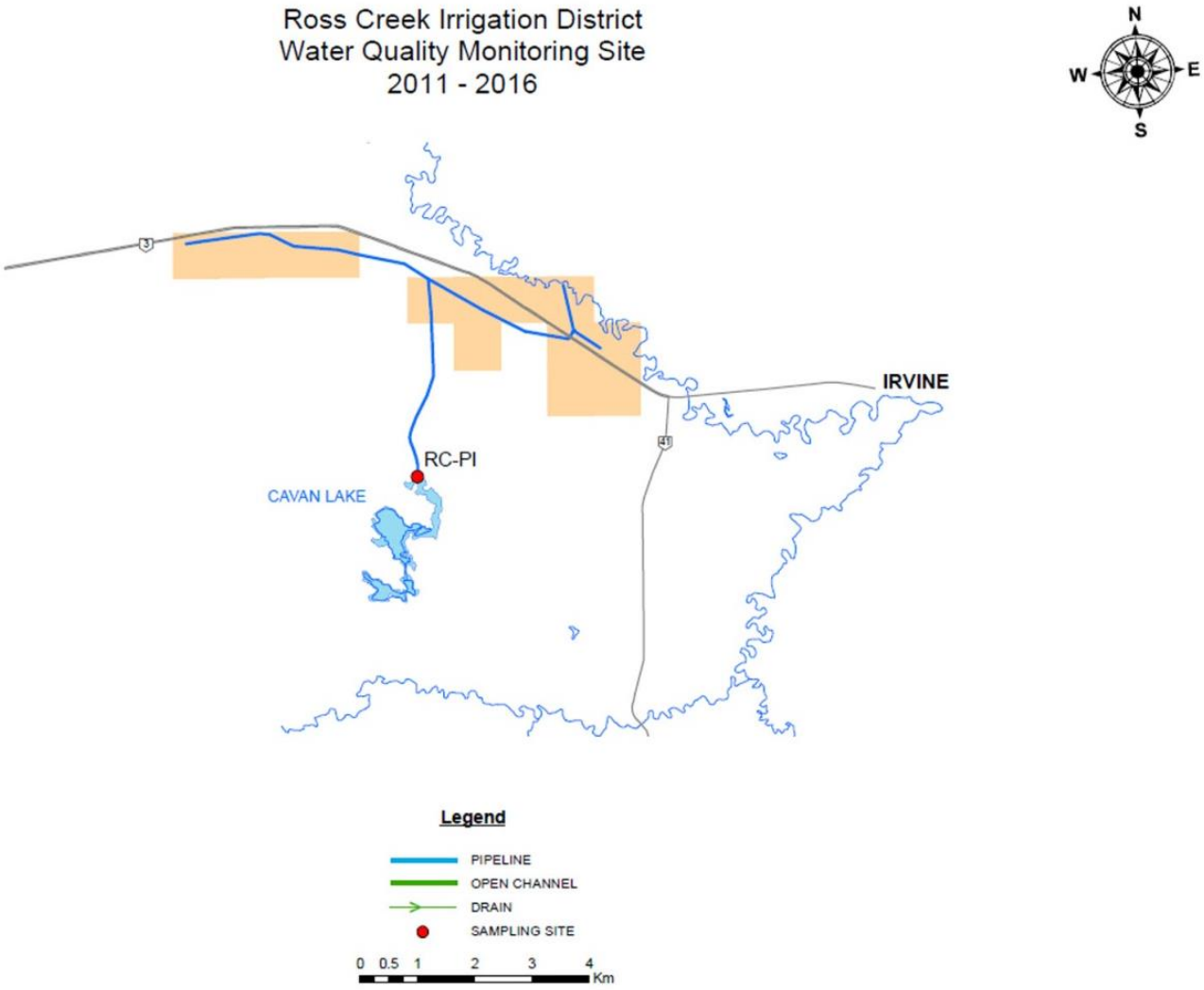



**Figure A.10. Water sampling sites in the Ross Creek Irrigation District.**

## A.2 Land-use Site Description

**NAME and SITE AREA:** T-S1 (Area 6a)

**LAND DESCRIPTION:** NW 15-9-17-4

**LATERAL NAME:** Taber Main Canal

**SAMPLING SITE CO-ORDINATES:** 49.7421 -112.2352

**FLOW SITE CO-ORDINATES:** 49.7421 -112.2352

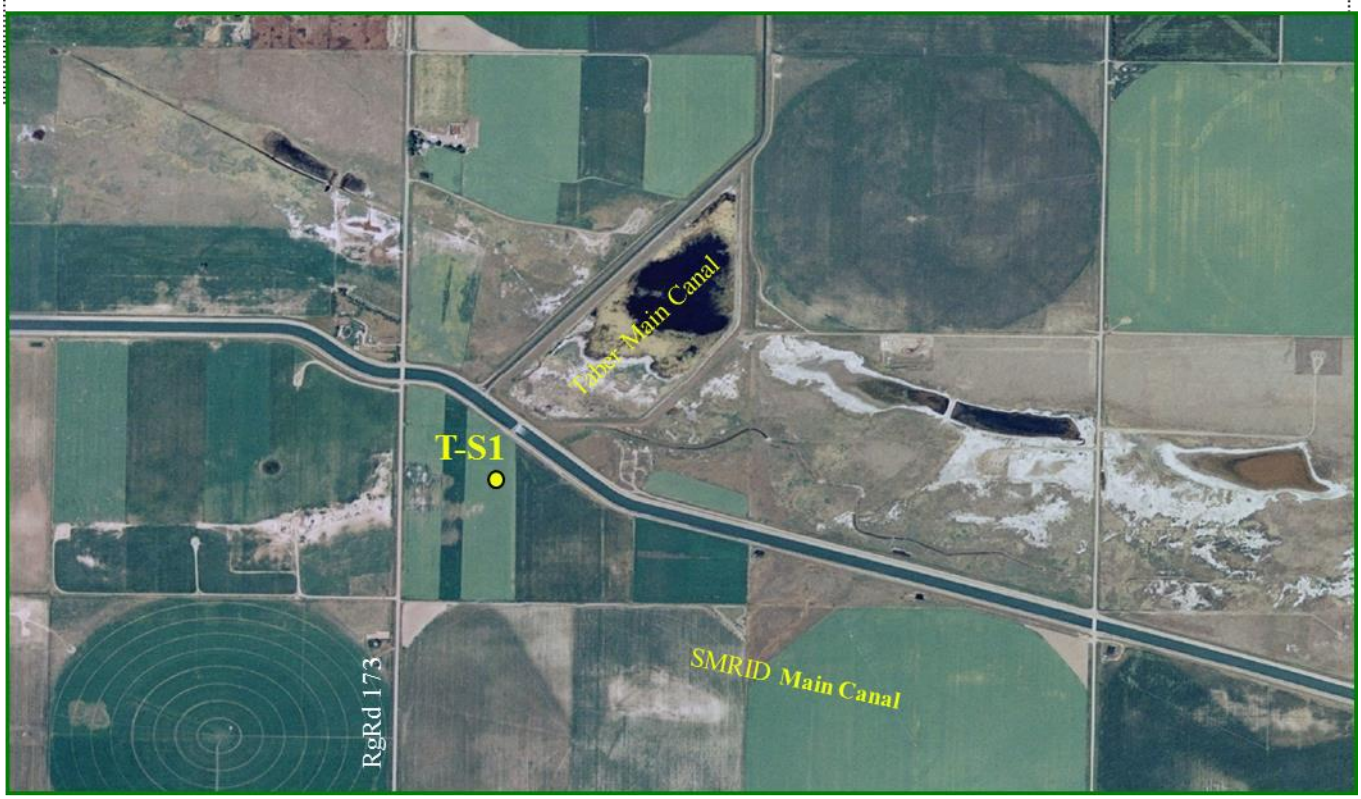
**DESIGN FLOW CAPACITY:** 7.79 $m^3 s^{-1}$ (275 $ft^3 s^{-1}$)

**FLOW MEASUREMENT METHOD:** Sontek Argonaut

**ARD STATION GID NUMBER:** 8013


**DESCRIPTION:** Site T-S1 is located on the Taber Main Canal close to the diversion from the SMRID Main Canal. Taber Main Canal serves about 5,060 irrigable hectares in the Barnwell and South Taber areas, and supplies water to the Town of Taber. T-S1 is the upstream site for the Taber Main Canal segment. The downstream site of this segment is T-LU4 where irrigation water from Lateral 17 flows into Taber Lake Reservoir. Water samples at T-S1 are taken 250 m downstream of the canal headgates at a concrete pad in the canal.

Flow at T-S1 is measured and recorded by TID using a Sontek Argonaut at the sampling site.



**NAME and SITE AREA:** T-S2 (Area 6a)

**LAND DESCRIPTION:** NW 10-10-16-4

**LATERAL NAME:** Big Bend Main Canal

**SAMPLING SITE CO-ORDINATES:** 49.8147 -112.0982

**FLOW SITE CO-ORDINATES:** 49.8162 -112.0990

**DESIGN FLOW CAPACITY:** 7.65 $m^3 s^{-1}$ (270 $ft^3 s^{-1}$)

**FLOW MEASUREMENT METHOD:** Slope gauge

**ARD STATION GID NUMBER:** 8020


**DESCRIPTION:** Site T-S2 is located on Big Bend Main Canal where water leaves Taber Lake Reservoir. Big Bend Main Canal serves approximately 7,050 irrigable hectares in the Big Bend irrigation block north of the Town of Taber. T-S2 is an outflow site of Taber Lake Reservoir and the upstream site for the Big Bend segment. The downstream site of this segment is T-R1 where the unused irrigation water from the Big Bend system and runoff from Drain G7 flows into the Oldman River via the G7 Spillway. Water samples at T-S2 are taken between the canal headgates off Taber Reservoir and Township Road 102.

Flow at T-S2 is measured using a slope gauge located on Big Bend Main Canal 200 m downstream of the sampling site. This site is instrumented with a pressure transducer datalogger to record water height.

**NAME and SITE AREA:** T-S3 (Area 6b)

**LAND DESCRIPTION:** SE 21-10-15-4

**LATERAL NAME:** Fincastle Lake Outlet Channel

**SAMPLING SITE CO-ORDINATES:** 49.8345 -111.9707

**FLOW SITE CO-ORDINATES:** NF East Canal 49.8391 -111.9574
NF West Canal 49.8401 -111.9683

**DESIGN FLOW CAPACITY:** NF West Canal 1.96 $m^3 s^{-1}$ (69 $ft^3 s^{-1}$)
NF East Canal 3.17$m^3s^{-1}$ (112 $ft^3s^{-1}$)

**FLOW MEASUREMENT METHOD:** Weirs

**ARD STATION GID NUMBER:** NF West Canal: 8008
NF East Canal: 8021


**DESCRIPTION:** Site T-S3 is located on the outlet channel of Fincastle Reservoir. This channel supplies water to North Fincastle East and West distribution systems. North Fincastle West Canal serves an area of 1746 irrigable hectares and North Fincastle East serves 2428 irrigable hectares. T-S3 is the outflow site of Fincastle Reservoir and the upstream site for the North Fincastle East segment. The downstream site for this segment is T-R2 where unused irrigation water flows to the Oldman River via the North Fincastle East Spill. Water samples at T-S3 are taken as water leaves the reservoir upstream of the headgates.

Flows at T-S3 are measured at check structures on North Fincastle East and West Canals using weir formulas. The check structure on North Fincastle West Canal is 100 m east and 300 m north of the sampling site. This site is instrumented with a Lakewood datalogger to record water heights. The check structure on North Fincastle East Canal is 500 m east of the sampling site. This site is instrumented with a pressure transducer datalogger to record water height. This flow is used for the North Fincastle East segment. The East and West Canal flows are added together to obtain a total outflow for Fincastle Reservoir.

**NAME and SITE AREA:** T-S4 (Area 6a)

**LAND DESCRIPTION:** SW 4-10-16-4

**LATERAL NAME:** Lateral 15

**SAMPLING SITE CO-ORDINATES:** 49.7882 -112.1158

**FLOW SITE CO-ORDINATES:** N/A

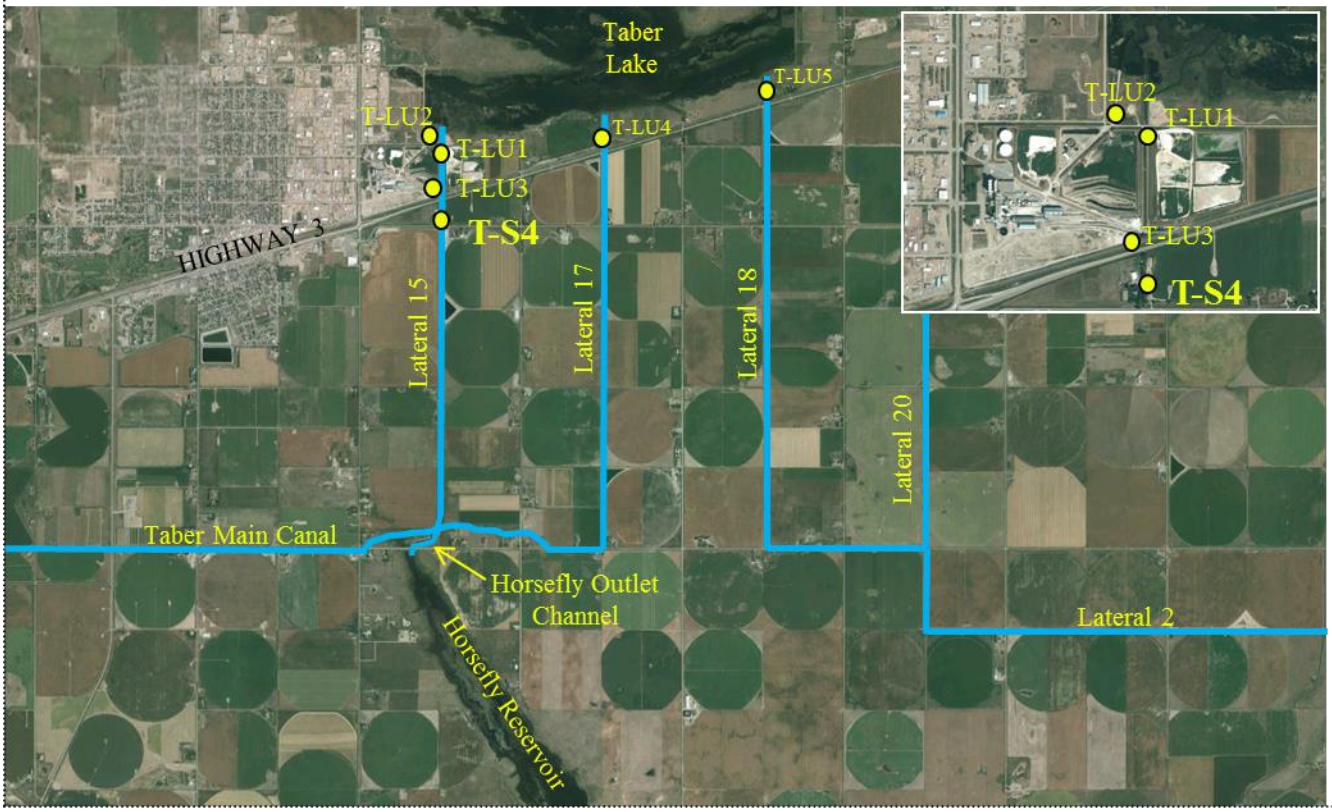
**DESIGN FLOW CAPACITY:** 7.08 $m^3 s^{-1}$ (250 $ft^3 s^{-1}$)

**FLOW MEASUREMENT METHOD:** Subtraction of T-LU3 from T-LU1

**ARD STATION GID NUMBER:** N/A

**DESCRIPTION:** Site T-S4 is located on Lateral 15. Lateral 15 carries the main supply of water to the Taber Reservoir for irrigable hectares served downstream of the reservoir. Water in Lateral 15 during the irrigation season is generally from Horsefly Reservoir, but if needed water can be diverted from the Taber Main Canal (T-S1) via the Horsefly Outlet Channel to Lateral 15. T-S4 is the upstream site of the Lateral 15 segment. The downstream site of this segment is T-LU1 which is located downstream of where field and municipal runoff from T-LU3 flow into Lateral 15. Water samples for T-S4 are taken at the check structure on the south side of Highway 3.

Flow for T-S4 is calculated by subtracting T-LU3 flow from T-LU1 flow.



**NAME and SITE AREA:** T-S5 (Area 6b)

**LAND DESCRIPTION:** SE 11-10-16-4

**LATERAL NAME:** Lateral M and Taber Lake Lateral

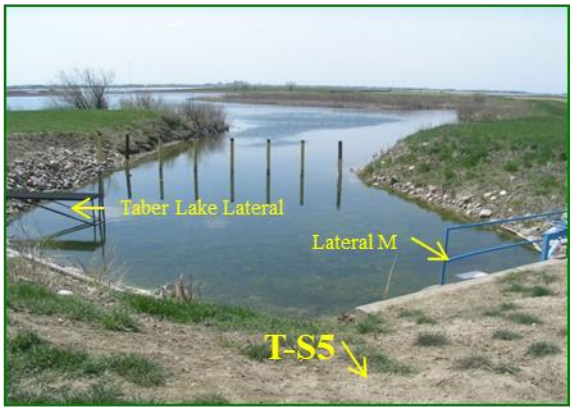
**SAMPLING SITE CO-ORDINATES:** 49.8073 -112.0660

**FLOW SITE CO-ORDINATES:** Lateral M: 49.8138 -112.0597

**DESIGN FLOW CAPACITY:** Lateral M: 1.64 $m^3 sec^{-1}$ (58 $ft^3 s^{-1}$)
Taber Lake Lateral: 0.25 $m^3 s^{-1}$ (9 $ft^3 s^{-1}$)

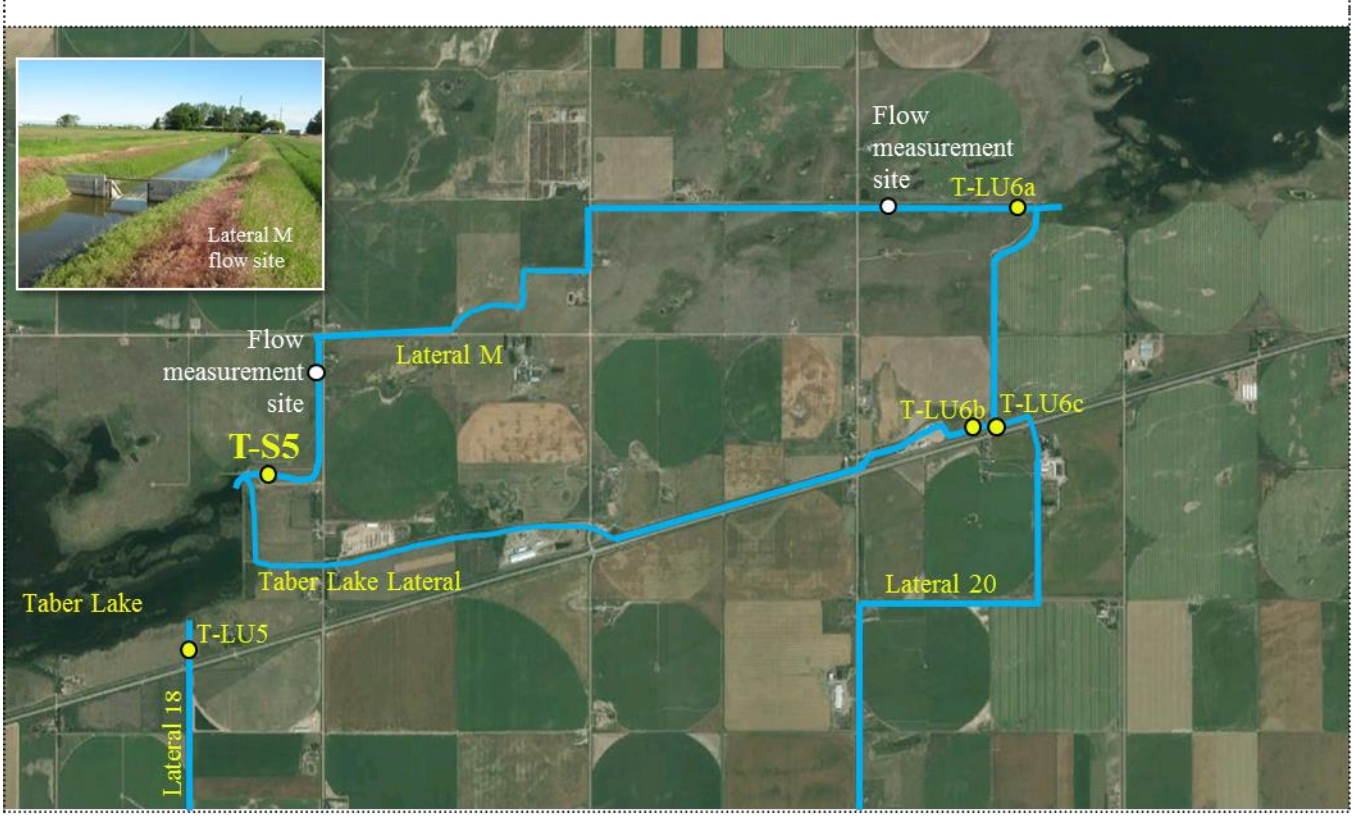
**FLOW MEASUREMENT METHOD:** Weir

**ARD STATION GID NUMBER:** N/A




**DESCRIPTION:** Site T-S5 is located on Lateral M where water leaves Taber Lake Reservoir. It is an outflow site for Taber Lake Reservoir and the upstream site for the Lateral M and Taber Lake Lateral segments. Taber Lake Lateral flows from Taber Reservoir directly upstream of T-S5. Lateral M serves 1229 irrigable hectares and Taber Lake Lateral serves 267 irrigable hectares. Downstream sites for these segments are T-LU6a and T-LU6b, where unused irrigation water flows to Fincastle Reservoir. Water samples are taken at T-S5 just downstream of the Lateral M headgates.

Flow at T-S5 is measured on Lateral M and Taber Lake Lateral. Flow in Lateral M is measured at a check structure on Lateral M 500 m downstream of the sampling site using a weir formula. This site is instrumented with a pressure transducer datalogger to record water height. Flow in Taber Lake Lateral is measured only at the downstream site (T-LU6b). An upstream flow site close to Taber Lake Reservoir was not available.



**NAME and SITE AREA:** T-R1 (Area 6a)

**LAND DESCRIPTION:** SW 12-11-16-4

**LATERAL NAME:** Lateral G7 Spillway

**SAMPLING SITE CO-ORDINATES:** 49.8885 -112.0736

**FLOW SITE CO-ORDINATES:** 49.8885 -112.0736

**DESIGN FLOW CAPACITY:** 1.00 $m^3 s^{-1}$ (35 $ft^3 s^{-1}$)

**FLOW MEASUREMENT METHOD:** Weir

**ARD STATION GID NUMBER:** 8006


**DESCRIPTION:** Site T-R1 is located on Lateral G7 Spillway. This is the unused irrigation water from the Big Bend Main Canal and runoff from Drain G7 flowing to the Oldman River. T-R1 is the downstream site for the Big Bend segment with water originating from Taber Reservoir (T-S2). Water samples at T-R1 are taken upstream of the check structure on the spillway.

Flow at T-R1 is measured by TID using a weir formula and datalogger located in a stilling well upstream of the sampling site.

**NAME and SITE AREA:** T-R2 (Area 6a)

**LAND DESCRIPTION:** NE 9-11-14-4

**LATERAL NAME:** North Fincastle East Canal spill

**SAMPLING SITE CO-ORDINATES:** 49.9023 -111.8582

**FLOW SITE CO-ORDINATES:** 49.9023 -111.8582

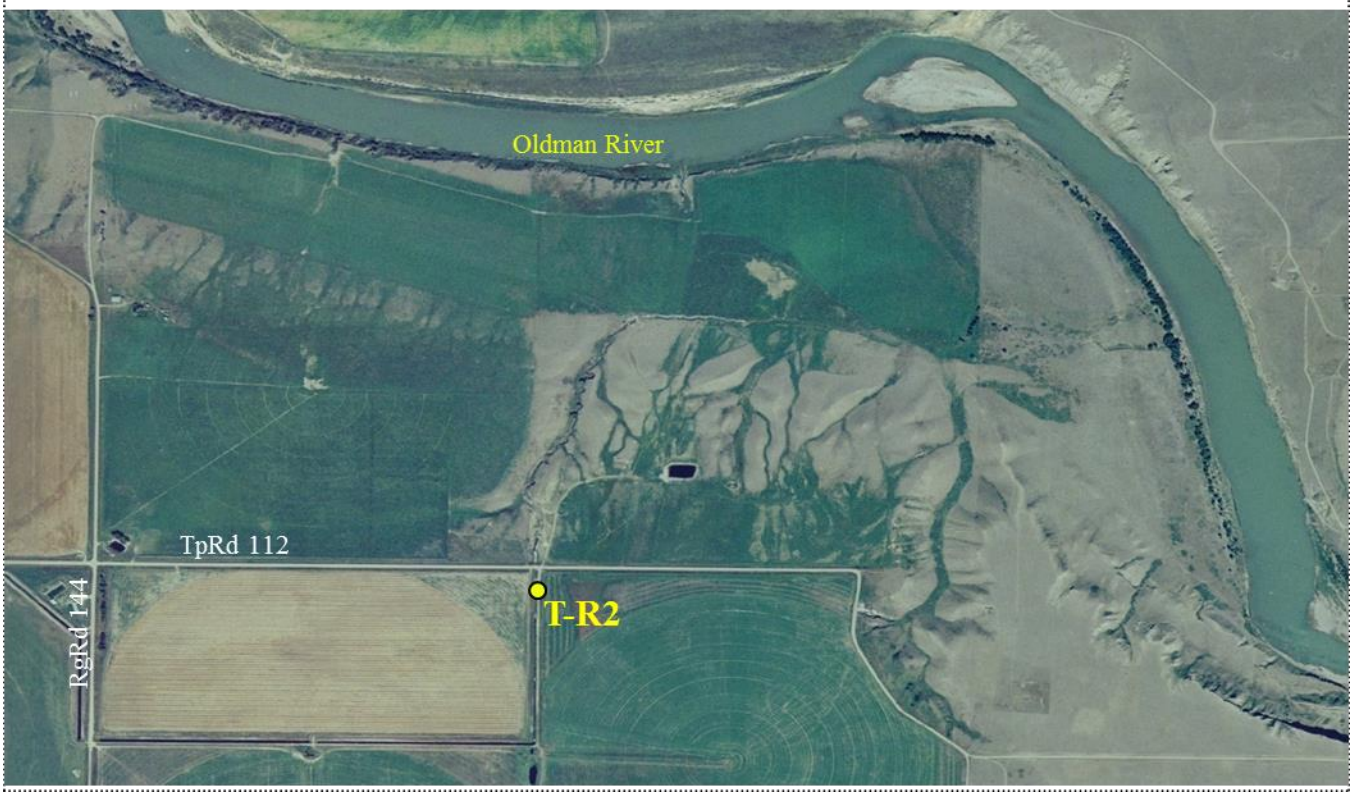
**DESIGN FLOW CAPACITY:** 0.91 $m^3 s^{-1}$ (32 $ft^3 s^{-1}$)

**FLOW MEASUREMENT METHOD:** Weir

**ARD STATION GID NUMBER:** 8011

**DESCRIPTION:** Site T-R2 is located on the North Fincastle East Canal Spill. This is the unused irrigation water from the North Fincastle East Canal flowing to the Oldman River. T-R2 is the downstream site for the North Fincastle East segment with water originating from Fincastle Reservoir (T-S3). Water samples at T-R2 are taken upstream of the check structure on the spill.

Flow at T-R2 is measured by TID using a weir formula and datalogger located in a stilling well at the site.



**SITE AREA and NAME:** Area 6b Site SMC-P1

**LAND DESCRIPTION:** SE 5-9-15-4

**LATERAL NAME:** SMRID Main Canal

**GPS CO-ORDINATES:** 49.7056 -112.0022

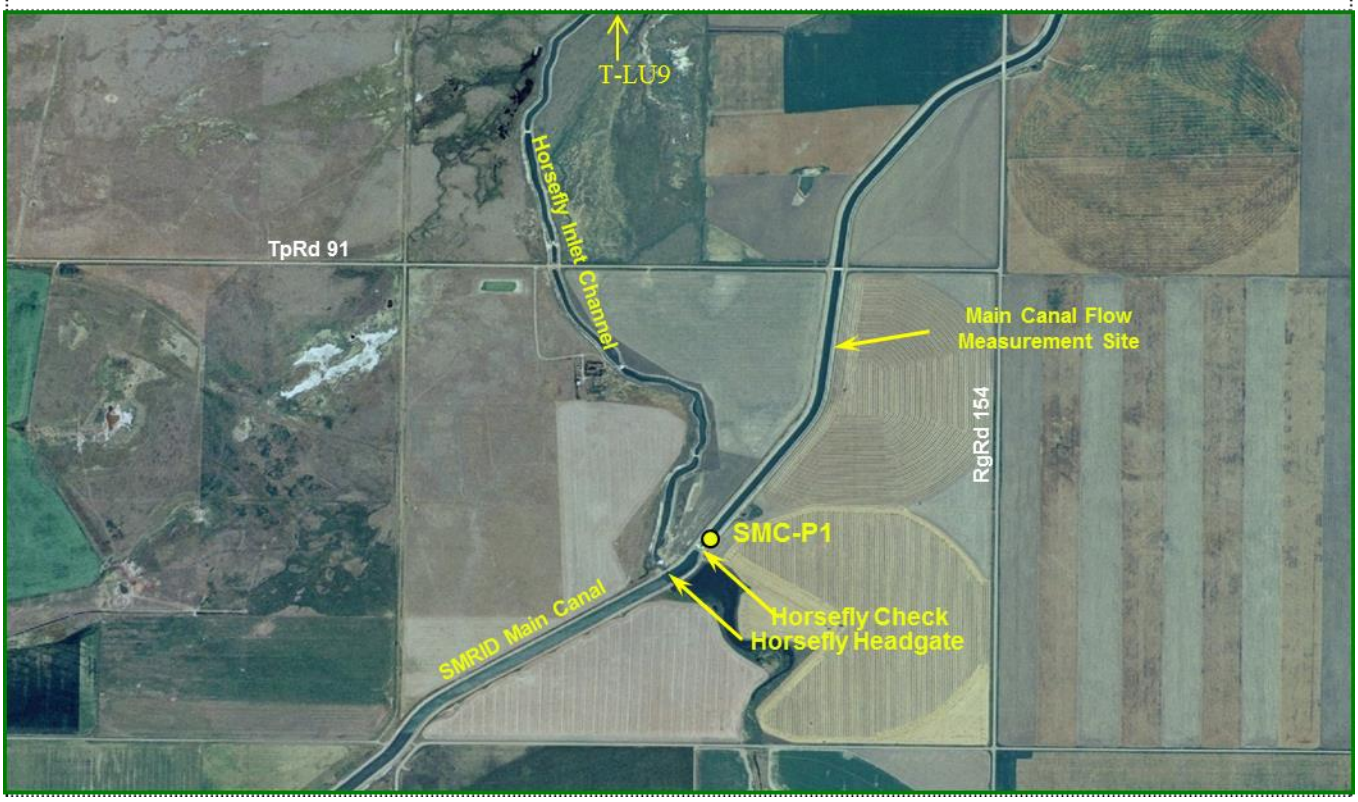
**DESIGNED FLOW CAPACITY:** 48.11 $m^3 s^{-1}$ (1700 $ft^3 s^{-1}$)

**ACTIVE GAUGING STATION:** Yes - operated by SMRID

**STATION GID # & LOCATION:** 9279 / NE 5-9-15-4

**DESCRIPTION:** Site SMC-P1 represents the quality of water diverted into the Horsefly Inlet Channel serving the East Horsefly block and Horsefly Reservoir of the TID, and the water entering the central block of the SMRID. Water samples are taken just downstream of the Horsefly Check in the SMRID Main Canal. There is a flow measurement station at Horsefly Check as well as an ultrasonic flow meter installed in the Main Canal approximately 1 km downstream from the sampling site. Flow capacity into Horsefly Inlet Channel is measured by gate opening.

This site (SMC-P1), in addition to T-LU9, is sampled during IDWQ Main sampling. During all other TID Land Use sampling dates, only T-LU9 is sampled.



**NAME and SITE AREA:** T-LU1 (Area 6a)

**LAND DESCRIPTION:** SE 4-10-16-4

**LATERAL NAME:** Lateral 15 tailout

**SAMPLING SITE CO-ORDINATES:** 49.7931 -112.1156

**FLOW SITE CO-ORDINATES:** 49.7931 -112.1156

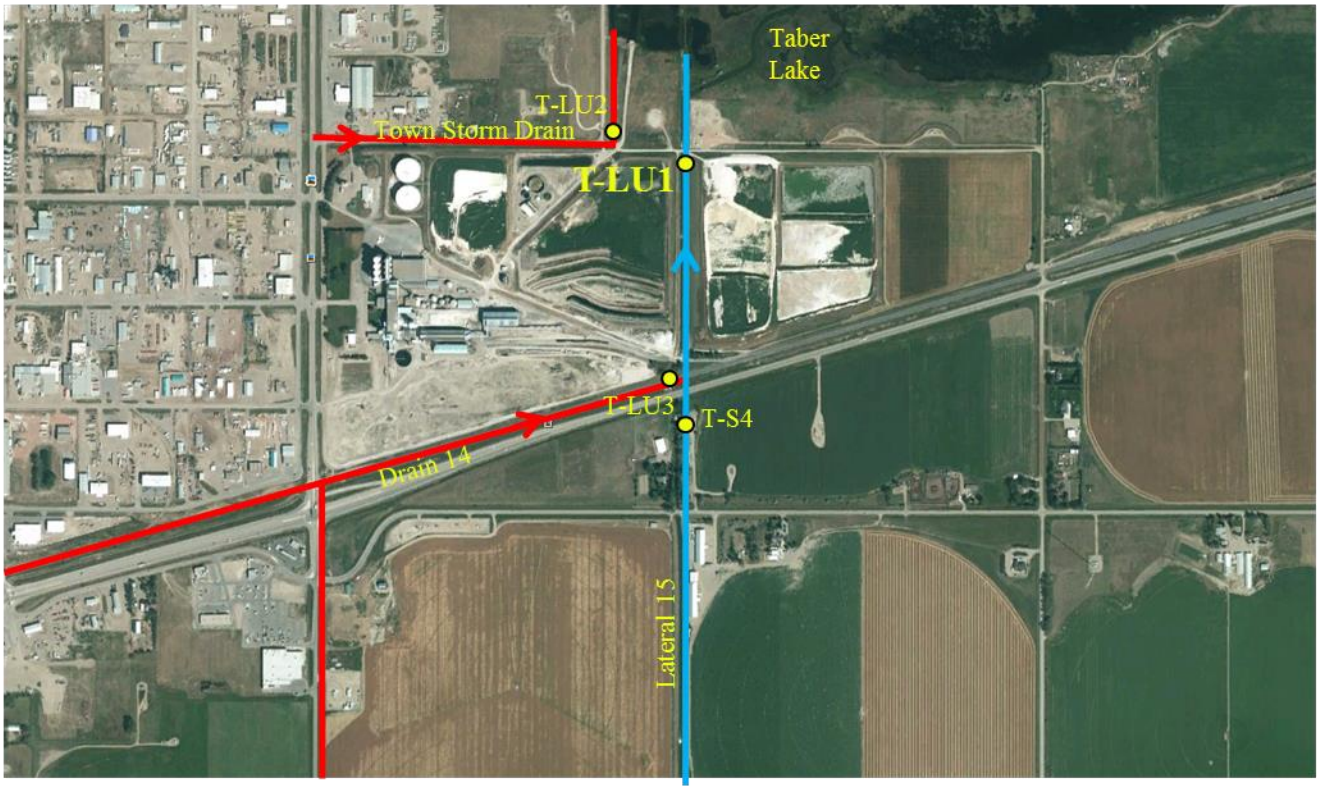
**DESIGN FLOW CAPACITY:** 7.08 $m^3 s^{-1}$ (250 $ft^3 s^{-1}$)

**FLOW MEASUREMENT METHOD:** Flow Curve

**ARD STATION GID NUMBER:** N/A

**DESCRIPTION:** Site T-LU1 is located on Lateral 15 just before it enters Taber Lake Reservoir. Lateral 15 is the main supply of water to the Taber Lake Reservoir and is generally from Horsefly Reservoir. When needed, water can be diverted from the Taber Main Canal (T-S1) via the Horsefly Outlet Channel to Lateral 15. During runoff, T-LU1 includes field runoff and Town of Taber storm water from T-LU3 that enters Lateral 15 downstream of T-S4. T-LU1 is an inflow site for Taber Lake Reservoir and the downstream site for the Lateral 15 segment. The upstream site for this segment is T-S4. Water samples at T-LU1 are taken upstream of the east-west road crossing culvert.

Flow at T-LU1 is measured using water height readings taken in the culvert at the sampling site and a flow curve. This site is instrumented with a pressure transducer datalogger to record water height.



**NAME and SITE AREA:** Site T-LU2 (Area 6a)

**LAND DESCRIPTION:** NW 4-10-16-4

**LATERAL NAME:** Town of Taber storm water drain

**SAMPLING SITE CO-ORDINATES:** 49.7933 -112.1179

**FLOW SITE CO-ORDINATES:** 49.7933 -112.1179

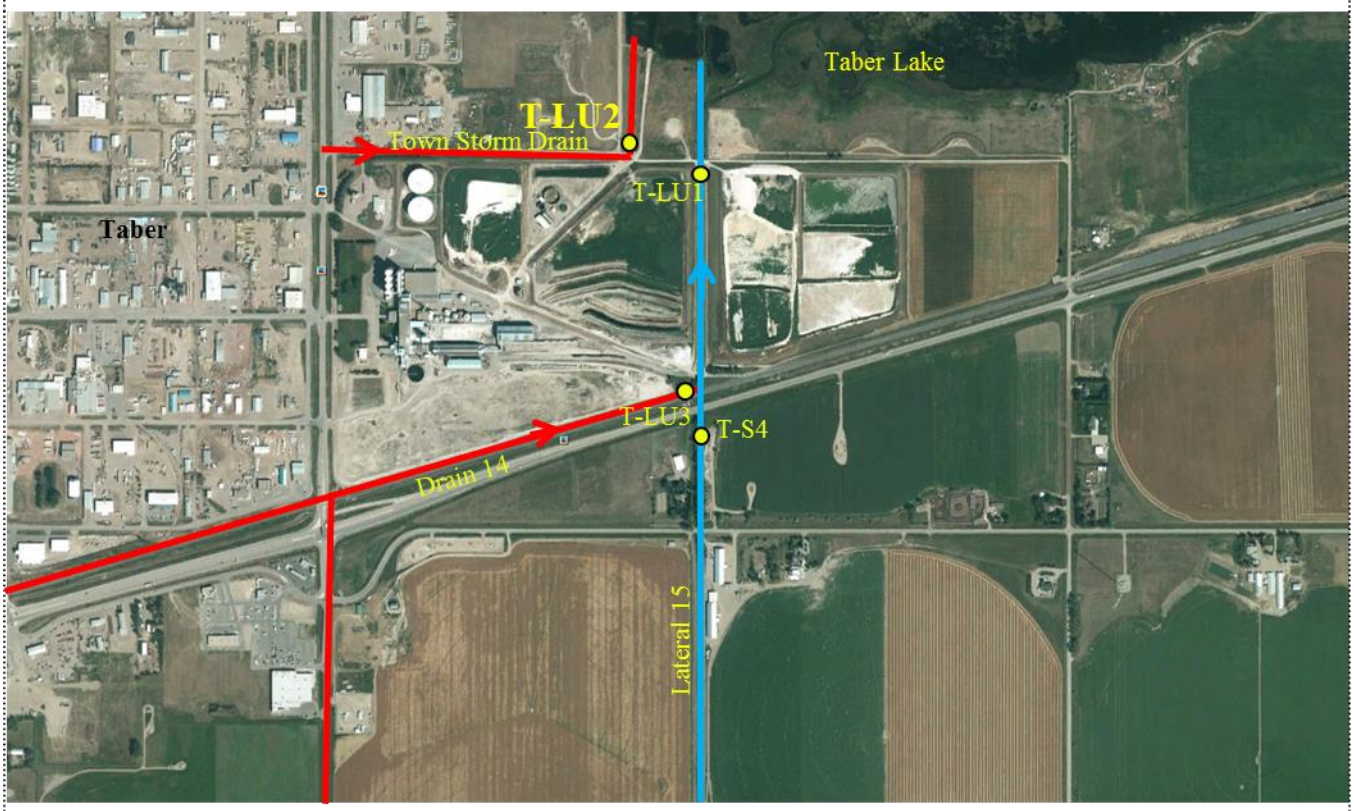
**DESIGN FLOW CAPACITY:** N/A

**FLOW MEASUREMENT METHOD:** Flow curve

**ARD STATION GID NUMBER:** N/A

**DESCRIPTION:** Site T-LU2 is located on a town of Taber storm water drain that includes runoff water from residential, industrial and commercial areas north of Highway 3, in the eastern half of the town of Taber. This site is one of two municipal storm water sites monitored. T-LU3 is the other municipal site but unlike T-LU3, T-LU2 does not flow into Lateral 15. T-LU2 flows directly into Taber Lake Reservoir. Water samples at T-LU2 are taken immediately downstream of the east-west road culvert just after the channel turns north to enter the reservoir.

Flow at T-LU2 is measured using water height reading taken in the culverts at the sampling site and a flow curve. This site is instrumented with a pressure transducer datalogger to record water height.



**NAME and SITE AREA:** T-LU3 (Area 6a)

**LAND DESCRIPTION:** SW 4-10-16-4

**LATERAL NAME:** Drain 14

**SAMPLING SITE CO-ORDINATES:** 49.7884 -112.1159

**FLOW SITE CO-ORDINATES:** 49.7884 -112.1159

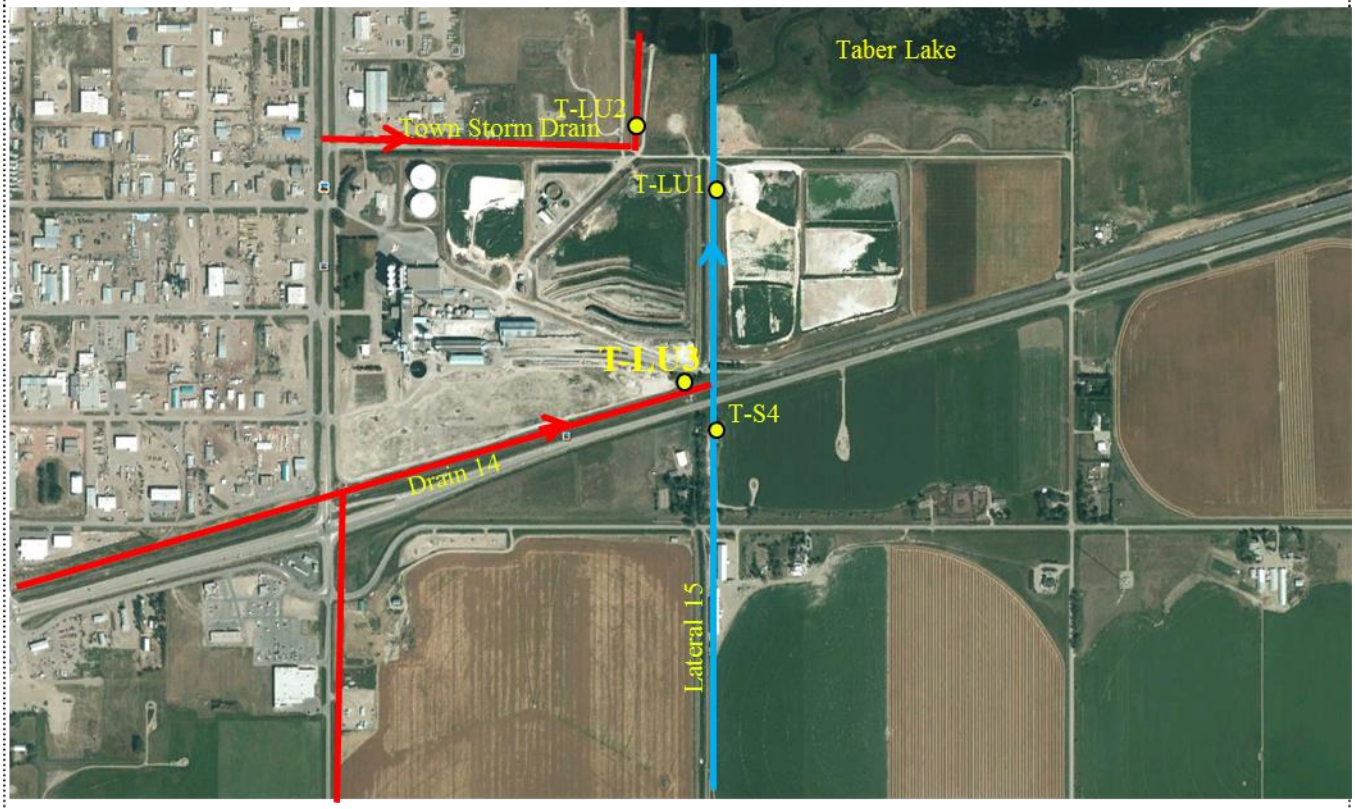
**DESIGN FLOW CAPACITY:** N/A

**FLOW MEASUREMENT METHOD:** Flow curve

**ARD STATION GID NUMBER:** N/A


**DESCRIPTION:** Site T-LU3 is located on Drain 14. Drain 14 was previously the tailout of Lateral 14. Lateral 14 was replaced with pipeline negating the need for a tailout channel for unused irrigation water. The downstream portion of the channel was retained to drain field runoff south of the Town of Taber and residential and commercial storm water from the southeast corner of Taber. T-LU3 is a municipal input that flows into Lateral 15. Lateral 15 is monitored upstream at T-S4 and downstream at T-LU1. Water samples at T-LU3 are taken on the west side of the culvert draining into Lateral 15 in the north ditch of Highway 3.

Flow at T-LU3 is calculated using water height readings measured in the culvert at the sampling site and a flow curve. This site is instrumented with a pressure transducer datalogger to record water height.



**NAME and SITE AREA:** T-LU4 (Area 6a)

**LAND DESCRIPTION:** NE 3-10-16-4

**LATERAL NAME:** Lateral 17 tailout

**SAMPLING SITE CO-ORDINATES:** 49.7931 -112.0932

**FLOW SITE CO-ORDINATES:** 49.7931 -112.0932

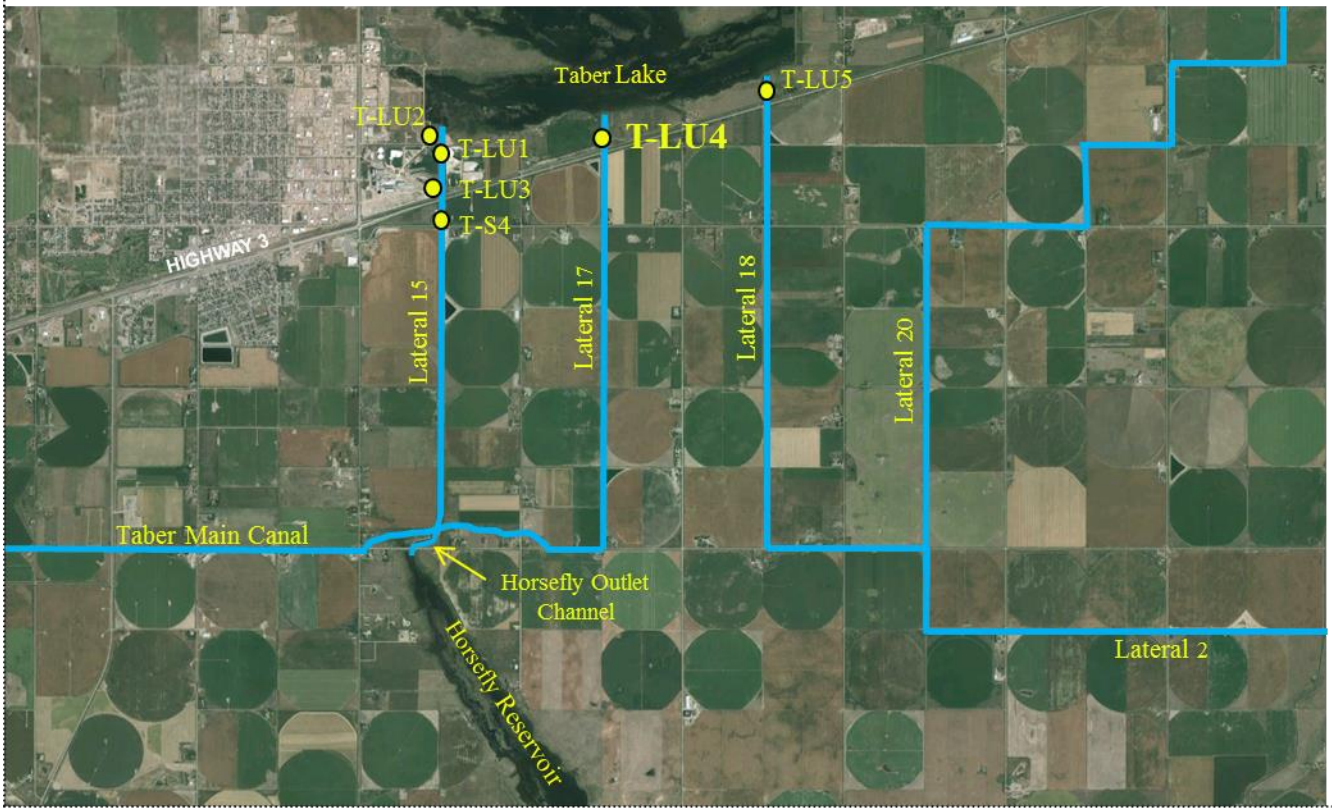
**DESIGN FLOW CAPACITY:** 0.71 $m^3 s^{-1}$ (25 $ft^3 s^{-1}$)

**FLOW MEASUREMENT METHOD:** Weir

**ARD STATION GID NUMBER:** N/A

**DESCRIPTION:** Site T-LU4 is located on the tailout of Lateral 17. This is the unused irrigation water from Lateral 17. Some supply water for Taber Lake Reservoir comes from Taber Main Canal and it flows to the reservoir via Lateral 17. T-LU4 is an inflow site for Taber Reservoir and the downstream site of the Taber Main Canal segment. This water originates from SMRID Main Canal and is diverted into the Taber Main Canal and then flows into Lateral 17. It may also contain water from Horsefly Reservoir if the Horsefly Outlet Channel is being used to supply Lateral 17. Water samples at T-LU4 are taken at the check structure downstream of the railway tracks.

Flow at T-LU4 is measured at the check structure at the sampling site using a weir formula. This site is instrumented with a pressure transducer datalogger to record water height.



**NAME and SITE AREA:** T-LU5 (Area 6a)

**LAND DESCRIPTION:** NE 2-10-16-4

**LATERAL NAME:** Lateral 18 tailout

**SAMPLING SITE CO-ORDINATES:** 49.7980 -112.0707

**FLOW SITE CO-ORDINATES:** 49.7980 -112.0707

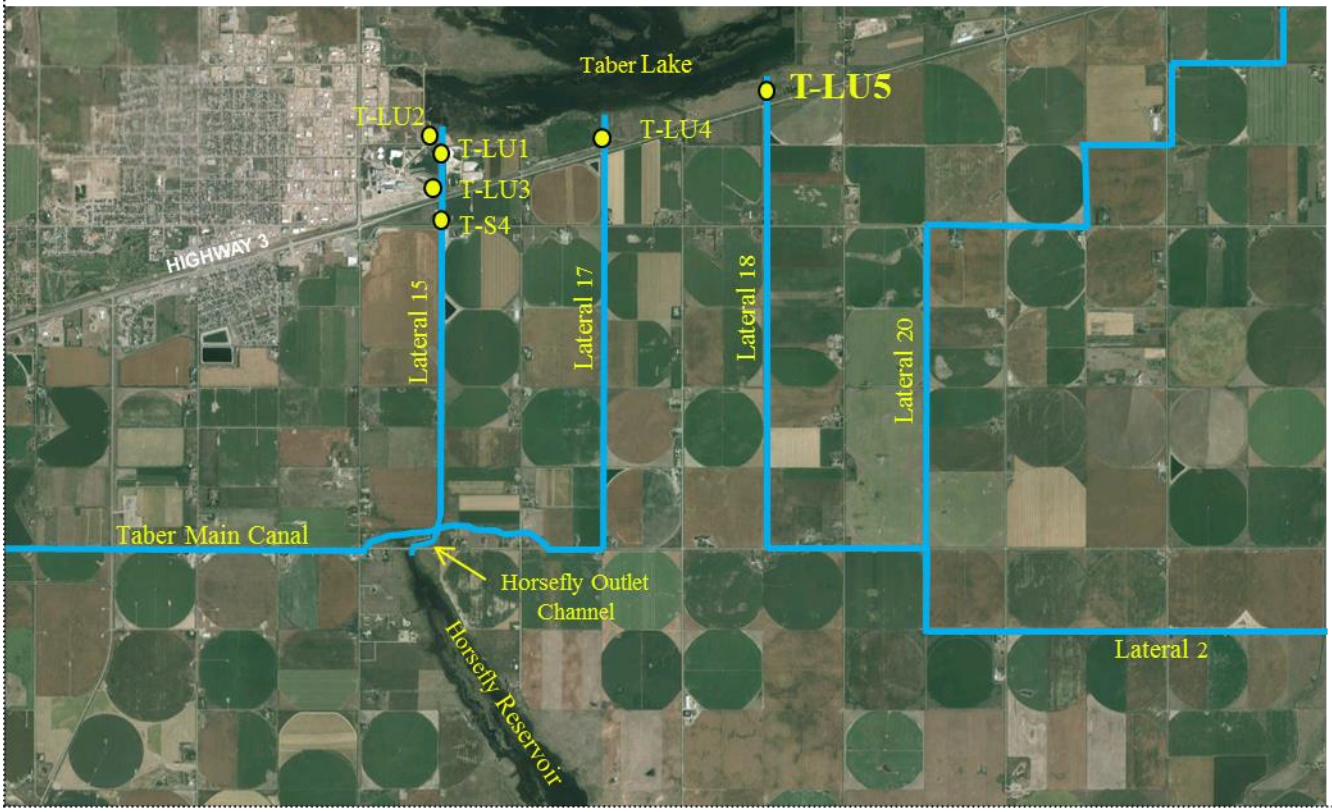
**DESIGN FLOW CAPACITY:** 1.47 $m^3 s^{-1}$ (52 $ft^3 s^{-1}$)

**FLOW MEASUREMENT METHOD:** Weir

**ARD STATION GID NUMBER:** N/A

**DESCRIPTION:** Site T-LU5 is located on the tailout of Lateral 18. This is the unused irrigation water from Lateral 18 flowing to Taber Lake Reservoir. T-LU5 is an inflow site for Taber Reservoir and the downstream site of Horsefly channel-Lateral 18 segment. The upstream site of this segment is T-LU9 on the East Horsefly Main Canal. This water originates from the SMRID Main Canal and is diverted into the Horsefly Inlet Channel and then to the East Horsefly Main Canal. It travels down Lateral 2 to Lateral 18. Water samples at T-LU5 are taken at the check structure downstream of the railway tracks.

Flow at T-LU5 is measured at the check structure at the sampling site using a weir formula. This site is instrumented with a pressure transducer datalogger to record water height.



**NAME and SITE AREA:** T-LU6a (Area 6b)

**LAND DESCRIPTION:** SE 17-10-15-4

**LATERAL NAME:** Lateral M tailout

**SAMPLING SITE CO-ORDINATES:** 49.8222 -111.9992

**FLOW SITE CO-ORDINATES:** 49.8222 -112.0120

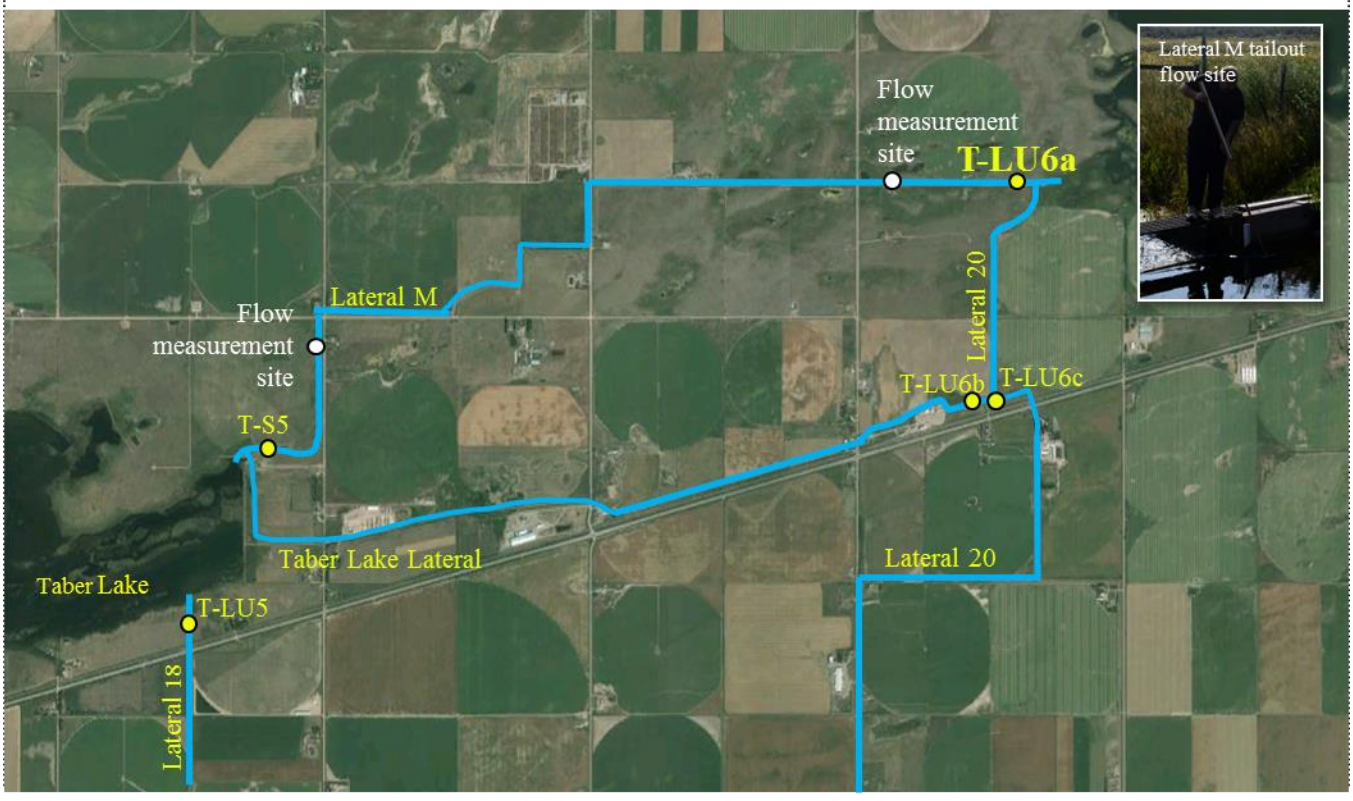
**DESIGN FLOW CAPACITY:** 0.65 $m^3 s^{-1}$ (23 $ft^3 s^{-1}$)

**FLOW MEASUREMENT METHOD:** Weir

**ARD STATION GID NUMBER:** N/A

**DESCRIPTION:** Site T-LU6a is located on tailout of Lateral M just upstream of where it merges with Lateral 20. This is the unused irrigation water from Lateral M flowing to Fincastle Reservoir. T-LU6a is an inflow site for Fincastle Reservoir and the downstream site of the Lateral M segment. Water in Lateral M originates from Taber Lake Reservoir (Site T-S5) and mixes with Lateral 20 water (combination of T-LUb and T-LUc) downstream of T-LU6a. T-LU6b flows into Lateral 20 (T-LU6c) 1.5 km upstream of where T-LU6a joins Lateral 20. Water samples at T-LU6a are taken directly upstream of the culvert before the intersection with Lateral 20.

Flow at T-LU6a is measured approximately 1 km upstream at a check structure east of Range Road 155 using a weir formula. This site is instrumented with a pressure transducer datalogger to record water height.



**NAME and SITE AREA:** T-LU6b (Area 6b)

**LAND DESCRIPTION:** NW 8-10-15-4

**LATERAL NAME:** Taber Lake Lateral tailout

**SAMPLING SITE CO-ORDINATES:** 49.8105 -112.0033

**FLOW SITE CO-ORDINATES:** 49.8105 -112.0033

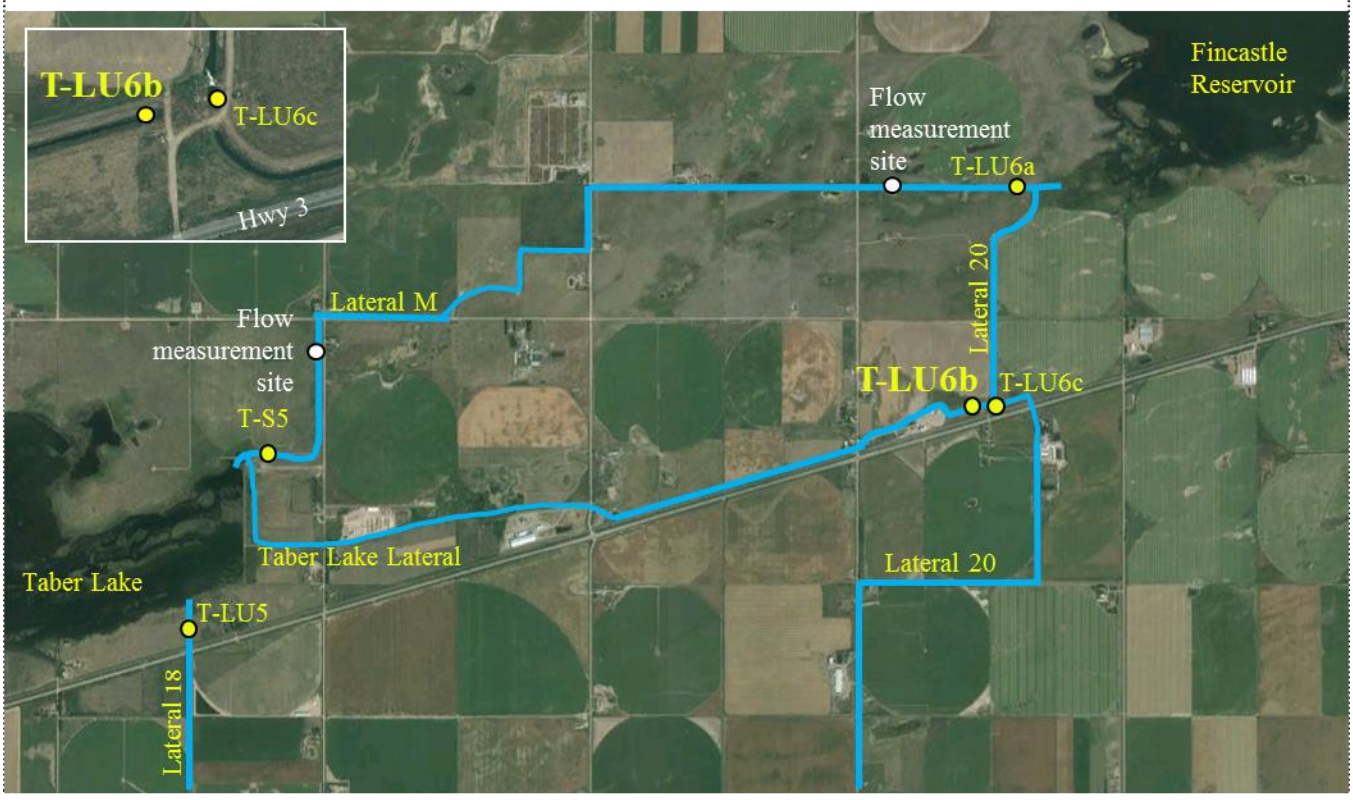
**DESIGN FLOW CAPACITY:** 0.25 $m^3 s^{-1}$ (9 $ft^3 s^{-1}$)

**FLOW MEASUREMENT METHOD:** Flow curve

**ARD STATION GID NUMBER:** N/A


**DESCRIPTION:** Site T-LU6b is located on the tailout of Taber Lake Lateral. This is the unused irrigation water of Taber Lake Lateral and includes several inlets that drain road and field runoff into the channel. This water is flowing to Fincastle Reservoir. T-LU6b is an inflow site for Fincastle Reservoir and the downstream site for the Taber Lake Lateral segment. This water originates from Taber Lake Reservoir (T-S5) and merges immediately downstream of T-LU6b with Lateral 20 (T-LU6c). Tailout of Lateral M (T-LU6a) joins Lateral 20 downstream before it flows into Fincastle Reservoir. Water samples at T-LU6b are taken upstream of the culvert before the intersection with Lateral 20.

Flow at T-LU6b is measured using water heights measured in the culvert at the sampling site and a flow curve. This site is instrumented with a pressure transducer datalogger to record water height.



**NAME and SITE AREA:** T-LU6c (Area 6b)

**LAND DESCRIPTION:** NE 8-10-15-4

**LATERAL NAME:** Lateral 20

**SAMPLING SITE CO-ORDINATES:** 49.8106 -112.0027

**FLOW SITE CO-ORDINATES:** 49.8106 -112.0027

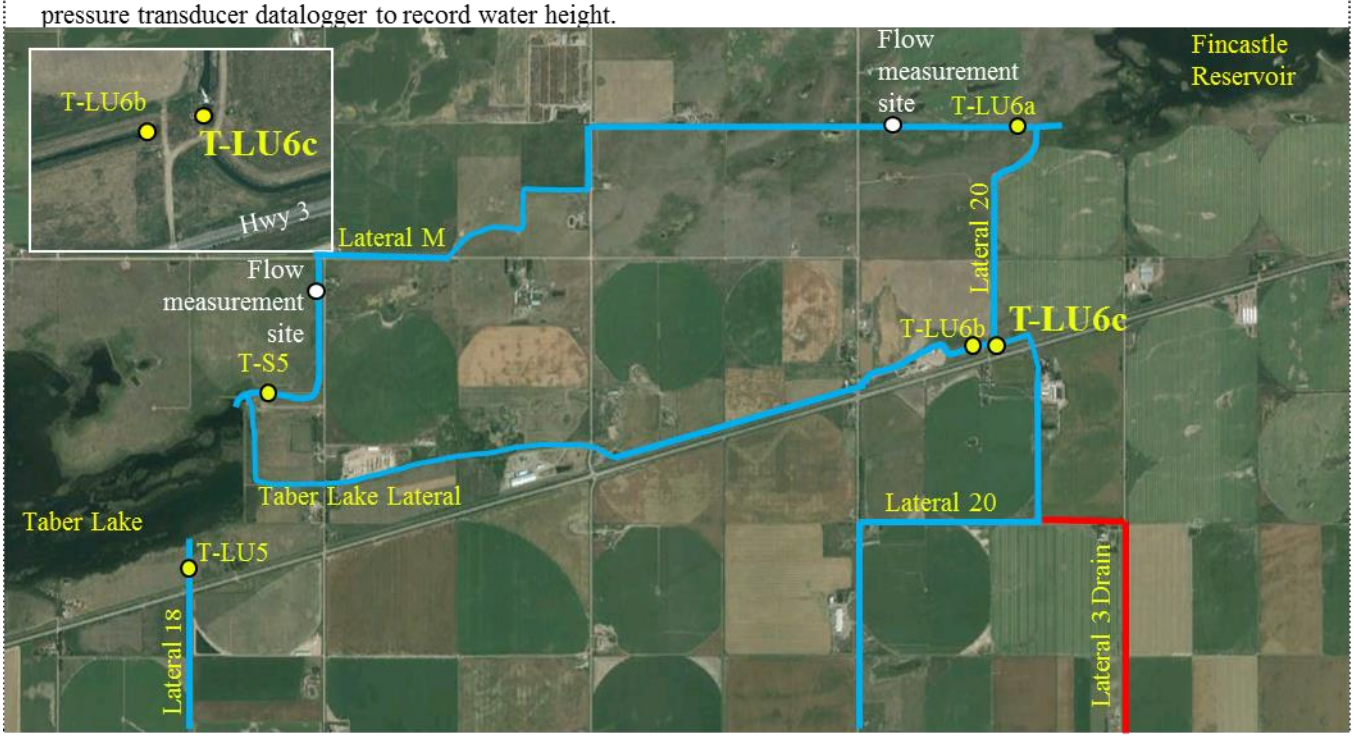
**DESIGN FLOW CAPACITY:** 1.67 $m^3 s^{-1}$ (59 $ft^3 s^{-1}$)

**FLOW MEASUREMENT METHOD:** Weir

**ARD STATION GID NUMBER:** N/A

**DESCRIPTION:** Site T-LU6c is located on Lateral 20. This is irrigation water flowing to Fincastle Reservoir. Prior to 2014, this water was a mixture of water from Lateral 3 and Lateral 20 but Lateral 3 has been replaced with a pipeline. This eliminated Lateral 3 but the channel was retained as a drain to collect field runoff during snow melt and heavy rainfall events. This drain water mixes with Lateral 20 during runoff events and would be sampled at T-LU6c. T-LU6c is an inflow site for Fincastle Reservoir and the downstream site for the Horsefly channel-Lateral 20 segment. The upstream site of this segment is T-LU9 on the East Horsefly Main Canal. This water originates from the SMRID Main Canal and is diverted into the Horsefly Inlet Channel and then to the East Horsefly Main Canal. The water is then diverted to Lateral 2 and then to Lateral 20. The tailout of Taber Lake Lateral (T-LU6b) flows into Lateral 20 immediately downstream of T-LU6c and tailout from Lateral M (T-LU6a) merges further downstream. Water samples at T-LU6c are taken just upstream of the check structure.

Flow is measured at the check structure at the sampling site using a weir formula. This site is instrumented with a pressure transducer datalogger to record water height.



**NAME and SITE AREA:** T-LU7 (Area 6b)

**LAND DESCRIPTION:** NW 15-10-15-4

**LATERAL NAME:** Lateral 7 tailout

**SAMPLING SITE CO-ORDINATES:** 49.8238 -111.9687

**FLOW SITE CO-ORDINATES:** 49.8238 -111.9687

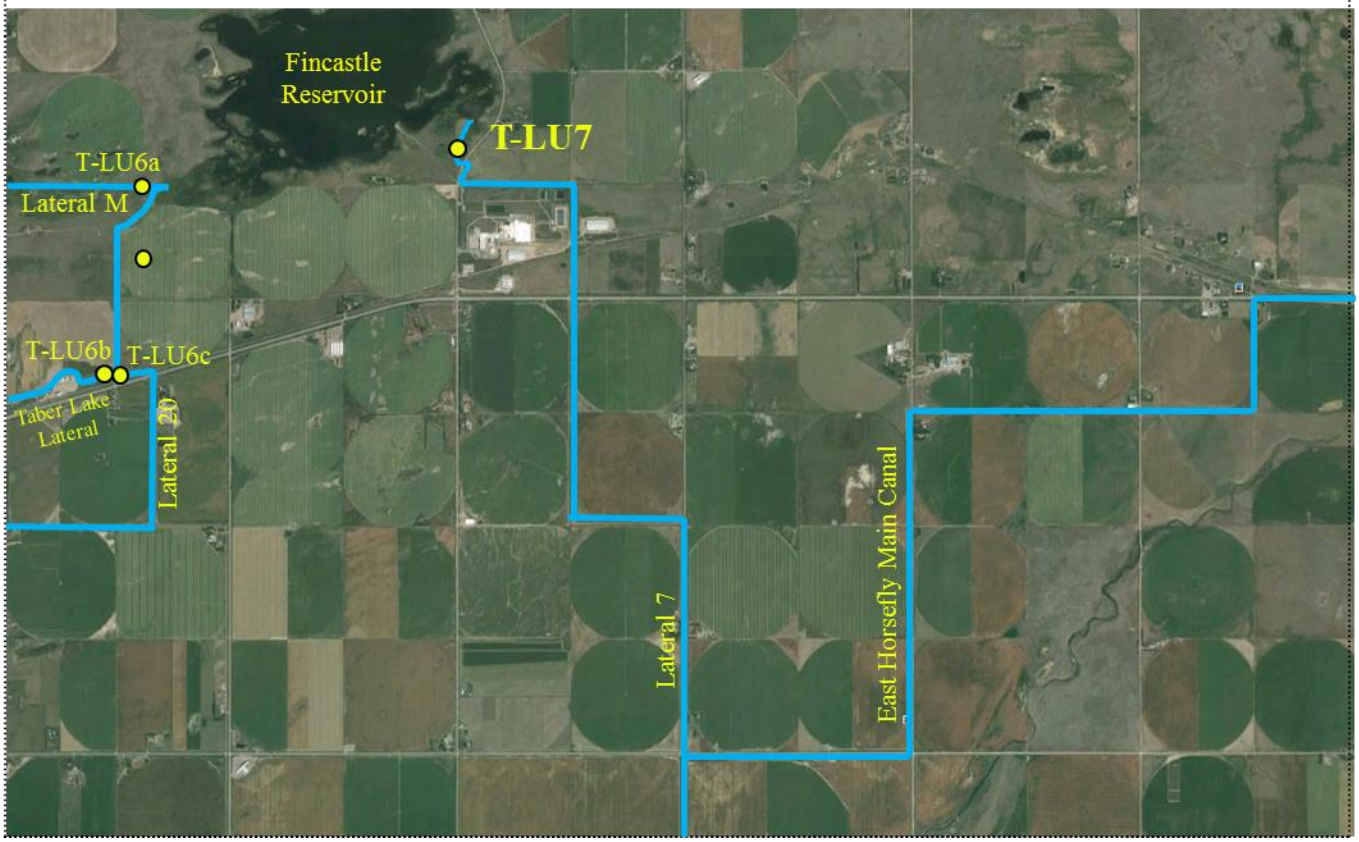
**DESIGN FLOW CAPACITY:** 2.66 $m^3 s^{-1}$ (94 $ft^3 s^{-1}$)

**FLOW MEASUREMENT METHOD:** Weir

**ARD STATION GID NUMBER:** N/A

**DESCRIPTION:** Site T-LU7 is located on the tailout of Lateral 7. This is the unused irrigation water from Lateral 7 that is flowing to Fincastle Reservoir. It is an inflow site for Fincastle Reservoir and the downstream site for the Horsefly Channel-Lateral 7 segment. The upstream site of this segment is T-LU9 on the East Horsefly Main Canal. This water originates from the SMRID Main Canal and is diverted into the Horsefly Inlet Channel, the East Horsefly Main Canal, and finally into Lateral 7. Water samples at T-LU7 are taken just upstream of the structure on the reservoir channel on the west side of the paved road.

Flow at T-LU7 is measured at the check structure of the sampling site using a weir formula. This site is instrumented with a pressure transducer datalogger to record water height.



## A.3 References

**Charest, J., Olson, B., Kalischuk, A., and Gross, D. (eds.). 2012.** Irrigation Districts Water Quality Project 2011 to 2015: 2011 Progress Report. Alberta Agriculture and Rural Development, Lethbridge, Alberta, Canada. 218 pp.

**Charest, J., Olson, B., Kalischuk, A., and Gross, D. (eds.). 2013.** Irrigation Districts Water Quality Project 2011 to 2015: 2012 Progress Report. Alberta Agriculture and Rural Development, Lethbridge, Alberta, Canada. 142 pp.

**Charest, J., Olson, B., Kalischuk, A., and Gross, D. (eds.). 2014.** Irrigation Districts Water Quality Project 2011 to 2015: 2013 Progress Report. Alberta Agriculture and Rural Development, Lethbridge, Alberta, Canada. 157 pp.

# Appendix B. Weather

## B.1 Introduction

Weather conditions can influence water quality. Temperature and precipitation are two important factors that can be used to help the interpretation of water quality data. Monthly data are presented to help compared the weather conditions every year.

## B.2 Method

Environment Canada weather stations at Cardston, Lethbridge CDA, Medicine Hat, Brooks, and Calgary INT'L CS (Figure B.1) were used to monitor the temperature and precipitation throughout the Alberta irrigation districts for this project. Monthly average daily temperatures and monthly total precipitation values for 2011 to2014 were compiled, and daily total precipitation values for 2014 were obtained from Environment Canada (2011-2014) and compared to the 30-yr averages (1971 to 2000) for each of the five weather stations.


**Figure B.1. Location of Environment Canada weather stations used to monitor weather for the project. Colored area represents the irrigation districts.**

## B.3 Results

Monthly average temperatures in 2014 were generally very similar to the prior years. Temperature in 2014 was most comparable with that of 2012 (Figure B.2) at all stations with the exception of the Lethbridge station. June of 2014 was cooler at all five stations as compared to the previous three years and the 30-ys average. In July 2014 temperatures where comparable or above the previous years but in August the 2014 temperatures were just above the 30-yr average and below that of the three preceding years.

Precipitation recorded during the irrigation season of 2014was highest at the Cardston and Calgary stations, followed by Medicine Hat and Brooks and then Lethbridge. (Table B.1). Four of the five weather stations recorded total yearly precipitation below the 30-yr averages in 2014 (Table B.1). Despite being below the 30-yr average for yearly precipitation, four of the stations recorded above average precipitation in June. (Figure B.3) Rainfall events in June and September (Figure B.4) were seen to impact the physical parameters of some samples, particularly TSS (Chapter 3).

**Table B.1. Total yearly precipitation from five Environment Canada weather stations from 2011-2014 and the 30-yr average.**

| Station | 30-yr average[z] | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|
| | ---------- (mm) ---------- | | | | |
| Cardston | 557 | 468 | 357 | 408 | 552 |
| Lethbridge CDA | 365 | 429 | 263 | 300 | 267 |
| Medicine Hat | 334 | 261 | 304 | 287 | 375 |
| Brooks | 348 | 256 | 348 | 283 | 330 |
| Calgary INT'L CS | 412 | 510 | 371 | 400 | 390 |

[z] Environment Canada (2012).

## B.4 References

**Environment Canada. 2014.** National Climate Data and Archives. Environment Canada. [Online] http://www.climate.weatheroffice.gc.ca/advanceSearch/searchHistoricData_e.html?Prov=AB&StationID=9999&Year=2014&Month=6&Day=20&timeframe=1.

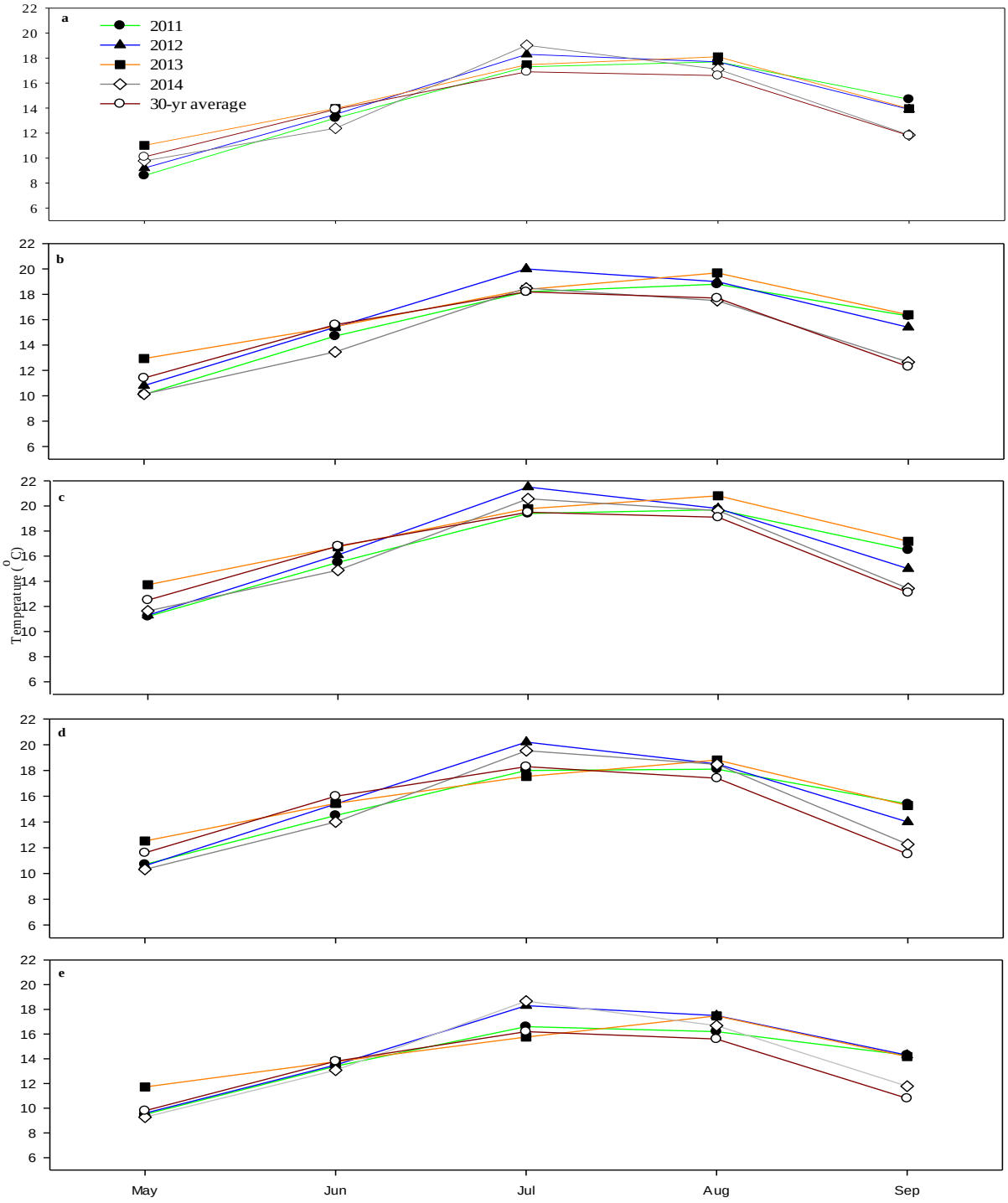



**Figure B.2. Comparison of 30-yr averages (1971 to 2000) with monthly average daily temperatures from (May to September) 2011 to 2014 at (a) Cardston, (b) Lethbridge, (c) Medicine Hat, (d) Brooks, and (e) Calgary weather stations (Environment Canada 2011-2014).**

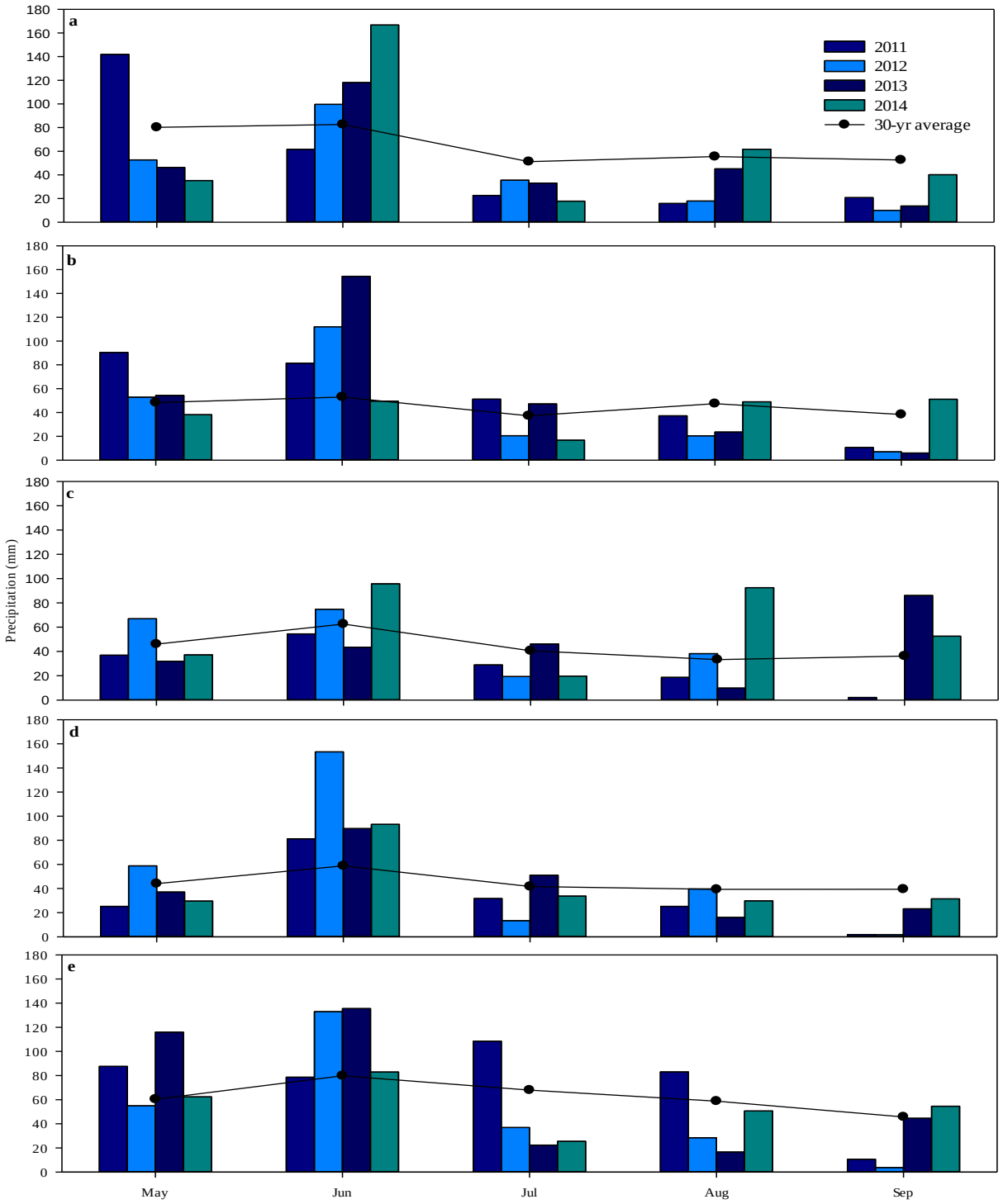



**Figure B.3. Comparison of 30-yr averages (1971 to 2000) to monthly total precipitation (May to September) from 2011 to 2014 at (a) Cardston, (b) Lethbridge, (c) Medicine Hat, (d) Brooks, and (e) Calgary weather stations (Environment Canada 2011- 2014).**

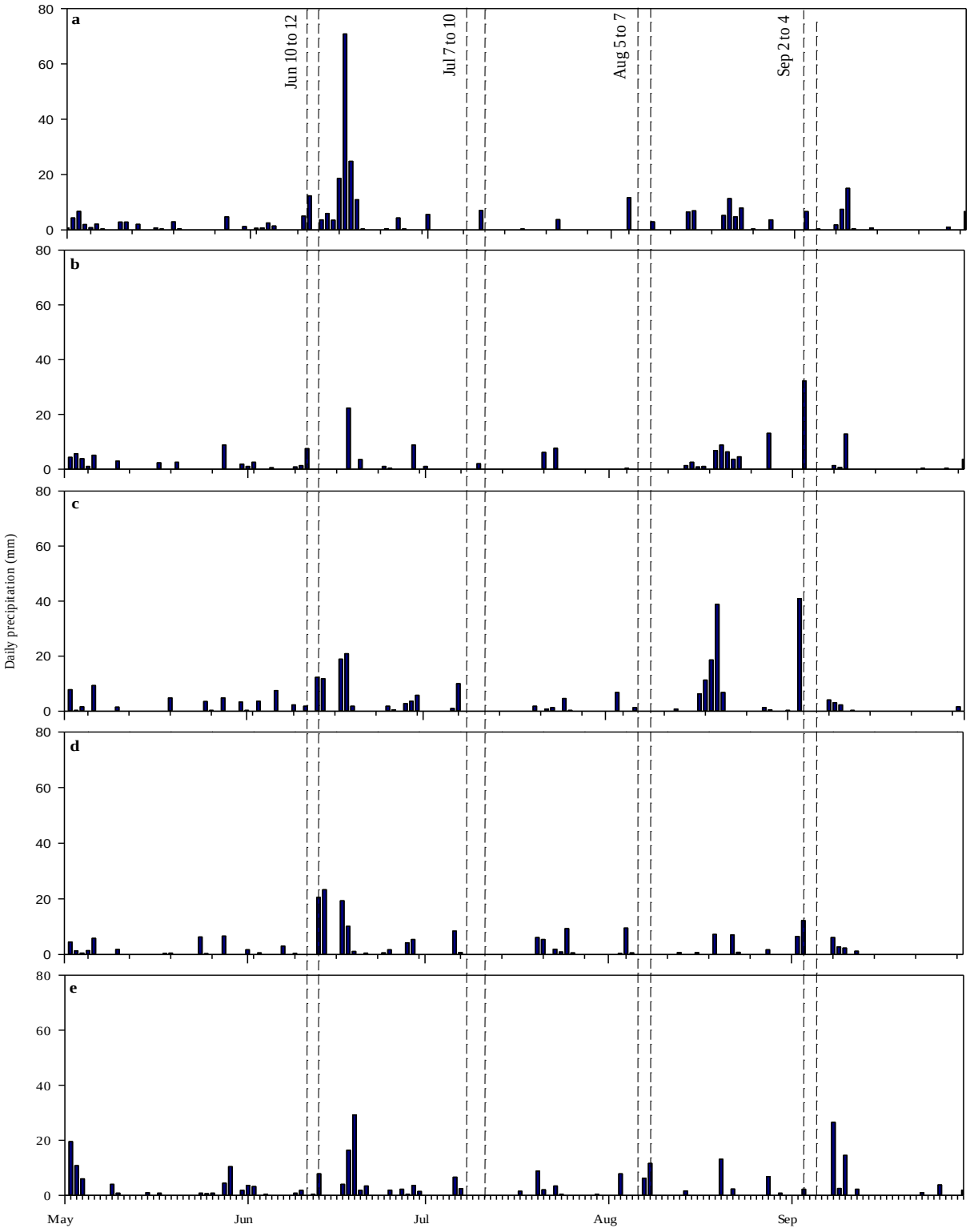



**Figure B.4. Daily total precipitation from May 1 to September 30, 2014 at (a) Cardston, (b) Lethbridge, (c) Medicine Hat, (d) Brooks, and (e) Calgary weather stations (Environment Canada 2014).** The four sampling dates are delineated by vertical dashed lines.

# Appendix C. Quality Assurance/Quality Control and Quality Assurance/Surveillance Plan

## C.1 Introduction

A quality assurance/quality control (QA/QC) plan was developed to ensure an accurate, precise, and representative water quality database by applying standard protocols for field sampling and sample shipping (section 2.2), as well as laboratory analysis and inter-laboratory comparison.

In 2014, Exova Group Limited (Exova laboratory in Calgary, Alberta) analyzed nutrient, salinity, metal, physical, and microbiological parameters. It was Exova's responsibility to manage the laboratory analysis QA/QC plan.

Alberta Agriculture and Forestry (AF) implemented a Quality Assurance and Surveillance Plan (QASP) to evaluate the quality of data from the field sampling and the laboratory analysis. The role of the QASP was to ensure the contract standards were achieved and maintained by following a predetermined action plan, including:

- Review and approve analytical methods and standard operation procedures for all analytes.
- Review the quality control program and ensure corrective steps are in place.
- Perform a visual inspection of the facility.
- Review the measurable method detection limits (MMDL).
- Compare field duplicate samples tested within Exova laboratory and between AF and Exova laboratories.
- Evaluate results from field and laboratory blank samples tested by AF and Exova laboratories.
- Compare results from blind reference samples (check standards) with known values of analytes prepared by the AF and analyzed by the Exova laboratory.

## C.2 Field QA/QC samples

A total of 16 QA/QC samples were collected for each of the four sampling events in 2014. The QA/QC samples included duplicates, field blanks, and check standards. The duplicates were defined as replicates composed of discrete samples collected consecutively from the same location over a short period of time. Duplicate and blank samples were collected at randomly selected sites (Table C.1). There were nine duplicate samples identified as D-ARD-1 to D-ARD-9, which were analyzed by the AF laboratory. There were also three duplicates samples (D-E1, D-E2, D-E3) collected and sent to the Exova, Agriculture and Agri-Food Canada

(AAFC), Alberta Innovates (AI) laboratories and the National Hydrology Research Centre (NHRC). The duplicates were irrigation water samples. The duplicate samples sent to the AF and Exova laboratories were analyzed for routine, nutrient, total nitrogen (TN) and coliforms. The duplicates sent to the AAFC and AI laboratories were analyzed for pesticides, and the duplicates sent to the NHRC were analyzed for pharmaceuticals. The D-E1 to D-E3 duplicate samples were sampled at the same sites and times as D-ARD-1 to D-ARD-3. Therefore, these were triplicates for the nutrient, salinity and coliforms parameters.

Three field blanks (BK-1, BK-2, BK-3) were collected per sampling event (Table C.1) by filling bottles with double distilled water at selected sampling sites. The double distilled water was prepared by the AF laboratory and transported to the sites in two, 1-L polyethylene bottles. The double distilled water was used to triple rinse and fill the 1-L sampling bottle. The filled sampling bottle was then used to triple-rinse and fill the routine, nutrient, TN, and coliform bottles as described in Sub-section 2.2. The sample methodology used for the blank samples was the same as for all other samples to maintain the same level of risk for potential contamination.

Finally, one check standard (CS-1) sample per sampling event (including one nutrient, one routine, and one metals bottle) was prepared by the AF laboratory and shipped to Exova with the other samples. For each sampling event, check standards with pre-determined concentrations of nutrient and salinity parameters were prepared by AF laboratory, and certified reference materials (SCP Science, Baie D'Urfé, Québec) were used to prepare the check standard for metals.

### C.3 Accuracy and Precision

Accuracy is a measure of how close an analyzed value is to the true value. The accuracy of an analysis can be determined by the measurement of reference materials of known value, either directly, or as a spiked sample having the same matrix as the samples in question. The results are entered into an X-bar control chart to track the accuracy and ensure that it is within the acceptable percent confidence interval, either 95 or 99%, depending on the performance quality of the individual laboratory or specified analyte.

Precision is a measure of the variability of individual measurements of either field or laboratory replicated samples. The variance of field and laboratory replicates should be equal if sampling and storage have no effect on analysis. The results are entered into an R-bar control chart to track the variability and ensure that it is within the acceptable percentage confidence interval (95 or 99%).

**Table C.1. Duplicate (D), field blank (BK), and check standard (CS) samples in 2014.** Duplicate samples were analyzed by Alberta Agriculture and Rural Development (D-ARD-1 to -9), Exova(D-E1 to 3; BK-1 to -3; CS-1), and Agriculture and Agri-Food Canada, Alberta Innovates laboratories and the National Hydrology Research Centre (D-E1 to 3).

| Qa/Qc sample[z] | Sampling date | Irrigation district | Sampling site |
|---|---|---|---|
| | *First sampling time* | | |
| D-ARD-1; D-E1 | June 10 | WID | W-P2 |
| D-ARD-2; D-E2 | June 11 | LNID | LN-S2 |
| D-ARD-3; D-E3 | June 11 | UID | U-R4 |
| D-ARD-4 | June 10 | EID | E-R5 |
| D-ARD-5 | June 12 | RCID | RC-P1 |
| D-ARD-6 | June 10 | WID | W-S4 |
| D-ARD-7 | June 11 | LNID | LN-R4 |
| D-ARD-8 | June 12 | EID | E-R7 |
| D-ARD-9 | June 12 | SMRID | SMW-P1 |
| BK-1 | June 10 | TID | T-R2 |
| BK-2 | June 11 | UID | U-P1 |
| BK-3 | June 11 | BRID | BR-S1 |
| CS-1 | June 12 | - | - |
| | *Second sampling time* | | |
| D-ARD-1; D-E1 | July 10 | EID | E-R4a |
| D-ARD-2; D-E2 | July 10 | EID | E-S2 |
| D-ARD-3; D-E3 | July 08 | MVID | MV-R1 |
| D-ARD-4 | July 07 | WID | W-S1 |
| D-ARD-5 | July 07 | WID | W-S3 |
| D-ARD-6 | July 10 | EID | E-R2 |
| D-ARD-7 | July 08 | BRID | BR-S5 |
| D-ARD-8 | July 09 | SMRID | SME-R2 |
| D-ARD-9 | July 08 | UID | U-S1 |
| BK-1 | July 10 | EID | E-S7 |
| BK-2 | July 09 | SMRID | SMC-S1 |
| BK-3 | July 07 | SMRID | SMC-P1 |
| CS-1 | July 08 | - | - |
| | *Third sampling time* | | |
| D-ARD-1; D-E1 | August 05 | WID | W-R1a |
| D-ARD-2; D-E3 | August 07 | EID | E-P1 |
| D-ARD-3; D-E2 | August 05 | EID | E-S6 |
| D-ARD-4 | August 05 | TID | T-S1 |
| D-ARD-5 | August 05 | TID | T-S2 |
| D-ARD-6 | August 06 | LNID | LN-S3 |
| D-ARD-7 | August 06 | - | AEP-S2 |
| D-ARD-8 | August 06 | BRID | BR-S3 |
| D-ARD-9 | August 06 | LNID | LN-R2 |
| BK-1 | August 06 | LNID | LN-S4 |
| BK-2 | August 05 | - | AEP-P3 |
| BK-3 | August 07 | SMRID | SMW-R1 |
| CS-1 | August 06 | - | - |
| | *Fourth sampling time* | | |
| D-ARD-1; D-E1 | September 02 | EID | E-S5 |
| D-ARD-2; D-E2 | September 02 | EID | E-S4 |
| D-ARD-3; D-E3 | September 02 | TID | T-R1 |
| D-ARD-4 | September 02 | TID | T-S4 |
| D-ARD-5 | September 04 | BRID | BR-R1 |
| D-ARD-6 | September 04 | SMRID | SMW-S2 |
| D-ARD-7 | September 03 | SMRID | SMC-R4 |
| D-ARD-8 | September 04 | BRID | BR-R7 |
| D-ARD-9 | September 03 | SMRID | SMC-R3 |
| BK-1 | September 02 | EID | E-R3 |
| BK-2 | September 02 | TID | T-S3 |
| BK-3 | September 03 | RID | R-R2 |
| CS-1 | September 03 | - | - |

[z] Samples were only sent to the Alberta Innovates laboratory for the first and last sampling event.

## C.4 Data Evaluation

For the Exova laboratory QC analysis, the generally accepted 99% confidence interval (three standard deviations) was applied to the X-bar and R-bar control charts. The QC control limits were established using historical data from Exova laboratory before the implementation of the contract. To improve accuracy of the data for this project, control limits were based on data collected after the start of the contract and the confidence interval was 95% (two standard deviations). The data were from internal samples from the Exova laboratory analysis QA/QC plan. For each parameter, 12 sets of low, middle, and high concentrations were analyzed. A data set would fail if one of the following rules used for the QC analysis was not met:

- No data points may be outside of the 95% confidence interval limits.
- No run of seven consecutive data points may be either above or below the average limits.
- No run of seven consecutive data points may be in either an upward or downward direction.
- Regardless of the 95% confidence interval limits, notes must be made on any set of analyses with reference material outside the range of 80 to 120%, and sample replicates >20% relative standard deviation (RSD).
- Each site data that falls outside of the historic data envelope will be investigated before flagged as a concern.
- Analytical results must make sense. For instance, total phosphorus must be higher than total dissolved phosphorus, which in turn must be higher than orthophosphate.

Control limits for nutrient, salinity and physical parameters, and metals were compared with the historical QC control limits. A set was considered biased if 70% or more of the points are below or above the target value.

Lab blanks were used to ensure that no contaminants were introduced into the samples during laboratory procedures. Lab replicates were used to evaluate the precision of the Exova laboratory analysis for nutrient, salinity, physical, and metal parameters. The analytical precision of Exova laboratory was also measured by the field duplicate results. Correlations were used to assess the relationship between the duplicate samples (D-E1 to D-E3) and the associate sample. The Lin's concordance coefficient test ($r_c$) (Lin 1989) was used to assess the deviation of the relationship between the duplicates from a 1:1 line through the origin. Correlations and Lin's concordance coefficient were also used to assess the relationship between the D-ARD duplicate samples and the associate samples.

Field blanks were used to assess the potential contamination of sample during sampling procedures and sample transportation. All field blanks were analyzed by AF laboratory. Also, four lab blanks were used by the AF laboratory.

Cations and anions of nutrient and salinity parameters from the check standards should be equally recovered. They were required to have a percent recovery between 90 and 110% to be considered satisfactory. Measured concentration of check standard samples for metals were compared to expected concentrations and +/- 12% error was considered acceptable. Only the last two sets of check standard samples (i.e., third and fourth sampling time) were reported due to technical difficulties from Exova laboratory for the first and second sampling time.

## C.5 Quality Control Results in 2014

All sets of nutrient, salinity, physical, and metal parameters passed the control limits (Tables C.2 to C.4). Relative standard deviation of lab replicates were all within the +/- 10% precision range for all parameters.

**Table C.2. Exova laboratory quality control data assessment and duplicate correlation for salinity and physical parameters in 2014.**

| | | Control samples | | | | Lab blank | Lab replicates | | Field duplicates (D-E1 to D-E3) (detected samples only) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Sets | Level[z] | Control limit | Sets failed | Comment[y] | Sets failed | % RSD[x] | Sets failed | Sets | r | $r_c$ | Agreement |
| pH | 57 | Mid | 98.69-101.31% | 0 | O.K. | 0 | +/- 10 | 0 | | | | |
| | 57 | High | 98.91-101.09% | 0 | O.K. | | | | | | | |
| EC | 57 | Mid | 91.50-108.50% | 0 | O.B. | 0 | +/- 10 | 0 | 12 | 0.964 | 0.952 | Moderate |
| | 57 | High | 94.78-105.22% | 0 | C.B. | | | | | | | |
| | 57 | Low | 89.32-110.68% | 0 | O.B. | | | | | | | |
| Ca | 57 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 10 | 0 | 11 | 0.999 | 0.989 | Perfect |
| | 57 | High | 95.64-104.36% | 0 | O.B. | | | | | | | |
| | 57 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| Mg | 57 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 10 | 0 | 11 | 0.992 | 0.992 | Perfect |
| | 57 | High | 95.67-104.33% | 0 | O.K. | | | | | | | |
| | 57 | Low | 90.38-109.62% | 0 | C.B. | | | | | | | |
| Na | 57 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 10 | 0 | 11 | 0.999 | 0.999 | Perfect |
| | 57 | High | 95.11-104.89% | 0 | O.B. | | | | | | | |
| | 13 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| K | 13 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 10 | 0 | 12 | 1.000 | 1.000 | Perfect |
| | 13 | High | 95.15-104.85% | 0 | C.B. | | | | | | | |
| | 25 | Low | 89.26-110.74% | 0 | C.B. | 0 | +/- 10 | 0 | 11 | 1.000 | 1.000 | Perfect |
| Cl | 25 | Mid | 89.26-110.74% | 0 | O.B. | | | | | | | |
| | 25 | High | 93.32-106.68% | 0 | C.K. | | | | | | | |
| $CO_3$[w] | | | | | | 0 | +/- 10 | 0 | | | | |
| $HCO_3$[w] | | | | | | 0 | +/- 10 | 0 | | | | |
| $SO_4$ | | | | | | | | | 11 | 1.000 | 1.000 | Perfect |

[z] Different levels of concentration: low, mid, and high.
[y] O.B. = occasionally biased, C.B. = consistently biased, O.K. = not biased.
[x] Relative standard deviation calculated as (standard deviation ÷ average value of replicate values) × 100
[w] No control samples because these parameters are too unstable.

No contamination was introduced during sample preparation activities in the Exova laboratory for all analytes (Tables C.2 to C.4).

Lab replicate samples demonstrated the precision of the Exova laboratory analysis for most nutrient, salinity, physical and metal parameters. The analytical precision of Exova laboratory was further supported by the field duplicate results with the exception of Al, Fe, Ni, and Zn . Correlations and Lin's concordance coefficient indicated from moderate to perfect agreement between the duplicate samples (D-E1 to D-E3 or D-ARD-1 to D-ARD-9) and the associate samples (Tables C.2 to C.5) for all parameters.

**Table C.3. Exova laboratory quality control data assessment for nutrient in 2014.**

| | | Control samples | | | | Lab blank | Lab replicates | | Field duplicates (D-E1 to D-E3) (detected samples only) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Sets | Level[z] | Control limit | Sets failed | Comment[y] | Sets failed | % RSD[x] | Sets failed | Sets | r | $r_c$ | Agreement |
| $NO_3$-N | 57 | Low | 88.24-111.76% | 0 | O.B | | | | | | | |
| | 57 | Mid | 89.38-110.63% | 0 | C.B. | 0 | +/- 10 | 0 | | | | |
| | 57 | High | 95.53-104.47% | 0 | O.B. | | | | | | | |
| $NH_3$-N | | | | | | | | | | | | |
| TN | 57 | Low | 82.30-117.70% | 0 | O.B. | | | | | | | |
| | 57 | Mid | 90.03-109.97% | 0 | C.B. | 0 | +/- 10 | 0 | 11 | 0.929 | 0.914 | Moderate |
| | 57 | High | 88.21-111.79% | 0 | C.B. | | | | | | | |
| $PO_4$-P | 57 | Low | 80.00-120.00% | 0 | O.B. | 0 | +/- 10 | 0 | 5 | 0.951 | 0.935 | Moderate |
| | 57 | Mid | 82.58-117.42% | 0 | O.B. | | | | | | | |
| TDP | 57 | Mid | 90.25-109.75% | 0 | C.B. | 0 | +/- 10 | 0 | 7 | 0.971 | 0.969 | Substantial |
| | 57 | High | 95.12-104.88% | 0 | C.B. | | | | | | | |
| TP | 57 | Mid | 90.25-109.75% | 0 | O.K. | 0 | +/- 10 | 0 | 9 | 0.996 | 0.995 | Perfect |
| | 57 | High | 95.12-104.88% | 0 | O.K. | | | | | | | |

[z] Different levels of concentration: low, mid, and high.

[y] O.B. = occasionally biased, C.B. = consistently biased, O.K. = not biased.

[x] Relative standard deviation calculated as (standard deviation ÷ average value of replicate values) × 100

**Table C.4. Exova laboratory quality control data assessment for metals in 2014.**

| | | Control samples | | | | Lab blank | Lab replicates | | Field duplicates (D-E1 to D-E3) (detected samples only) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Sets | Level[z] | Control limit | Sets failed | Comment[y] | Sets failed | % RSD[x] | Sets failed | Sets | r | $r_c$ | Agreement |
| Al | 53 | Low | 92.45-107.55% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | 8 | 0.565 | 0.494 | Poor |
| | 53 | High | 89.74-110.26% | 0 | C.B. | | | | | | | |
| Sb | 53 | Low | 90.00-110.00% | 0 | O.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.B. | 0 | +/- 15 | 0 | | | | |
| | 53 | High | 92.70-107.30% | 0 | C.B. | | | | | | | |
| As | 53 | Low | 87.80-112.20% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | 11 | 0.956 | 0.950 | Moderate |
| | 53 | High | 91.50-108.50% | 0 | C.B. | | | | | | | |
| Ba | 53 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | 11 | 0.923 | 0.874 | Moderate |
| | 53 | High | 93.64-106.36% | 0 | O.B. | | | | | | | |
| Be | 53 | Low | 84.21-115.79% | 0 | O.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.B. | 0 | +/- 15 | 0 | | | | |
| | 53 | High | 87.88-112.12% | 0 | O.K. | | | | | | | |
| B | 53 | Low | 85.00-115.00% | 0 | O.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.B. | 0 | +/- 15 | 0 | 11 | 0.982 | 0.971 | Substantial |
| | 53 | High | 88.06-111.94% | 0 | O.B. | | | | | | | |
| Cd | 53 | Low | 84.21-115.79% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | | | | |
| | 53 | High | 93.20-106.80% | 0 | O.B. | | | | | | | |
| Cr | 53 | Low | 92.00-108.00% | 0 | O.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.B. | 0 | +/- 15 | 0 | | | | |
| | 53 | High | 93.13-106.87% | 0 | O.B. | | | | | | | |
| Co | 53 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | 5 | 1.000 | 1.000 | Perfect |
| | 53 | High | 91.87-108.13% | 0 | O.B. | | | | | | | |
| Cu | 53 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.B. | 0 | +/- 15 | 0 | | | | |
| | 53 | High | 91.91-108.09% | 0 | O.B. | | | | | | | |
| Fe | 53 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | 7 | -0.329 | -0.158 | Poor |
| | 53 | High | 94.38-105.62% | 0 | C.B. | | | | | | | |
| Pb | 53 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | | | | |
| | 53 | High | 92.08-107.92% | 0 | O.B. | | | | | | | |
| Li | 53 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | 11 | 0.998 | 0.986 | Perfect |
| | 53 | High | 87.59-112.41% | 0 | C.B. | | | | | | | |

[z] Different levels of concentration: low, mid, and high.

[y] O.B. = occasionally biased, C.B. = consistently biased, O.K. = not biased.

[x] Relative standard deviation calculated as (standard deviation ÷ average value of replicate values) × 100

**Table C.4. continued**

| | | Control samples | | | | Lab blank | Lab replicates | | Field duplicates (D-E1 to D-E3) (detected samples only) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Sets | Level[z] | Control limit | Sets failed | Comment[y] | Sets failed | % RSD[x] | Sets failed | Sets | r | $r_c$ | Agreement |
| Mn | 53 | Low | 90.20-109.80% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 89.80-110.20% | 0 | C.B. | 0 | +/- 15 | 0 | 12 | 0.908 | 0.888 | Moderate |
| | 53 | High | 93.78-106.22% | 0 | C.B. | | | | | | | |
| Mo | 53 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.B. | 0 | +/- 15 | 0 | 7 | 1.000 | 1.000 | Perfect |
| | 53 | High | 93.78-106.22% | 0 | C.B. | | | | | | | |
| Ni | 53 | Low | 90.00-110.00% | 0 | O.K. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.B. | 0 | +/- 15 | 0 | 8 | -0.48 | -0.235 | Poor |
| | 53 | High | 93.47-106.53% | 0 | C.B. | | | | | | | |
| Se | 53 | Low | 84.21-115.79% | 0 | O.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | 8 | 0.898 | 0.887 | Moderate |
| | 53 | High | 91.39-108.61% | 0 | O.B. | | | | | | | |
| Ag | 53 | Low | 92.38-107.62% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.B. | 0 | +/- 15 | 0 | | | | |
| | 53 | High | 90.00-110.00% | 0 | O.B. | | | | | | | |
| Tl | 53 | Low | 91.43-108.57% | 0 | C.B. | | | | | | | |
| | 53 | Mid | | 0 | O.B. | | | | | | | |
| | 53 | High | 92.02-107.98% | 0 | O.B. | 0 | +/- 15 | 0 | | | | |
| Sn | 53 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.B. | 0 | +/- 15 | 0 | | | | |
| | 53 | High | 92.15-107.85% | 0 | C.B. | | | | | | | |
| Ti | 53 | Low | 90.91-109.09% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | 8 | 0.797 | 0.776 | Moderate |
| | 53 | High | 92.52-107.48% | 0 | C.B. | | | | | | | |
| U | 53 | Low | 90.38-109.62% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.K. | 0 | +/- 15 | 0 | 10 | 0.957 | 0.954 | Substantial |
| | 53 | High | 90.08-109.02% | 0 | O.K. | | | | | | | |
| V | 53 | Low | 85.71-114.29% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | 11 | 0.915 | 0.909 | Moderate |
| | 53 | High | 90.91-109.09% | 0 | C.B. | | | | | | | |
| Zn | 53 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.K. | 0 | +/- 15 | 0 | 10 | 0.565 | 0.494 | Poor |
| | 53 | High | 91.85-108.15% | 0 | C.B. | | | | | | | |
| | 53 | Low | | 0 | O.B. | | | | | | | |
| Hg | 53 | Mid | 88.61-111.39% | 0 | O.B. | 0 | +/- 15 | 0 | | | | |
| | 53 | High | 89.66-110.34% | 0 | O.B. | | | | | | | |

[z] Different levels of concentration: low, mid, and high.

[y] O.B. = occasionally biased, C.B. = consistently biased, O.K. = not biased.

[x] Relative standard deviation calculated as (standard deviation ÷ average value of replicate values) × 100

**Table C.5. Duplicate field samples comparison between EXOVA and AF laboratories (detected samples only).**

| Parameter | n | unit | AF average | SD | EXOVA average | SD | Difference of average | r | $r_c$ | Agreement between labs |
|---|---|---|---|---|---|---|---|---|---|---|
| pH[z] | | | | | | | | | | |
| EC | 36 | dS $m^{-1}$ | 0.404 | 0.133 | 0.403 | 0.133 | 0.001 | 0.997 | 0.997 | Perfect |
| Ca | 35 | $mmol_c$ $L^{-1}$ | 1.745 | 0.372 | 1.767 | 0.356 | 0.016 | 0.965 | 0.963 | Substantial |
| Mg | 35 | $mmol_c$ $L^{-1}$ | 1.470 | 0.473 | 1.451 | 0.442 | 0.019 | 0.984 | 0.981 | Substantial |
| Na | 25 | $mmol_c$ $L^{-1}$ | 1.288 | 0.672 | 1.346 | 0.649 | 0.058 | 0.993 | 0.989 | Perfect |
| K | 4 | $mmol_c$ $L^{-1}$ | 0.233 | 0.200 | 0.233 | 0.187 | 0.000 | 1.000 | 0.997 | Perfect |
| $SO_4$ | 34 | $mmol_c$ $L^{-1}$ | 1.445 | 0.902 | 1.469 | 0.907 | 0.240 | 0.992 | 0.992 | Perfect |
| Cl | 13 | $mmol_c$ $L^{-1}$ | 0.393 | 0.175 | 0.399 | 0.151 | 0.006 | 0.973 | 0.962 | Substantial |
| $HCO_3 + CO_3$ | | $mmol_c$ $L^{-1}$ | | | | | | | | |
| TN | 16 | mg $L^{-1}$ | 0.779 | 0.320 | 0.646 | 0.272 | 0.133 | 0.951 | 0.848 | Moderate |
| $PO_4$-P | 11 | mg $L^{-1}$ | 0.047 | 0.047 | 0.052 | 0.051 | 0.005 | 0.996 | 0.987 | Perfect |
| TDP | 16 | mg $L^{-1}$ | 0.049 | 0.052 | 0.051 | 0.054 | 0.002 | 0.992 | 0.991 | Perfect |
| TP | 31 | mg $L^{-1}$ | 0.055 | 0.054 | 0.050 | 0.054 | 0.005 | 0.992 | 0.991 | Perfect |
| $NO_3$-N | | mg $L^{-1}$ | | | | | | | | |
| $NH_4$-N[y] | | mg $L^{-1}$ | | | | | | | | |

[z] pH and HCO3 + CO3 values were not compared because of their poor stability.

[y] Analytes value below detection limit

No contamination or errors were found in the field blanks and AF laboratory blanks samples analyzed for nutrient, salinity, physical, or metals parameters (Table C.6).

**Table C.6. Blank samples analyzed by the AF laboratory.**

| | AF laboratory | |
|---|---|---|
| | Field blank n = 12 | Lab blank n = 4 |
| Parameter | Sets failed | Sets failed |
| pH | 0 | 0 |
| EC | 0 | 0 |
| Ca | 0 | 0 |
| Mg | 0 | 0 |
| Na | 0 | 0 |
| K | 0 | 0 |
| $SO_4$ | 0 | 0 |
| Cl | 0 | 0 |
| $HCO_3 + CO_3$ | 0 | 0 |
| TN | 0 | 0 |
| $PO_4$-P | 0 | 0 |
| TDP | 0 | 0 |
| TP | 0 | 0 |
| $NO_3$-N | 0 | 0 |
| $NH_4$-N | 0 | 0 |

Most of the cations and anions of nutrient and salinity parameters from the check standards were recovered between 90 and 110% (Table C.7). In the third set of check standards sodium was below acceptable limits for % recovery. In all check standard chloride was below acceptable limits for % recovery. However, when the chloride results were compared between Exova laboratory and AF laboratory there was a substantial agreement in the results.

**Table C.7. Percent recovery check standard samples for nutrient and salinity parameters in 2014.**

| | $NH_4NO_3$ | | $KHPO_4$ | | $MgSO_4$ | | NaCl | | $CaCl_2$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $NH_4^+$ | $NO_3^-$ | $K^+$ | $HPO_4^{-2}$ | $Mg^{+2}$ | $SO_4^{-2}$ | $Na^+$ | $Cl^-$ | $Ca^{+2}$ | $Cl^-$ |
| Set | (%) | | | | | | | | | |
| 1 | 94.1 | 97.1 | 107.0 | 103.9 | 99.0 | 106.5 | 99.2 | 88.3 | 94.2 | 88.3 |
| 2 | | | | | | | | | | |
| 3 | 92.9 | 99.4 | 96.7 | 102.2 | 99.0 | 97.8 | 89.1 | 67.4 | 99.7 | 67.4 |
| 4 | 108.2 | 90.9 | 106.7 | 103.0 | 99.0 | 104.0 | 96.7 | 75.5 | 102.5 | 75.5 |

A total of 21 out of 73 analyzed metals met the allowable +/-12% of error (Table C.8). The fifteen metals that exceeded the allowable error were Al, As, Ba, Be, B, Cu, Fe, Li, Ni, Se, Ag, Ti, V, Zn and Hg. These may have been affected by the larger variability of the error at low concentration. The three metals that exceeded the allowable error for a three levels of concentration were Al, Ag and Hg. We have requested the a full re-evaluation of MMDL according to our service agreement for metals for 2015.

**Table C.8. Percent error of check standard samples for metals in 2014.**

| Metal parameter | MMDL (mg $L^{-1}$) | Expected value (mg $L^{-1}$) | Allowable % error | Set | Observed value (mg $L^{-1}$) | % error |
|---|---|---|---|---|---|---|
| | 0.02 | 0.25 | +/- 12.00 | 1 | 0.31 | -24.00 |
| Al | | 0.025 | | 3 | 0.04 | -60.00 |
| | | 0.625 | | 4 | <0.02 | - |
| | 0.002 | 0.01 | +/- 12.00 | 1 | 0.0103 | -3.00 |
| Sb | | 0.001 | | 3 | 0.001 | 0.00 |
| | | 0.025 | | 4 | 0.0238 | 4.80 |
| | 0.0002 | 0.0098 | +/- 12.00 | 1 | 0.0102 | -4.08 |
| As | | 0.00098 | | 3 | 0.0011 | -12.24 |
| | | 0.0245 | | 4 | 0.0231 | 5.71 |
| | 0.001 | 0.05 | +/- 12.00 | 1 | 0.055 | -10.00 |
| Ba | | 0.005 | | 3 | 0.006 | -20.00 |
| | | 0.125 | | 4 | 0.126 | -0.80 |
| | 0.0001 | 0.005 | +/- 12.00 | 1 | 0.0047 | 6.00 |
| Be | | 0.0005 | | 3 | 0.0006 | -20.00 |
| | | 0.0125 | | 4 | 0.0117 | 6.40 |
| | 0.002 | 0.1 | +/- 12.00 | 1 | 0.11 | -10.00 |
| B | | 0.01 | | 3 | 0.015 | -50.00 |
| | | 0.25 | | 4 | 0.244 | 2.40 |

**Table C.8. continued**

| Metal parameter | MMDL (mg $L^{-1}$) | Expected value (mg $L^{-1}$) | Allowable % error | Set | Observed value (mg $L^{-1}$) | % error |
|---|---|---|---|---|---|---|
| | 0.00001 | 0.005 | +/- 12.00 | 1 | 0.00515 | -3.00 |
| Cd | | 0.0005 | | 3 | 0.00053 | -6.00 |
| | | 0.0125 | | 4 | 0.0118 | 5.60 |
| | 0.0005 | 0.0248 | +/- 12.00 | 1 | 0.0265 | -6.85 |
| Cr | | 0.00248 | | 3 | 0.0027 | -8.87 |
| | | 0.062 | | 4 | 0.0629 | -1.45 |
| | 0.0001 | 0.005 | +/- 12.00 | 1 | 0.0051 | -2.00 |
| Co | | 0.0005 | | 3 | 0.0005 | 0.00 |
| | | 0.0125 | | 4 | 0.0125 | 0.00 |
| | 0.001 | 0.0502 | +/- 12.00 | 1 | 0.053 | -5.58 |
| Cu | | 0.00502 | | 3 | 0.006 | -19.52 |
| | | 0.1255 | | 4 | 0.131 | -4.38 |
| | 0.05 | 2.504 | +/- 12.00 | 1 | 2.75 | -9.82 |
| Fe | | 0.2504 | | 3 | 0.29 | -15.81 |
| | | 6.26 | | 4 | <0.05 | - |
| | 0.0001 | 0.005 | +/- 12.00 | 1 | 0.0053 | -6.00 |
| Pb | | 0.0005 | | 3 | 0.0005 | 0.00 |
| | | 0.0125 | | 4 | 0.0126 | -0.80 |
| | 0.001 | 0.05 | +/- 12.00 | 1 | 0.053 | -6.00 |
| Li | | 0.005 | | 3 | 0.006 | -20.00 |
| | | 0.125 | | 4 | 0.128 | -2.40 |
| | 0.005 | 0.248 | +/- 12.00 | 3 | 0.277 | -11.69 |
| Mn | | 0.0248 | | 4 | 0.027 | -8.87 |
| | | 0.62 | | | <0.005 | - |
| | 0.001 | 0.0502 | +/- 12.00 | 1 | 0.052 | -3.59 |
| Mo | | 0.00502 | | 3 | 0.005 | 0.40 |
| | | 0.1255 | | 4 | 0.13 | -3.59 |
| | 0.0005 | 0.025 | +/- 12.00 | 1 | 0.0256 | -2.40 |
| Ni | | 0.0025 | | 3 | 0.0032 | -28.00 |
| | | 0.0625 | | 4 | 0.0622 | 0.48 |
| | 0.0002 | 0.01 | +/- 12.00 | 1 | 0.0099 | 1.00 |
| Se | | 0.001 | | 3 | 0.001 | 0.00 |
| | | 0.025 | | 4 | 0.0219 | 12.40 |
| | 0.00001 | 0.0005 | +/- 12.00 | 1 | 0.00021 | 58.00 |
| Ag | | 0.00005 | | 3 | 0.00238 | -4660.00 |
| | | 0.00125 | | 4 | | |
| | 0.00005 | 0.00246 | +/- 12.00 | 1 | 0.00269 | -9.35 |
| Tl | | 0.000246 | | 3 | 0.00026 | -5.69 |
| | | 0.00615 | | 4 | 0.0065 | -5.69 |
| | 0.001 | 0.05 | +/- 12.00 | 1 | 0.052 | -4.00 |
| Sn | | 0.005 | | 3 | 0.005 | 0.00 |
| | | 0.125 | | 4 | 0.123 | 1.60 |

**Table C.8. continued**

| Metal parameter | MMDL (mg $L^{-1}$) | Expected value (mg $L^{-1}$) | Allowable % error | Set | Observed value (mg $L^{-1}$) | % error |
|---|---|---|---|---|---|---|
| | 0.0005 | 0.0246 | +/- 12.00 | 1 | 0.0289 | -17.48 |
| Ti | | 0.00246 | | 3 | 0.0026 | -5.69 |
| | | 0.0615 | | 4 | 0.0619 | -0.65 |
| | 0.0005 | 0.0252 | +/- 12.00 | 1 | 0.0261 | -3.57 |
| U | | 0.00252 | | 3 | 0.0024 | 4.76 |
| | | 0.063 | | 4 | 0.0645 | -2.38 |
| | 0.0001 | 0.005 | +/- 12.00 | 1 | 0.0053 | -6.00 |
| V | | 0.0005 | | 3 | 0.0006 | -20.00 |
| | | 0.0125 | | 4 | 0.0126 | -0.80 |
| Zn | 0.001 | 0.0502 | +/- 12.00 | 1 | 0.052 | -3.59 |
| | | 0.00502 | | 3 | 0.006 | -19.52 |
| | | 0.1255 | | 4 | 0.119 | 5.18 |
| | 0.0001 | 0.005 | +/- 12.00 | 1 | 0.000073 | 98.54 |
| Hg | | 0.0005 | | 3 | <0.000005 | - |
| | | 0.0125 | | 4 | <0.000005 | - |

[z] ND = not detected

## C.6 Conclusions

Exova laboratory produced quality data for nutrient, salinity, physical, and metals parameters in 2014.

## C.7 References

**Lin, L.I. 1989.** A concordance correlation coefficient to evaluate reproducibility. Biometrics 45: 255-268.

## C.8 Glossary

**Control Limit.** The individual analytical values in the series are plotted and evaluated against control limits. The limits are calculated as +/- 3 standard deviations of the average of the historical data.

**Correlation Coefficient (r).** This is used to measure the degree of linear relationship between two variables. The correlation coefficient is a value ranging from -1 to +1. If one variable tends

to increase as the other decreases, the correlation coefficient is negative. Conversely, if the two variables tend to increase together the correlation coefficient is positive.

**Field Blank.** A field blank is deionized water, which is treated as a sample. It is used to identify potential errors or contamination during sample collection and analysis.

**Field Duplicate.** A field duplicate sample collected by the same team or by another sampler or team at the same place, at the same time. It is used to estimate sampling and laboratory analysis precision.

**Lin's Concordance Coefficient ($r_c$).** The concordance correlation coefficient (Lin 1989) evaluates the degree to which pairs of observations fall on the 45° line through the origin: $r_c >$ 0.99 shows perfect agreement, $r_c >$ 0.95 to 0.99 shows substantial agreement, $r_c =$ 0.90 to 0.95 shows moderate agreement, and $r_c <$ 0.90 shows poor agreement.

**Laboratory Blanks.** A blank prepared to represent the matrix as closely as possible. The laboratory blank is prepared, extracted, digested, and analyzed in the same way as for the field samples. These blanks are used to assess contamination introduced during sample preparation.

**Laboratory Replicate.** This is a subsample of a routine sample, which is homogenized, divided into separate containers, and analyzed using the same analytical method. Laboratory replicates are used to determine method precision. However, because it is a non-blind sample, or known to the analyst, it can only be used by the analyst as an internal control tool and not as an unbiased estimate of analytical precision.

**% RSD.** This is the percent relative standard deviation and it is calculated from repeated analysis by:

(standard deviation ÷ average value of replicate values) × 100

**% Error.** [(expected value – observed value) ÷ expected value] × 100

# Appendix C. Quality Assurance/Quality Control and Quality Assurance/Surveillance Plan

## C.1 Introduction

A quality assurance/quality control (QA/QC) plan was developed to ensure an accurate, precise, and representative water quality database by applying standard protocols for field sampling and sample shipping (section 2.2), as well as laboratory analysis and inter-laboratory comparison.

In 2014, Exova Group Limited (Exova laboratory in Calgary, Alberta) analyzed nutrient, salinity, metal, physical, and microbiological parameters. It was Exova's responsibility to manage the laboratory analysis QA/QC plan.

Alberta Agriculture and Forestry (AF) implemented a Quality Assurance and Surveillance Plan (QASP) to evaluate the quality of data from the field sampling and the laboratory analysis. The role of the QASP was to ensure the contract standards were achieved and maintained by following a predetermined action plan, including:

- Review and approve analytical methods and standard operation procedures for all analytes.
- Review the quality control program and ensure corrective steps are in place.
- Perform a visual inspection of the facility.
- Review the measurable method detection limits (MMDL).
- Compare field duplicate samples tested within Exova laboratory and between AF and Exova laboratories.
- Evaluate results from field and laboratory blank samples tested by AF and Exova laboratories.
- Compare results from blind reference samples (check standards) with known values of analytes prepared by the AF and analyzed by the Exova laboratory.

## C.2 Field QA/QC samples

A total of 16 QA/QC samples were collected for each of the four sampling events in 2014. The QA/QC samples included duplicates, field blanks, and check standards. The duplicates were defined as replicates composed of discrete samples collected consecutively from the same location over a short period of time. Duplicate and blank samples were collected at randomly selected sites (Table C.1). There were nine duplicate samples identified as D-ARD-1 to D-ARD-9, which were analyzed by the AF laboratory. There were also three duplicates samples (D-E1, D-E2, D-E3) collected and sent to the Exova, Agriculture and Agri-Food Canada

(AAFC), Alberta Innovates (AI) laboratories and the National Hydrology Research Centre (NHRC). The duplicates were irrigation water samples. The duplicate samples sent to the AF and Exova laboratories were analyzed for routine, nutrient, total nitrogen (TN) and coliforms. The duplicates sent to the AAFC and AI laboratories were analyzed for pesticides, and the duplicates sent to the NHRC were analyzed for pharmaceuticals. The D-E1 to D-E3 duplicate samples were sampled at the same sites and times as D-ARD-1 to D-ARD-3. Therefore, these were triplicates for the nutrient, salinity and coliforms parameters.

Three field blanks (BK-1, BK-2, BK-3) were collected per sampling event (Table C.1) by filling bottles with double distilled water at selected sampling sites. The double distilled water was prepared by the AF laboratory and transported to the sites in two, 1-L polyethylene bottles. The double distilled water was used to triple rinse and fill the 1-L sampling bottle. The filled sampling bottle was then used to triple-rinse and fill the routine, nutrient, TN, and coliform bottles as described in Sub-section 2.2. The sample methodology used for the blank samples was the same as for all other samples to maintain the same level of risk for potential contamination.

Finally, one check standard (CS-1) sample per sampling event (including one nutrient, one routine, and one metals bottle) was prepared by the AF laboratory and shipped to Exova with the other samples. For each sampling event, check standards with pre-determined concentrations of nutrient and salinity parameters were prepared by AF laboratory, and certified reference materials (SCP Science, Baie D'Urfé, Québec) were used to prepare the check standard for metals.

### C.3 Accuracy and Precision

Accuracy is a measure of how close an analyzed value is to the true value. The accuracy of an analysis can be determined by the measurement of reference materials of known value, either directly, or as a spiked sample having the same matrix as the samples in question. The results are entered into an X-bar control chart to track the accuracy and ensure that it is within the acceptable percent confidence interval, either 95 or 99%, depending on the performance quality of the individual laboratory or specified analyte.

Precision is a measure of the variability of individual measurements of either field or laboratory replicated samples. The variance of field and laboratory replicates should be equal if sampling and storage have no effect on analysis. The results are entered into an R-bar control chart to track the variability and ensure that it is within the acceptable percentage confidence interval (95 or 99%).

**Table C.1. Duplicate (D), field blank (BK), and check standard (CS) samples in 2014.** Duplicate samples were analyzed by Alberta Agriculture and Rural Development (D-ARD-1 to -9), Exova(D-E1 to 3; BK-1 to -3; CS-1), and Agriculture and Agri-Food Canada, Alberta Innovates laboratories and the National Hydrology Research Centre (D-E1 to 3).

| Qa/Qc sample[z] | Sampling date | Irrigation district | Sampling site |
|---|---|---|---|
| | *First sampling time* | | |
| D-ARD-1; D-E1 | June 10 | WID | W-P2 |
| D-ARD-2; D-E2 | June 11 | LNID | LN-S2 |
| D-ARD-3; D-E3 | June 11 | UID | U-R4 |
| D-ARD-4 | June 10 | EID | E-R5 |
| D-ARD-5 | June 12 | RCID | RC-P1 |
| D-ARD-6 | June 10 | WID | W-S4 |
| D-ARD-7 | June 11 | LNID | LN-R4 |
| D-ARD-8 | June 12 | EID | E-R7 |
| D-ARD-9 | June 12 | SMRID | SMW-P1 |
| BK-1 | June 10 | TID | T-R2 |
| BK-2 | June 11 | UID | U-P1 |
| BK-3 | June 11 | BRID | BR-S1 |
| CS-1 | June 12 | - | - |
| | *Second sampling time* | | |
| D-ARD-1; D-E1 | July 10 | EID | E-R4a |
| D-ARD-2; D-E2 | July 10 | EID | E-S2 |
| D-ARD-3; D-E3 | July 08 | MVID | MV-R1 |
| D-ARD-4 | July 07 | WID | W-S1 |
| D-ARD-5 | July 07 | WID | W-S3 |
| D-ARD-6 | July 10 | EID | E-R2 |
| D-ARD-7 | July 08 | BRID | BR-S5 |
| D-ARD-8 | July 09 | SMRID | SME-R2 |
| D-ARD-9 | July 08 | UID | U-S1 |
| BK-1 | July 10 | EID | E-S7 |
| BK-2 | July 09 | SMRID | SMC-S1 |
| BK-3 | July 07 | SMRID | SMC-P1 |
| CS-1 | July 08 | - | - |
| | *Third sampling time* | | |
| D-ARD-1; D-E1 | August 05 | WID | W-R1a |
| D-ARD-2; D-E3 | August 07 | EID | E-P1 |
| D-ARD-3; D-E2 | August 05 | EID | E-S6 |
| D-ARD-4 | August 05 | TID | T-S1 |
| D-ARD-5 | August 05 | TID | T-S2 |
| D-ARD-6 | August 06 | LNID | LN-S3 |
| D-ARD-7 | August 06 | - | AEP-S2 |
| D-ARD-8 | August 06 | BRID | BR-S3 |
| D-ARD-9 | August 06 | LNID | LN-R2 |
| BK-1 | August 06 | LNID | LN-S4 |
| BK-2 | August 05 | - | AEP-P3 |
| BK-3 | August 07 | SMRID | SMW-R1 |
| CS-1 | August 06 | - | - |
| | *Fourth sampling time* | | |
| D-ARD-1; D-E1 | September 02 | EID | E-S5 |
| D-ARD-2; D-E2 | September 02 | EID | E-S4 |
| D-ARD-3; D-E3 | September 02 | TID | T-R1 |
| D-ARD-4 | September 02 | TID | T-S4 |
| D-ARD-5 | September 04 | BRID | BR-R1 |
| D-ARD-6 | September 04 | SMRID | SMW-S2 |
| D-ARD-7 | September 03 | SMRID | SMC-R4 |
| D-ARD-8 | September 04 | BRID | BR-R7 |
| D-ARD-9 | September 03 | SMRID | SMC-R3 |
| BK-1 | September 02 | EID | E-R3 |
| BK-2 | September 02 | TID | T-S3 |
| BK-3 | September 03 | RID | R-R2 |
| CS-1 | September 03 | - | - |

[z] Samples were only sent to the Alberta Innovates laboratory for the first and last sampling event.

## C.4 Data Evaluation

For the Exova laboratory QC analysis, the generally accepted 99% confidence interval (three standard deviations) was applied to the X-bar and R-bar control charts. The QC control limits were established using historical data from Exova laboratory before the implementation of the contract. To improve accuracy of the data for this project, control limits were based on data collected after the start of the contract and the confidence interval was 95% (two standard deviations). The data were from internal samples from the Exova laboratory analysis QA/QC plan. For each parameter, 12 sets of low, middle, and high concentrations were analyzed. A data set would fail if one of the following rules used for the QC analysis was not met:

- No data points may be outside of the 95% confidence interval limits.
- No run of seven consecutive data points may be either above or below the average limits.
- No run of seven consecutive data points may be in either an upward or downward direction.
- Regardless of the 95% confidence interval limits, notes must be made on any set of analyses with reference material outside the range of 80 to 120%, and sample replicates >20% relative standard deviation (RSD).
- Each site data that falls outside of the historic data envelope will be investigated before flagged as a concern.
- Analytical results must make sense. For instance, total phosphorus must be higher than total dissolved phosphorus, which in turn must be higher than orthophosphate.

Control limits for nutrient, salinity and physical parameters, and metals were compared with the historical QC control limits. A set was considered biased if 70% or more of the points are below or above the target value.

Lab blanks were used to ensure that no contaminants were introduced into the samples during laboratory procedures. Lab replicates were used to evaluate the precision of the Exova laboratory analysis for nutrient, salinity, physical, and metal parameters. The analytical precision of Exova laboratory was also measured by the field duplicate results. Correlations were used to assess the relationship between the duplicate samples (D-E1 to D-E3) and the associate sample. The Lin's concordance coefficient test ($r_c$) (Lin 1989) was used to assess the deviation of the relationship between the duplicates from a 1:1 line through the origin. Correlations and Lin's concordance coefficient were also used to assess the relationship between the D-ARD duplicate samples and the associate samples.

Field blanks were used to assess the potential contamination of sample during sampling procedures and sample transportation. All field blanks were analyzed by AF laboratory. Also, four lab blanks were used by the AF laboratory.

Cations and anions of nutrient and salinity parameters from the check standards should be equally recovered. They were required to have a percent recovery between 90 and 110% to be considered satisfactory. Measured concentration of check standard samples for metals were compared to expected concentrations and +/- 12% error was considered acceptable. Only the last two sets of check standard samples (i.e., third and fourth sampling time) were reported due to technical difficulties from Exova laboratory for the first and second sampling time.

## C.5 Quality Control Results in 2014

All sets of nutrient, salinity, physical, and metal parameters passed the control limits (Tables C.2 to C.4). Relative standard deviation of lab replicates were all within the +/- 10% precision range for all parameters.

**Table C.2. Exova laboratory quality control data assessment and duplicate correlation for salinity and physical parameters in 2014.**

| | | Control samples | | | | Lab blank | Lab replicates | | Field duplicates (D-E1 to D-E3) (detected samples only) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Sets | Level[z] | Control limit | Sets failed | Comment[y] | Sets failed | % RSD[x] | Sets failed | Sets | r | $r_c$ | Agreement |
| pH | 57 | Mid | 98.69-101.31% | 0 | O.K. | 0 | +/- 10 | 0 | | | | |
| | 57 | High | 98.91-101.09% | 0 | O.K. | | | | | | | |
| EC | 57 | Mid | 91.50-108.50% | 0 | O.B. | 0 | +/- 10 | 0 | 12 | 0.964 | 0.952 | Moderate |
| | 57 | High | 94.78-105.22% | 0 | C.B. | | | | | | | |
| | 57 | Low | 89.32-110.68% | 0 | O.B. | | | | | | | |
| Ca | 57 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 10 | 0 | 11 | 0.999 | 0.989 | Perfect |
| | 57 | High | 95.64-104.36% | 0 | O.B. | | | | | | | |
| | 57 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| Mg | 57 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 10 | 0 | 11 | 0.992 | 0.992 | Perfect |
| | 57 | High | 95.67-104.33% | 0 | O.K. | | | | | | | |
| | 57 | Low | 90.38-109.62% | 0 | C.B. | | | | | | | |
| Na | 57 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 10 | 0 | 11 | 0.999 | 0.999 | Perfect |
| | 57 | High | 95.11-104.89% | 0 | O.B. | | | | | | | |
| | 13 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| K | 13 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 10 | 0 | 12 | 1.000 | 1.000 | Perfect |
| | 13 | High | 95.15-104.85% | 0 | C.B. | | | | | | | |
| | 25 | Low | 89.26-110.74% | 0 | C.B. | 0 | +/- 10 | 0 | 11 | 1.000 | 1.000 | Perfect |
| Cl | 25 | Mid | 89.26-110.74% | 0 | O.B. | | | | | | | |
| | 25 | High | 93.32-106.68% | 0 | C.K. | | | | | | | |
| $CO_3$[w] | | | | | | 0 | +/- 10 | 0 | | | | |
| $HCO_3$[w] | | | | | | 0 | +/- 10 | 0 | | | | |
| $SO_4$ | | | | | | | | | 11 | 1.000 | 1.000 | Perfect |

[z] Different levels of concentration: low, mid, and high.
[y] O.B. = occasionally biased, C.B. = consistently biased, O.K. = not biased.
[x] Relative standard deviation calculated as (standard deviation ÷ average value of replicate values) × 100
[w] No control samples because these parameters are too unstable.

No contamination was introduced during sample preparation activities in the Exova laboratory for all analytes (Tables C.2 to C.4).

Lab replicate samples demonstrated the precision of the Exova laboratory analysis for most nutrient, salinity, physical and metal parameters. The analytical precision of Exova laboratory was further supported by the field duplicate results with the exception of Al, Fe, Ni, and Zn . Correlations and Lin's concordance coefficient indicated from moderate to perfect agreement between the duplicate samples (D-E1 to D-E3 or D-ARD-1 to D-ARD-9) and the associate samples (Tables C.2 to C.5) for all parameters.

**Table C.3. Exova laboratory quality control data assessment for nutrient in 2014.**

| | | Control samples | | | | Lab blank | Lab replicates | | Field duplicates (D-E1 to D-E3) (detected samples only) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Sets | Level[z] | Control limit | Sets failed | Comment[y] | Sets failed | % RSD[x] | Sets failed | Sets | r | $r_c$ | Agreement |
| $NO_3$-N | 57 | Low | 88.24-111.76% | 0 | O.B | | | | | | | |
| | 57 | Mid | 89.38-110.63% | 0 | C.B. | 0 | +/- 10 | 0 | | | | |
| | 57 | High | 95.53-104.47% | 0 | O.B. | | | | | | | |
| $NH_3$-N | | | | | | | | | | | | |
| TN | 57 | Low | 82.30-117.70% | 0 | O.B. | | | | | | | |
| | 57 | Mid | 90.03-109.97% | 0 | C.B. | 0 | +/- 10 | 0 | 11 | 0.929 | 0.914 | Moderate |
| | 57 | High | 88.21-111.79% | 0 | C.B. | | | | | | | |
| $PO_4$-P | 57 | Low | 80.00-120.00% | 0 | O.B. | 0 | +/- 10 | 0 | 5 | 0.951 | 0.935 | Moderate |
| | 57 | Mid | 82.58-117.42% | 0 | O.B. | | | | | | | |
| TDP | 57 | Mid | 90.25-109.75% | 0 | C.B. | 0 | +/- 10 | 0 | 7 | 0.971 | 0.969 | Substantial |
| | 57 | High | 95.12-104.88% | 0 | C.B. | | | | | | | |
| TP | 57 | Mid | 90.25-109.75% | 0 | O.K. | 0 | +/- 10 | 0 | 9 | 0.996 | 0.995 | Perfect |
| | 57 | High | 95.12-104.88% | 0 | O.K. | | | | | | | |

[z] Different levels of concentration: low, mid, and high.

[y] O.B. = occasionally biased, C.B. = consistently biased, O.K. = not biased.

[x] Relative standard deviation calculated as (standard deviation ÷ average value of replicate values) × 100

**Table C.4. Exova laboratory quality control data assessment for metals in 2014.**

| | | Control samples | | | | Lab blank | Lab replicates | | Field duplicates (D-E1 to D-E3) (detected samples only) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Sets | Level[z] | Control limit | Sets failed | Comment[y] | Sets failed | % RSD[x] | Sets failed | Sets | r | $r_c$ | Agreement |
| Al | 53 | Low | 92.45-107.55% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | 8 | 0.565 | 0.494 | Poor |
| | 53 | High | 89.74-110.26% | 0 | C.B. | | | | | | | |
| Sb | 53 | Low | 90.00-110.00% | 0 | O.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.B. | 0 | +/- 15 | 0 | | | | |
| | 53 | High | 92.70-107.30% | 0 | C.B. | | | | | | | |
| As | 53 | Low | 87.80-112.20% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | 11 | 0.956 | 0.950 | Moderate |
| | 53 | High | 91.50-108.50% | 0 | C.B. | | | | | | | |
| Ba | 53 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | 11 | 0.923 | 0.874 | Moderate |
| | 53 | High | 93.64-106.36% | 0 | O.B. | | | | | | | |
| Be | 53 | Low | 84.21-115.79% | 0 | O.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.B. | 0 | +/- 15 | 0 | | | | |
| | 53 | High | 87.88-112.12% | 0 | O.K. | | | | | | | |
| B | 53 | Low | 85.00-115.00% | 0 | O.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.B. | 0 | +/- 15 | 0 | 11 | 0.982 | 0.971 | Substantial |
| | 53 | High | 88.06-111.94% | 0 | O.B. | | | | | | | |
| Cd | 53 | Low | 84.21-115.79% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | | | | |
| | 53 | High | 93.20-106.80% | 0 | O.B. | | | | | | | |
| Cr | 53 | Low | 92.00-108.00% | 0 | O.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.B. | 0 | +/- 15 | 0 | | | | |
| | 53 | High | 93.13-106.87% | 0 | O.B. | | | | | | | |
| Co | 53 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | 5 | 1.000 | 1.000 | Perfect |
| | 53 | High | 91.87-108.13% | 0 | O.B. | | | | | | | |
| Cu | 53 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.B. | 0 | +/- 15 | 0 | | | | |
| | 53 | High | 91.91-108.09% | 0 | O.B. | | | | | | | |
| Fe | 53 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | 7 | -0.329 | -0.158 | Poor |
| | 53 | High | 94.38-105.62% | 0 | C.B. | | | | | | | |
| Pb | 53 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | | | | |
| | 53 | High | 92.08-107.92% | 0 | O.B. | | | | | | | |
| Li | 53 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | 11 | 0.998 | 0.986 | Perfect |
| | 53 | High | 87.59-112.41% | 0 | C.B. | | | | | | | |

[z] Different levels of concentration: low, mid, and high.

[y] O.B. = occasionally biased, C.B. = consistently biased, O.K. = not biased.

[x] Relative standard deviation calculated as (standard deviation ÷ average value of replicate values) × 100

**Table C.4. continued**

| | | Control samples | | | | Lab blank | Lab replicates | | Field duplicates (D-E1 to D-E3) (detected samples only) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Sets | Level[z] | Control limit | Sets failed | Comment[y] | Sets failed | % RSD[x] | Sets failed | Sets | r | $r_c$ | Agreement |
| Mn | 53 | Low | 90.20-109.80% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 89.80-110.20% | 0 | C.B. | 0 | +/- 15 | 0 | 12 | 0.908 | 0.888 | Moderate |
| | 53 | High | 93.78-106.22% | 0 | C.B. | | | | | | | |
| Mo | 53 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.B. | 0 | +/- 15 | 0 | 7 | 1.000 | 1.000 | Perfect |
| | 53 | High | 93.78-106.22% | 0 | C.B. | | | | | | | |
| Ni | 53 | Low | 90.00-110.00% | 0 | O.K. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.B. | 0 | +/- 15 | 0 | 8 | -0.48 | -0.235 | Poor |
| | 53 | High | 93.47-106.53% | 0 | C.B. | | | | | | | |
| Se | 53 | Low | 84.21-115.79% | 0 | O.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | 8 | 0.898 | 0.887 | Moderate |
| | 53 | High | 91.39-108.61% | 0 | O.B. | | | | | | | |
| Ag | 53 | Low | 92.38-107.62% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.B. | 0 | +/- 15 | 0 | | | | |
| | 53 | High | 90.00-110.00% | 0 | O.B. | | | | | | | |
| Tl | 53 | Low | 91.43-108.57% | 0 | C.B. | | | | | | | |
| | 53 | Mid | | 0 | O.B. | | | | | | | |
| | 53 | High | 92.02-107.98% | 0 | O.B. | 0 | +/- 15 | 0 | | | | |
| Sn | 53 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.B. | 0 | +/- 15 | 0 | | | | |
| | 53 | High | 92.15-107.85% | 0 | C.B. | | | | | | | |
| Ti | 53 | Low | 90.91-109.09% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | 8 | 0.797 | 0.776 | Moderate |
| | 53 | High | 92.52-107.48% | 0 | C.B. | | | | | | | |
| U | 53 | Low | 90.38-109.62% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | O.K. | 0 | +/- 15 | 0 | 10 | 0.957 | 0.954 | Substantial |
| | 53 | High | 90.08-109.02% | 0 | O.K. | | | | | | | |
| V | 53 | Low | 85.71-114.29% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.B. | 0 | +/- 15 | 0 | 11 | 0.915 | 0.909 | Moderate |
| | 53 | High | 90.91-109.09% | 0 | C.B. | | | | | | | |
| Zn | 53 | Low | 90.00-110.00% | 0 | C.B. | | | | | | | |
| | 53 | Mid | 90.00-110.00% | 0 | C.K. | 0 | +/- 15 | 0 | 10 | 0.565 | 0.494 | Poor |
| | 53 | High | 91.85-108.15% | 0 | C.B. | | | | | | | |
| | 53 | Low | | 0 | O.B. | | | | | | | |
| Hg | 53 | Mid | 88.61-111.39% | 0 | O.B. | 0 | +/- 15 | 0 | | | | |
| | 53 | High | 89.66-110.34% | 0 | O.B. | | | | | | | |

[z] Different levels of concentration: low, mid, and high.

[y] O.B. = occasionally biased, C.B. = consistently biased, O.K. = not biased.

[x] Relative standard deviation calculated as (standard deviation ÷ average value of replicate values) × 100

**Table C.5. Duplicate field samples comparison between EXOVA and AF laboratories (detected samples only).**

| Parameter | n | unit | AF average | SD | EXOVA average | SD | Difference of average | r | $r_c$ | Agreement between labs |
|---|---|---|---|---|---|---|---|---|---|---|
| pH[z] | | | | | | | | | | |
| EC | 36 | dS $m^{-1}$ | 0.404 | 0.133 | 0.403 | 0.133 | 0.001 | 0.997 | 0.997 | Perfect |
| Ca | 35 | $mmol_c$ $L^{-1}$ | 1.745 | 0.372 | 1.767 | 0.356 | 0.016 | 0.965 | 0.963 | Substantial |
| Mg | 35 | $mmol_c$ $L^{-1}$ | 1.470 | 0.473 | 1.451 | 0.442 | 0.019 | 0.984 | 0.981 | Substantial |
| Na | 25 | $mmol_c$ $L^{-1}$ | 1.288 | 0.672 | 1.346 | 0.649 | 0.058 | 0.993 | 0.989 | Perfect |
| K | 4 | $mmol_c$ $L^{-1}$ | 0.233 | 0.200 | 0.233 | 0.187 | 0.000 | 1.000 | 0.997 | Perfect |
| $SO_4$ | 34 | $mmol_c$ $L^{-1}$ | 1.445 | 0.902 | 1.469 | 0.907 | 0.240 | 0.992 | 0.992 | Perfect |
| Cl | 13 | $mmol_c$ $L^{-1}$ | 0.393 | 0.175 | 0.399 | 0.151 | 0.006 | 0.973 | 0.962 | Substantial |
| $HCO_3 + CO_3$ | | $mmol_c$ $L^{-1}$ | | | | | | | | |
| TN | 16 | mg $L^{-1}$ | 0.779 | 0.320 | 0.646 | 0.272 | 0.133 | 0.951 | 0.848 | Moderate |
| $PO_4$-P | 11 | mg $L^{-1}$ | 0.047 | 0.047 | 0.052 | 0.051 | 0.005 | 0.996 | 0.987 | Perfect |
| TDP | 16 | mg $L^{-1}$ | 0.049 | 0.052 | 0.051 | 0.054 | 0.002 | 0.992 | 0.991 | Perfect |
| TP | 31 | mg $L^{-1}$ | 0.055 | 0.054 | 0.050 | 0.054 | 0.005 | 0.992 | 0.991 | Perfect |
| $NO_3$-N | | mg $L^{-1}$ | | | | | | | | |
| $NH_4$-N[y] | | mg $L^{-1}$ | | | | | | | | |

[z] pH and HCO3 + CO3 values were not compared because of their poor stability.

[y] Analytes value below detection limit

No contamination or errors were found in the field blanks and AF laboratory blanks samples analyzed for nutrient, salinity, physical, or metals parameters (Table C.6).

**Table C.6. Blank samples analyzed by the AF laboratory.**

| | AF laboratory | |
|---|---|---|
| | Field blank n = 12 | Lab blank n = 4 |
| Parameter | Sets failed | Sets failed |
| pH | 0 | 0 |
| EC | 0 | 0 |
| Ca | 0 | 0 |
| Mg | 0 | 0 |
| Na | 0 | 0 |
| K | 0 | 0 |
| $SO_4$ | 0 | 0 |
| Cl | 0 | 0 |
| $HCO_3 + CO_3$ | 0 | 0 |
| TN | 0 | 0 |
| $PO_4$-P | 0 | 0 |
| TDP | 0 | 0 |
| TP | 0 | 0 |
| $NO_3$-N | 0 | 0 |
| $NH_4$-N | 0 | 0 |

Most of the cations and anions of nutrient and salinity parameters from the check standards were recovered between 90 and 110% (Table C.7). In the third set of check standards sodium was below acceptable limits for % recovery. In all check standard chloride was below acceptable limits for % recovery. However, when the chloride results were compared between Exova laboratory and AF laboratory there was a substantial agreement in the results.

**Table C.7. Percent recovery check standard samples for nutrient and salinity parameters in 2014.**

| | $NH_4NO_3$ | | $KHPO_4$ | | $MgSO_4$ | | NaCl | | $CaCl_2$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $NH_4^+$ | $NO_3^-$ | $K^+$ | $HPO_4^{-2}$ | $Mg^{+2}$ | $SO_4^{-2}$ | $Na^+$ | $Cl^-$ | $Ca^{+2}$ | $Cl^-$ |
| Set | (%) | | | | | | | | | |
| 1 | 94.1 | 97.1 | 107.0 | 103.9 | 99.0 | 106.5 | 99.2 | 88.3 | 94.2 | 88.3 |
| 2 | | | | | | | | | | |
| 3 | 92.9 | 99.4 | 96.7 | 102.2 | 99.0 | 97.8 | 89.1 | 67.4 | 99.7 | 67.4 |
| 4 | 108.2 | 90.9 | 106.7 | 103.0 | 99.0 | 104.0 | 96.7 | 75.5 | 102.5 | 75.5 |

A total of 21 out of 73 analyzed metals met the allowable +/-12% of error (Table C.8). The fifteen metals that exceeded the allowable error were Al, As, Ba, Be, B, Cu, Fe, Li, Ni, Se, Ag, Ti, V, Zn and Hg. These may have been affected by the larger variability of the error at low concentration. The three metals that exceeded the allowable error for a three levels of concentration were Al, Ag and Hg. We have requested the a full re-evaluation of MMDL according to our service agreement for metals for 2015.

**Table C.8. Percent error of check standard samples for metals in 2014.**

| Metal parameter | MMDL (mg $L^{-1}$) | Expected value (mg $L^{-1}$) | Allowable % error | Set | Observed value (mg $L^{-1}$) | % error |
|---|---|---|---|---|---|---|
| | 0.02 | 0.25 | +/- 12.00 | 1 | 0.31 | -24.00 |
| Al | | 0.025 | | 3 | 0.04 | -60.00 |
| | | 0.625 | | 4 | <0.02 | - |
| | 0.002 | 0.01 | +/- 12.00 | 1 | 0.0103 | -3.00 |
| Sb | | 0.001 | | 3 | 0.001 | 0.00 |
| | | 0.025 | | 4 | 0.0238 | 4.80 |
| | 0.0002 | 0.0098 | +/- 12.00 | 1 | 0.0102 | -4.08 |
| As | | 0.00098 | | 3 | 0.0011 | -12.24 |
| | | 0.0245 | | 4 | 0.0231 | 5.71 |
| | 0.001 | 0.05 | +/- 12.00 | 1 | 0.055 | -10.00 |
| Ba | | 0.005 | | 3 | 0.006 | -20.00 |
| | | 0.125 | | 4 | 0.126 | -0.80 |
| | 0.0001 | 0.005 | +/- 12.00 | 1 | 0.0047 | 6.00 |
| Be | | 0.0005 | | 3 | 0.0006 | -20.00 |
| | | 0.0125 | | 4 | 0.0117 | 6.40 |
| | 0.002 | 0.1 | +/- 12.00 | 1 | 0.11 | -10.00 |
| B | | 0.01 | | 3 | 0.015 | -50.00 |
| | | 0.25 | | 4 | 0.244 | 2.40 |

**Table C.8. continued**

| Metal parameter | MMDL (mg $L^{-1}$) | Expected value (mg $L^{-1}$) | Allowable % error | Set | Observed value (mg $L^{-1}$) | % error |
|---|---|---|---|---|---|---|
| | 0.00001 | 0.005 | +/- 12.00 | 1 | 0.00515 | -3.00 |
| Cd | | 0.0005 | | 3 | 0.00053 | -6.00 |
| | | 0.0125 | | 4 | 0.0118 | 5.60 |
| | 0.0005 | 0.0248 | +/- 12.00 | 1 | 0.0265 | -6.85 |
| Cr | | 0.00248 | | 3 | 0.0027 | -8.87 |
| | | 0.062 | | 4 | 0.0629 | -1.45 |
| | 0.0001 | 0.005 | +/- 12.00 | 1 | 0.0051 | -2.00 |
| Co | | 0.0005 | | 3 | 0.0005 | 0.00 |
| | | 0.0125 | | 4 | 0.0125 | 0.00 |
| | 0.001 | 0.0502 | +/- 12.00 | 1 | 0.053 | -5.58 |
| Cu | | 0.00502 | | 3 | 0.006 | -19.52 |
| | | 0.1255 | | 4 | 0.131 | -4.38 |
| | 0.05 | 2.504 | +/- 12.00 | 1 | 2.75 | -9.82 |
| Fe | | 0.2504 | | 3 | 0.29 | -15.81 |
| | | 6.26 | | 4 | <0.05 | - |
| | 0.0001 | 0.005 | +/- 12.00 | 1 | 0.0053 | -6.00 |
| Pb | | 0.0005 | | 3 | 0.0005 | 0.00 |
| | | 0.0125 | | 4 | 0.0126 | -0.80 |
| | 0.001 | 0.05 | +/- 12.00 | 1 | 0.053 | -6.00 |
| Li | | 0.005 | | 3 | 0.006 | -20.00 |
| | | 0.125 | | 4 | 0.128 | -2.40 |
| | 0.005 | 0.248 | +/- 12.00 | 3 | 0.277 | -11.69 |
| Mn | | 0.0248 | | 4 | 0.027 | -8.87 |
| | | 0.62 | | | <0.005 | - |
| | 0.001 | 0.0502 | +/- 12.00 | 1 | 0.052 | -3.59 |
| Mo | | 0.00502 | | 3 | 0.005 | 0.40 |
| | | 0.1255 | | 4 | 0.13 | -3.59 |
| | 0.0005 | 0.025 | +/- 12.00 | 1 | 0.0256 | -2.40 |
| Ni | | 0.0025 | | 3 | 0.0032 | -28.00 |
| | | 0.0625 | | 4 | 0.0622 | 0.48 |
| | 0.0002 | 0.01 | +/- 12.00 | 1 | 0.0099 | 1.00 |
| Se | | 0.001 | | 3 | 0.001 | 0.00 |
| | | 0.025 | | 4 | 0.0219 | 12.40 |
| | 0.00001 | 0.0005 | +/- 12.00 | 1 | 0.00021 | 58.00 |
| Ag | | 0.00005 | | 3 | 0.00238 | -4660.00 |
| | | 0.00125 | | 4 | | |
| | 0.00005 | 0.00246 | +/- 12.00 | 1 | 0.00269 | -9.35 |
| Tl | | 0.000246 | | 3 | 0.00026 | -5.69 |
| | | 0.00615 | | 4 | 0.0065 | -5.69 |
| | 0.001 | 0.05 | +/- 12.00 | 1 | 0.052 | -4.00 |
| Sn | | 0.005 | | 3 | 0.005 | 0.00 |
| | | 0.125 | | 4 | 0.123 | 1.60 |

**Table C.8. continued**

| Metal parameter | MMDL (mg $L^{-1}$) | Expected value (mg $L^{-1}$) | Allowable % error | Set | Observed value (mg $L^{-1}$) | % error |
|---|---|---|---|---|---|---|
| | 0.0005 | 0.0246 | +/- 12.00 | 1 | 0.0289 | -17.48 |
| Ti | | 0.00246 | | 3 | 0.0026 | -5.69 |
| | | 0.0615 | | 4 | 0.0619 | -0.65 |
| | 0.0005 | 0.0252 | +/- 12.00 | 1 | 0.0261 | -3.57 |
| U | | 0.00252 | | 3 | 0.0024 | 4.76 |
| | | 0.063 | | 4 | 0.0645 | -2.38 |
| | 0.0001 | 0.005 | +/- 12.00 | 1 | 0.0053 | -6.00 |
| V | | 0.0005 | | 3 | 0.0006 | -20.00 |
| | | 0.0125 | | 4 | 0.0126 | -0.80 |
| Zn | 0.001 | 0.0502 | +/- 12.00 | 1 | 0.052 | -3.59 |
| | | 0.00502 | | 3 | 0.006 | -19.52 |
| | | 0.1255 | | 4 | 0.119 | 5.18 |
| | 0.0001 | 0.005 | +/- 12.00 | 1 | 0.000073 | 98.54 |
| Hg | | 0.0005 | | 3 | <0.000005 | - |
| | | 0.0125 | | 4 | <0.000005 | - |

[z] ND = not detected

## C.6 Conclusions

Exova laboratory produced quality data for nutrient, salinity, physical, and metals parameters in 2014.

## C.7 References

**Lin, L.I. 1989.** A concordance correlation coefficient to evaluate reproducibility. Biometrics 45: 255-268.

## C.8 Glossary

**Control Limit.** The individual analytical values in the series are plotted and evaluated against control limits. The limits are calculated as +/- 3 standard deviations of the average of the historical data.

**Correlation Coefficient (r).** This is used to measure the degree of linear relationship between two variables. The correlation coefficient is a value ranging from -1 to +1. If one variable tends

to increase as the other decreases, the correlation coefficient is negative. Conversely, if the two variables tend to increase together the correlation coefficient is positive.

**Field Blank.** A field blank is deionized water, which is treated as a sample. It is used to identify potential errors or contamination during sample collection and analysis.

**Field Duplicate.** A field duplicate sample collected by the same team or by another sampler or team at the same place, at the same time. It is used to estimate sampling and laboratory analysis precision.

**Lin's Concordance Coefficient ($r_c$).** The concordance correlation coefficient (Lin 1989) evaluates the degree to which pairs of observations fall on the 45° line through the origin: $r_c >$ 0.99 shows perfect agreement, $r_c >$ 0.95 to 0.99 shows substantial agreement, $r_c =$ 0.90 to 0.95 shows moderate agreement, and $r_c <$ 0.90 shows poor agreement.

**Laboratory Blanks.** A blank prepared to represent the matrix as closely as possible. The laboratory blank is prepared, extracted, digested, and analyzed in the same way as for the field samples. These blanks are used to assess contamination introduced during sample preparation.

**Laboratory Replicate.** This is a subsample of a routine sample, which is homogenized, divided into separate containers, and analyzed using the same analytical method. Laboratory replicates are used to determine method precision. However, because it is a non-blind sample, or known to the analyst, it can only be used by the analyst as an internal control tool and not as an unbiased estimate of analytical precision.

**% RSD.** This is the percent relative standard deviation and it is calculated from repeated analysis by:

(standard deviation ÷ average value of replicate values) × 100

**% Error.** [(expected value – observed value) ÷ expected value] × 100

# Appendix D. Sampling Sites Water Quality

The irrigation districts infrastructure is a complex network of canals. Understanding the flow connectivity among sampling sites is essential to interpret changes in water quality within the irrigation districts (Figure A.1). From the 2014 water quality sampling, results for selected parameters are presented in Tables D.1 to D.4 to show how water quality changed as water flowed from upstream to downstream.

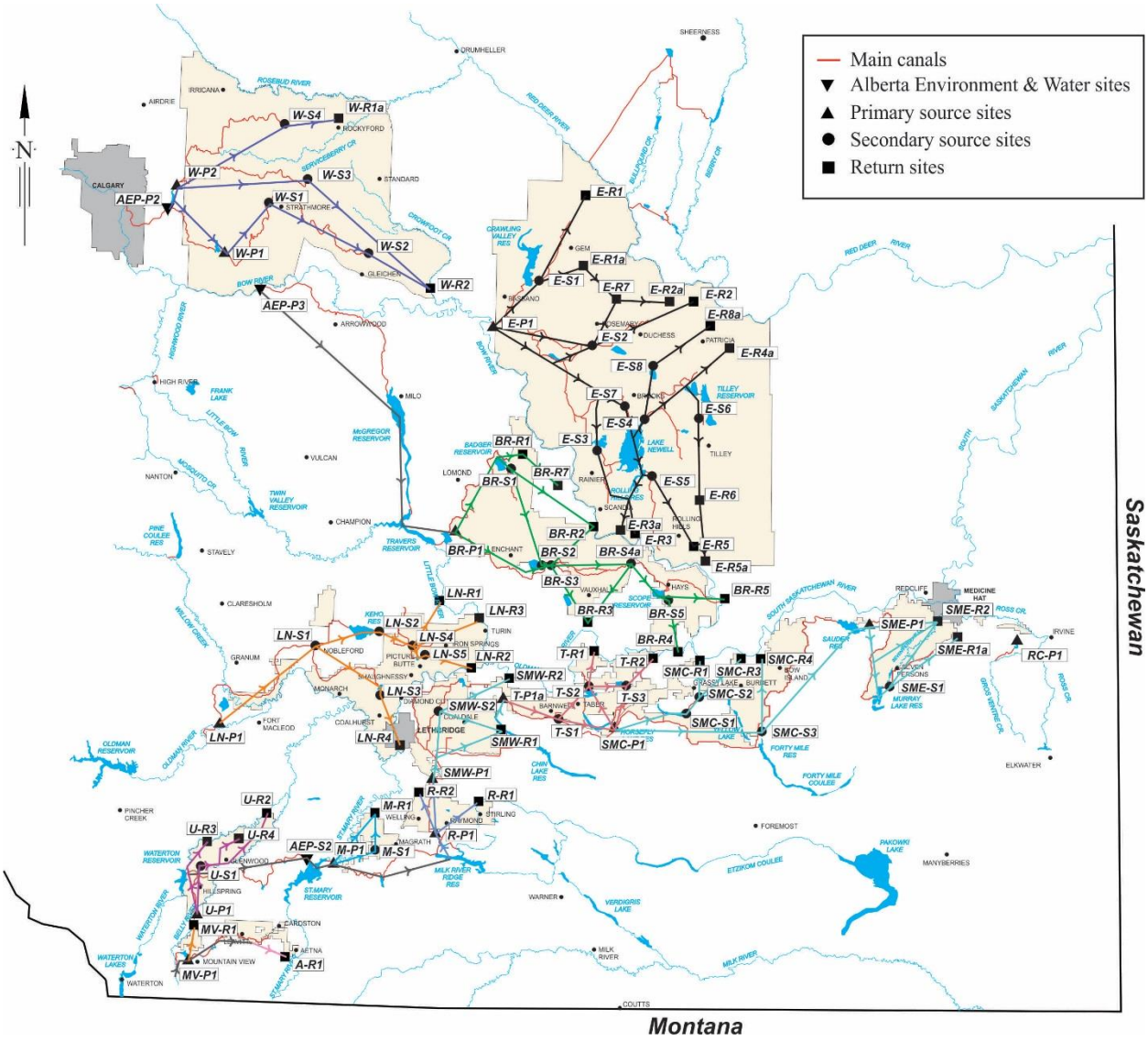



**Figure D.1. Flow connectivity among water quality sampling sites in 2014.**

**Table D.1. Results of selected water quality parameters for sampling sites in MVID, AID, UID, MID, RID, and LNID in 2014.[z]**

| Sampling site | Average TP (mg $L^{-1}$) | Average TDP (mg $L^{-1}$) | Average TN (mg $L^{-1}$) | Average $NO_3$-N (mg $L^{-1}$) | Average TDS (mg $L^{-1}$) | Average SAR | Average TSS (mg $L^{-1}$) | Median *E. coli* (CFU 100 $mL^{-1}$) | Average 2,4-D (µg $L^{-1}$) | Average Glyphosate[y] (µg $L^{-1}$) | No. of different pesticides |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Mountain View Irrigation District* | | | | | | | | | | | |
| MV-P1 | 0.017 | 0.014 | 0.29 | 0.01 | 144 | 0.1 | 3 | 7 | 0.045 | 0.0 | 2 |
| MV-R1 | 0.020 | 0.017 | 0.30 | 0.01 | 149 | 0.2 | 6 | 49 | 0.007 | 0.0 | 1 |
| *Aetna Irrigation District* | | | | | | | | | | | |
| A-R1 | 0.023 | 0.019 | 0.38 | 0.02 | 147 | 0.225 | 4 | 366 | 0.072 | 0.0 | 3 |
| *United Irrigation District* | | | | | | | | | | | |
| U-P1 | 0.004 | 0.003 | 0.17 | 0.10 | 102 | 0.1 | 10 | 29 | 0.000 | - | 0 |
| U-R2 | 0.047 | 0.025 | 0.27 | 0.01 | 141 | 0.2 | 20 | 105 | 0.085 | 0.0 | 5 |
| U-R3 | 0.158 | 0.023 | 0.31 | 0.02 | 130 | 0.1 | 183 | 175 | 0.000 | 2.2 | 5 |
| U-R4[w] | 0.030 | 0.019 | 0.48 | 0.22 | 139 | 0.3 | 7 | 0 | 0.000 | 0.0 | 4 |
| U-S1 | 0.019 | 0.012 | 0.29 | 0.01 | 123 | 0.2 | 2 | 5 | 0.000 | - | 4 |
| *Magrath Irrigation District* | | | | | | | | | | | |
| AEP-S2 | 0.016 | 0.005 | 0.16 | 0.09 | 108 | 0.1 | 17 | 22 | 0.000 | - | 0 |
| M-P1 | 0.016 | 0.006 | 0.28 | 0.13 | 121 | 0.2 | 5 | 4 | 0.036 | - | 4 |
| M-R1 | 0.104 | 0.035 | 0.58 | 0.24 | 349 | 1.5 | 60 | 250 | 0.048 | 0.0 | 6 |
| M-S1 | 0.116 | 0.055 | 0.32 | 0.07 | 184 | 0.5 | 18 | 77 | 0.047 | - | 6 |
| *Raymond Irrigation District* | | | | | | | | | | | |
| R-P1 | 0.020 | 0.019 | 0.29 | 0.11 | 139 | 0.3 | 8 | 11 | 0.059 | - | 7 |
| R-R1 | 0.263 | 0.231 | 0.68 | 0.04 | 471 | 2.1 | 27 | 148 | 0.104 | 0.2 | 6 |
| R-R2 | 0.109 | 0.074 | 0.36 | 0.03 | 212 | 0.7 | 29 | 230 | 0.113 | 0.4 | 7 |
| *Lethbridge Northern Irrigation District* | | | | | | | | | | | |
| LN-P1 | 0.028 | 0.008 | 0.27 | 0.13 | 157 | 0.2 | 20 | 86 | 0.028 | 0.0 | 2 |
| LN-R1 | 0.136 | 0.021 | 0.36 | 0.03 | 194 | 0.6 | 161 | 480 | 0.091 | 0.1 | 5 |
| LN-R2 | 0.117 | 0.078 | 0.60 | 0.11 | 211 | 0.6 | 26 | 210 | 0.147 | 0.0 | 7 |
| LN-R3[x] | 0.070 | 0.032 | 0.56 | 0.23 | 196 | 0.6 | 17 | 750 | 0.094 | 2.0 | 9 |
| LN-R4 | 0.056 | 0.025 | 0.47 | 0.01 | 227 | 0.7 | 7 | 17 | 0.093 | 0.2 | 8 |
| LN-S1 | 0.044 | 0.009 | 0.29 | 0.07 | 157 | 0.3 | 19 | 52 | 0.027 | - | 1 |
| LN-S2 | 0.015 | 0.011 | 0.30 | 0.01 | 187 | 0.5 | 4 | 7 | 0.101 | - | 1 |
| LN-S3 | 0.033 | 0.023 | 0.41 | 0.06 | 233 | 0.9 | 4 | 26 | 0.066 | - | 4 |
| LN-S4 | 0.034 | 0.024 | 0.29 | 0.01 | 223 | 0.8 | 7 | 46 | 0.136 | 0.0 | 3 |
| LN-S5 | 0.059 | 0.047 | 0.51 | 0.01 | 185 | 0.6 | 5 | 12 | 0.088 | - | 4 |

[z] n= 4

[y] n= 2, not all sites were sampled for glyphosate.

[w] n=3, Site was not sampled during one event due to accessibility issues.

**Table D.2. Results of selected water quality parameters for sampling sites in SMRID, TID and RCID in 2014.[z]**

| Sampling site | Average TP (mg $L^{-1}$) | Average TDP (mg $L^{-1}$) | Average TN (mg $L^{-1}$) | Average $NO_3$-N (mg $L^{-1}$) | Average TDS (mg $L^{-1}$) | Average SAR | Average TSS (mg $L^{-1}$) | Median *E. coli* (CFU 100 $mL^{-1}$) | Average 2,4-D (µg $L^{-1}$) | Average Glyphosate[y] (µg $L^{-1}$) | No. of different pesticides |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *St. Mary River Irrigation District west section* | | | | | | | | | | | |
| SMW-P1 | 0.023 | 0.014 | 0.30 | 0.08 | 146 | 0.4 | 8 | 11 | 0.045 | - | 4 |
| SMW-R1 | 0.079 | 0.055 | 0.32 | 0.04 | 169 | 0.4 | 18 | 185 | 0.204 | 0.6 | 8 |
| SMW-R2 | 0.099 | 0.083 | 0.50 | 0.02 | 165 | 0.5 | 14 | 35 | 0.332 | 0.5 | 9 |
| SMW-S2 | 0.036 | 0.021 | 0.30 | 0.08 | 150 | 0.3 | 12 | 46 | 0.164 | 0.4 | 5 |
| *Taber Irrigation District* | | | | | | | | | | | |
| T-P1a | 0.043 | 0.031 | 0.30 | 0.02 | 179 | 0.5 | 4 | - | 0.150 | 0.0 | 8 |
| T-R1 | 0.058 | 0.039 | 0.75 | 0.02 | 310 | 1.7 | 7 | 54 | 0.000 | 0.0 | 9 |
| T-R2 | 0.066 | 0.033 | 0.58 | 0.04 | 214 | 1.0 | 6 | 52 | 0.150 | 0.0 | 9 |
| T-S1 | 0.050 | 0.027 | 0.39 | 0.03 | 179 | 0.5 | 6 | 14 | - | - | 8 |
| T-S2 | 0.057 | 0.040 | 0.80 | 0.02 | 316 | 1.7 | 5 | 1 | - | - | 9 |
| T-S3[w] | 0.053 | 0.036 | 0.78 | 0.04 | 215 | 1.0 | 5 | 24 | 0.000 | 0.0 | 8 |
| *St. Mary River Irrigation District central section* | | | | | | | | | | | |
| SMC-P1[w] | 0.053 | 0.029 | 0.34 | 0.03 | 181 | 0.5 | 12 | 25 | 0.118 | - | 6 |
| SMC-R1 | 0.049 | 0.024 | 0.58 | 0.09 | 210 | 0.7 | 7 | 78 | 0.113 | 0.5 | 6 |
| SMC-R3 | 0.053 | 0.021 | 0.54 | 0.01 | 197 | 0.7 | 11 | 44 | 0.084 | 0.6 | 6 |
| SMC-R4 | 0.052 | 0.027 | 0.33 | 0.01 | 189 | 0.5 | 18 | 197 | 0.256 | 0.0 | 5 |
| SMC-S1 | 0.034 | 0.018 | 0.44 | 0.01 | 199 | 0.7 | 4 | 18 | 0.094 | - | 6 |
| SMC-S2 | 0.035 | 0.018 | 0.42 | 0.01 | 196 | 0.7 | 8 | 22 | 0.092 | 0.2 | 7 |
| SMC-S3 | 0.054 | 0.028 | 0.34 | 0.04 | 182 | 0.5 | 16 | 8 | 0.128 | 0.2 | 8 |
| *St. Mary River Irrigation District east section* | | | | | | | | | | | |
| SME-P1 | 0.054 | 0.022 | 0.65 | 0.01 | 197 | 0.7 | 5 | 9 | 0.187 | 0.3 | 6 |
| SME-R1a | 0.126 | 0.050 | 1.29 | 0.07 | 222 | 1.0 | 17 | 40 | 0.085 | 0.4 | 2 |
| SME-R2 | 0.233 | 0.185 | 1.15 | 0.10 | 356 | 1.3 | 19 | 240 | 0.232 | 0.6 | 6 |
| SME-S1 | 0.149 | 0.041 | 1.55 | 0.01 | 219 | 1.0 | 15 | 1 | 0.097 | - | 3 |
| *Ross Creek Irrigation District* | | | | | | | | | | | |
| RC-P1 | 0.355 | 0.294 | 1.70 | 0.02 | 510 | 2.0 | 7 | 33 | 0.063 | - | 2 |

[z] n= 4

[y] n= 2, not all sites were sampled for glyphosate.

[w] n=3, Site was not sampled during one event due to accessibility issues.

**Table D.3. Results of selected water quality parameters for sampling sites in WID and BRID in 2014.[z]**

| Sampling site | Average TP (mg $L^{-1}$) | Average TDP (mg $L^{-1}$) | Average TN (mg $L^{-1}$) | Average $NO_3$-N (mg $L^{-1}$) | Average TDS (mg $L^{-1}$) | Average SAR | Average TSS (mg $L^{-1}$) | Median *E. coli* (CFU 100 $mL^{-1}$) | Average 2,4-D (µg $L^{-1}$) | Average Glyphosate[y] (µg $L^{-1}$) | No. of different pesticides |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Western Irrigation District* | | | | | | | | | | | |
| AEP-P2 | 0.023 | 0.008 | 0.35 | 0.15 | 212 | 0.5 | 16 | 245 | 0.281 | 0.0 | 4 |
| W-P1 | 0.014 | 0.011 | 0.31 | 0.01 | 246 | 0.8 | 3 | 11 | 0.150 | 0.0 | 3 |
| W-P2 | 0.011 | 0.008 | 0.27 | 0.06 | 235 | 0.7 | 9 | 7 | 0.150 | 0.2 | 6 |
| W-R1a | 0.040 | 0.033 | 0.34 | 0.01 | 262 | 0.9 | 5 | 103 | 0.131 | 0.0 | 3 |
| W-R2 | 0.115 | 0.088 | 0.56 | 0.01 | 446 | 2.2 | 9 | 300 | 0.190 | 0.3 | 5 |
| W-S1 | 0.018 | 0.012 | 0.32 | 0.02 | 246 | 0.8 | 4 | 17 | 0.165 | - | 3 |
| W-S2 | 0.021 | 0.009 | 0.32 | 0.01 | 250 | 1.0 | 13 | 49 | 0.119 | - | 2 |
| W-S3 | 0.043 | 0.034 | 0.37 | 0.01 | 268 | 1.0 | 4 | 21 | 0.249 | - | 3 |
| W-S4 | 0.047 | 0.029 | 0.35 | 0.02 | 260 | 0.9 | 16 | 310 | 0.109 | - | 3 |
| *Bow River Irrigation District* | | | | | | | | | | | |
| AEP-P3 | 0.013 | 0.007 | 0.69 | 0.55 | 197 | 0.3 | 12 | 65 | 0.036 | - | 1 |
| BR-P1 | 0.009 | 0.006 | 0.32 | 0.01 | 328 | 1.1 | 2 | 2 | 0.080 | 0.0 | 2 |
| BR-R1 | 0.014 | 0.012 | 0.39 | 0.01 | 316 | 1.2 | 3 | 48 | 0.072 | 0.0 | 2 |
| BR-R2 | 0.062 | 0.056 | 0.49 | 0.01 | 358 | 1.3 | 8 | 99 | 0.152 | 0.0 | 6 |
| BR-R3 | 0.119 | 0.092 | 1.02 | 0.04 | 736 | 2.8 | 13 | 119 | 0.092 | 0.0 | 2 |
| BR-R4 | 0.078 | 0.051 | 0.68 | 0.01 | 374 | 1.6 | 6 | 125 | 0.064 | 0.0 | 5 |
| BR-R5 | 0.018 | 0.008 | 0.49 | 0.01 | 329 | 1.4 | 4 | 5 | 0.128 | 0.0 | 4 |
| BR-R7 | 0.118 | 0.117 | 0.74 | 0.04 | 399 | 1.7 | 4 | 97 | 0.061 | 0.0 | 3 |
| BR-S1 | 0.011 | 0.008 | 0.38 | 0.01 | 364 | 1.6 | 4 | 12 | 0.108 | - | 4 |
| BR-S2 | 0.112 | 0.040 | 1.59 | 0.01 | 422 | 2.2 | 15 | 4 | 0.068 | 0.0 | 3 |
| BR-S3 | 0.022 | 0.011 | 0.43 | 0.01 | 336 | 1.3 | 5 | 8 | 0.175 | - | 4 |
| BR-S4a | 0.018 | 0.012 | 0.47 | 0.03 | 335 | 1.3 | 3 | 8 | 0.259 | - | 4 |
| BR-S5 | 0.021 | 0.013 | 0.53 | 0.01 | 328 | 1.5 | 4 | 1 | 0.076 | 0.0 | 4 |

[z] n= 4

[y] n= 2, not all sites were sampled for glyphosate.

**Table D.4. Results of selected water quality parameters for sampling sites in EID in 2014.[z]**

| Sampling site | Average TP (mg $L^{-1}$) | Average TDP (mg $L^{-1}$) | Average TN (mg $L^{-1}$) | Average $NO_3$-N (mg $L^{-1}$) | Average TDS (mg $L^{-1}$) | Average SAR | Average TSS (mg $L^{-1}$) | Median *E. coli* (CFU 100 $mL^{-1}$) | Average 2,4-D (µg $L^{-1}$) | Average Glyphosate[y] (µg $L^{-1}$) | No. of different pesticides |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Eastern Irrigation District* | | | | | | | | | | | |
| E-P1 | 0.019 | 0.005 | 0.54 | 0.45 | 201 | 0.4 | 13 | 36 | 0.072 | 0.0 | 3 |
| E-R1 | 0.039 | 0.023 | 0.51 | 0.01 | 221 | 0.6 | 16 | 44 | 0.008 | 0.0 | 3 |
| E-R1a | 0.049 | 0.039 | 0.57 | 0.04 | 320 | 1.0 | 6 | 46 | 0.021 | 0.0 | 5 |
| E-R2 | 0.035 | 0.021 | 0.35 | 0.06 | 245 | 0.6 | 6 | 200 | 0.008 | 1.3 | 4 |
| E-R2a[w] | 0.111 | 0.032 | 0.53 | 0.06 | 352 | 1.5 | 144 | 250 | 0.036 | 0.2 | 7 |
| E-R3 | 0.013 | 0.005 | 0.38 | 0.21 | 202 | 0.4 | 4 | 49 | 0.018 | 0.0 | 3 |
| E-R3a | 0.035 | 0.008 | 0.47 | 0.21 | 288 | 0.6 | 20 | 163 | 0.024 | 0.0 | 4 |
| E-R4a | 0.008 | 0.005 | 0.27 | 0.01 | 215 | 0.6 | 2 | 35 | 0.022 | 0.0 | 3 |
| E-R5 | 0.005 | 0.005 | 0.31 | 0.01 | 222 | 0.7 | 2 | 11 | 0.029 | 0.0 | 3 |
| E-R5a | 0.091 | 0.071 | 0.67 | 0.01 | 305 | 1.1 | 6 | 26 | 0.056 | 0.2 | 7 |
| E-R6 | 0.087 | 0.071 | 0.49 | 0.01 | 249 | 0.8 | 6 | 31 | 0.060 | 0.2 | 8 |
| E-R7 | 0.080 | 0.065 | 0.41 | 0.05 | 316 | 1.1 | 14 | 105 | 0.096 | 0.0 | 5 |
| E-R8a | 0.331 | 0.290 | 0.72 | 0.03 | 417 | 1.5 | 19 | 157 | 0.146 | 0.1 | 7 |
| E-S1 | 0.025 | 0.011 | 0.47 | 0.02 | 227 | 0.6 | 5 | 1 | 0.015 | - | 1 |
| E-S2 | 0.016 | 0.005 | 0.48 | 0.36 | 202 | 0.4 | 10 | 10 | 0.050 | - | 2 |
| E-S3 | 0.035 | 0.009 | 0.52 | 0.38 | 200 | 0.4 | 33 | 18 | 0.018 | - | 2 |
| E-S4 | 0.007 | 0.005 | 0.24 | 0.01 | 220 | 0.5 | 3 | 2 | 0.015 | - | 1 |
| E-S5 | 0.005 | 0.005 | 0.28 | 0.01 | 225 | 0.7 | 2 | 25 | 0.030 | - | 1 |
| E-S6 | 0.043 | 0.015 | 0.68 | 0.01 | 225 | 1.0 | 5 | 5 | 0.000 | - | 0 |
| E-S7 | 0.029 | 0.007 | 0.46 | 0.39 | 199 | 0.4 | 23 | 30 | 0.020 | 0.0 | 2 |
| E-S8 | 0.179 | 0.136 | 0.60 | 0.01 | 346 | 1.3 | 5 | 4 | 0.136 | - | 5 |

[z] n= 4

[y] n= 2, not all sites were sampled for glyphosate.