

# Developing a treatment for Alberta's irrigation infrastructure to control invasive mussels using potash



**Barry Olson, Brad Calder, Andrea Kalischuk,  
Lloyd Healy, Nicole Seitz Vermeer, and Ivan Friesen**

*Alberta* 

# **Developing a treatment for Alberta's irrigation infrastructure to control invasive mussels using potash**

**Barry Olson<sup>1</sup>, Brad Calder<sup>1</sup>, Andrea Kalischuk<sup>1</sup>,  
Lloyd Healy<sup>1</sup>, Nicole Seitz Vermeer<sup>1</sup>, and Ivan Friesen<sup>2</sup>**

**<sup>1</sup>Irrigation and Farm Water Branch, Alberta Agriculture and Forestry,  
Lethbridge, Alberta, Canada**

**<sup>2</sup>Eastern Irrigation District, Brooks, Alberta, Canada**

**December 2018**

**Citation**

Olson, B., Calder, B., Kalischuk, A., Healy, L., Seitz Vermeer, N., and Friesen, I. 2018. Developing a treatment for Alberta's irrigation infrastructure to control invasive mussels using potash. Irrigation and Farm Water Branch, Alberta Agriculture and Forestry, Lethbridge, Alberta, Canada. 104 pp.

**Published by**

Irrigation and Farm Water Branch  
Alberta Agriculture and Forestry  
Lethbridge, Alberta, Canada

**Copyright © 2018**

All rights reserved by her Majesty the Queen in Right of Alberta (Alberta Agriculture and Forestry). Any reproduction of this publication or its parts may only be done in accordance with the Open Government Licence — Alberta (website: <http://open.alberta.ca/licence>), under the terms of the Government of Alberta Open Information Policy (<http://open.alberta.ca/policy>).

**Images**

Except where indicated, all images are courteous of Alberta Agriculture and Forestry.

## Acknowledgements

We would like to acknowledge the generous cooperation of the land owners in the Eastern, Taber, and St. Mary River irrigation districts who allowed access to their property and participated in the pipeline field study.

Funding for this research was provided by Growing Forward 2 (2016–2018; Project BO6970276), Alberta Innovates (2016–2018; Project AI-EES 2329), and the Eastern Irrigation District. In particular, we would like to thank Richard Nelson of Alberta Innovates for his support and flexibility during this project.

Special thanks to staff members of the Eastern, Taber, and St. Mary River irrigation districts who assisted in preparing for and carrying out the pipeline field trials. We would particularly like to acknowledge Jason Thompson, Ryan Gagley, Kevin Bridges, Chuck Getz, and Pedro Isidoro of the Eastern Irrigation District; Chris Gallagher, Tony Wikkerink, Jack Rop, and Fred Williams of the Taber Irrigation District; and Terrence Lazarus, George Bohner, and Butch Egeland of the St. Mary River Irrigation District.

Resources were also provided by Alberta Agriculture and Forestry (Irrigation and Farm Water Branch), and we gratefully acknowledge the assistance of the following Alberta Agriculture and Forestry staff (in alphabetical order by surname): Dana Coles, Brian Cook, Shaun Cook, Mike Ellefson, Dorothy Graham, Paul Graveland, Adele Harding, Shannon Healy, Ward Henry, Evan Hillman, Bonnie Hofer, Lauren Jackson, Mark Kadijk, Gyan Mankee, Gerald Ontkean, Troy Ormann, Jim Parker, Lawrence Schinkel, Bryce Steeves, Darryle Thiessen, and Janelle Villeneuve.

Special acknowledgements to Ki Au (retired, Alberta Agriculture and Forestry) for leading the potash solution preparation component. Also, thanks to Jennifer Kerr of Alberta Agriculture and Forestry for reviewing this report.

Finally, we acknowledge Agrium® Inc. (now Nutrien™), and in particular, Jim Jenkins and Ray Dowbenko, for supporting the use of their potash product for this project.

# Executive Summary

## Introduction

Irrigation in Alberta is essential for high agricultural production and crop diversity in the province. Irrigation infrastructure in Alberta includes 13 irrigation districts, 57 reservoirs, and 7900 km of conveyance works, supporting 675,300 ha of irrigated land. Irrigation district infrastructure is valued at \$3.66 billion. Recently, the irrigation industry has been concerned with the threat of possible introduction of aquatic invasive mussels into Alberta. Though Alberta is currently free of invasive mussels, they have spread throughout much of North America after being initially introduced to the Great Lakes in the late 1980s.

Aquatic Invasive mussels include zebra (*Dreissena polymorpha* (Pallas 1771)) and quagga (*Dreissena bugensis* (Andrusov 1897)) mussels, and they both originated from the Ponto-Caspian region in southeastern Europe. Invasive mussels are typically introduced to new water bodies on trailered watercraft, and can have significant negative effects on aquatic ecosystems and any water infrastructure such as raw-water treatment or conveyance works, e.g., irrigation systems. Effects of invasive mussel infestations are far reaching environmentally, economically, and socially.

Preventing the infestation of invasive mussels in a region through education, regulations, and monitoring is considered less costly than trying to manage the presences of mussels. However, if invasive mussels become established, control options include the use of mechanical, biological, and chemical methods. Of these, chemical control is likely the most practical option for the large-scale, irrigation conveyance system in Alberta.

Potential chemical treatments include oxidizing chemicals (chlorine, chloride dioxide, chloramines, ozone, bromine, hydrogen peroxide, potassium permanganate, and ferrate) and non-oxidizing chemicals (molluscicides, ammonium nitrate, copper ions, potassium salts, sodium metabisulfite, flocculation, BioBullets<sup>®</sup>, salinity, and pH adjustment). Currently, there are no registered chemical products for the control of mussels in Canada that can be used in Alberta's irrigation infrastructure. Of these various options, chemical treatment using potash or potassium chloride (KCl) is likely the most practical option for Alberta. Potassium ion (K<sup>+</sup>) can be highly toxic to mussels, has low implications to crops and water quality, is economically available, and has been used successfully in other jurisdictions. The effects of chemical control options on invasive mussels has been shown to vary depending on water temperature, pH, and water hardness. Potash is not registered in Canada as a pesticide to control invasive mussels. However, Alberta Environment and Parks, is preparing an application for registration to the federal Pest Management Regulatory Agency.

An infestation of invasive mussels in Alberta's irrigation infrastructure will likely first occur in a reservoir through transportation on watercraft. Established mussels in a reservoir will then propagate through the canals and pipelines. Considering the size of most reservoirs in Alberta (120 to 490,180 dam<sup>3</sup>), it is unlikely a mussel infestation can be eradicated. Instead, an ongoing maintenance program for keeping pipelines clear of mussels is a more likely scenario. Providing potash becomes the product of choice, regular treatment of pipelines will result in the application

of KCl-treated water onto agricultural soils and crops. Even though potash is primarily used as an agricultural fertilizer, there is some concern that repeat applications of KCl may have negative effects on crop quality for livestock feed (e.g., grass tetany) and on soil quality in terms of salinity.

## Research Objectives

The objectives of this 2-yr research project were to:

1. Develop and test potash preparation methods and pipeline injection equipment,
2. Determine how to ensure a steady concentration of  $100 \text{ mg L}^{-1}$  of  $\text{K}^+$  in irrigation pipelines,
3. Document and assess the irrigation of potash-treated water on soil and crop quality, and
4. Confirm economic costs and considerations for treating Alberta's irrigation systems with potash.

This report summarizes the background, methods, and results for Objectives 1 to 3. Objective 4 was achieved through a separate contract, and the final report was prepared by Paterson Earth & Water Consulting (2018)<sup>1</sup>.

## Methods Used

### *Potash Preparation*

For the purpose of the current research project, a concentration of  $100 \text{ mg L}^{-1} \text{ K}^+$  and an exposure duration of 24 to 48 h were selected to develop the injection methods; however, this may not be appropriate for invasive mussel control. The source of potash used was from Agrium<sup>®</sup> Inc. (now Nutrien<sup>™</sup>), special standard grade (product code 2003-2577). This product is a granular solid material with low sodium chloride content.

Preliminary, small-scale investigations were carried out at the Alberta Agriculture and Forestry laboratory in Lethbridge, Alberta to determine how to prepare a dissolved solution of KCl using granular potash. Investigations included dissolution of different types of potash products, methods of dissolution, the removal of impurities, and determining the effects of KCl solution on irrigation equipment.

Lessons learned from laboratory method development were applied to the dissolution of a bulk mass of potash. Stock solutions of KCl were prepared by dissolving granular potash into potable water (City of Lethbridge) at a rate of  $0.3 \text{ kg L}^{-1}$  in an 1100-L mixing tank using a circulation pump. Mixing occurred for 1.5 to 2 h followed by a 2-wk period to allow insoluble material to settle. After the settling period and removal of insoluble material, the solution was then filtered. The resulting concentration was about  $120,000 \text{ mg L}^{-1} \text{ K}^+$ .

---

<sup>1</sup> Paterson Earth & Water Consulting, 2018. Dreissenid mussels and Alberta's irrigation infrastructure: Strategic pest management plan and cost estimate. Prepared for the Eastern Irrigation District, Brooks, Alberta. 130 pp.

## Pipeline Study

Five irrigation-district pipelines were selected for the study: three in the Eastern Irrigation District (EID) (Pipelines A, B, and C), one in the Taber Irrigation District (TID) (Pipeline D), and one in the St. Mary River Irrigation District (SMRID) (Pipeline E) (Table 1). All of the pipelines were supplied with water from settling ponds, sourced from nearby canals. Only centre pivots supplied by the pipelines were used in the trials.

**Table 1 Technical details on pipelines used in the 2016 and 2017 field trials.**

Pipeline <sup>z</sup>	District <sup>y</sup>	Total length <sup>x</sup> (km)	Total volume <sup>x</sup> (m <sup>3</sup> )	Pipe diameter at inlet (m)	Number of irrigation systems on pipeline	Number of irrigation systems used <sup>w</sup>	Number of participating producers in the project	Date of trial
A	EID	2.9	207	0.307	1	1	1	Jul 4–7, 2016
B	EID	5.7	950	0.623	7	3	3	Jun 7–9, 2017
C	EID	4.3	779	0.623	5	2	1	Jun 20–21, 2017
D	TID	10.8	3489	1.072	23	9	7	Sep 12–13, 2017
E	SMRID	7.3	1180	0.772	7	6	3	Sep 19–20, 2017

<sup>z</sup> Actual names of the pipelines were not used for reporting purposes.

<sup>y</sup> EID = Eastern Irrigation District; TID = Taber Irrigation District; SMRID = St. Mary River Irrigation District.

<sup>x</sup> Includes district- and producer-owned pipelines.

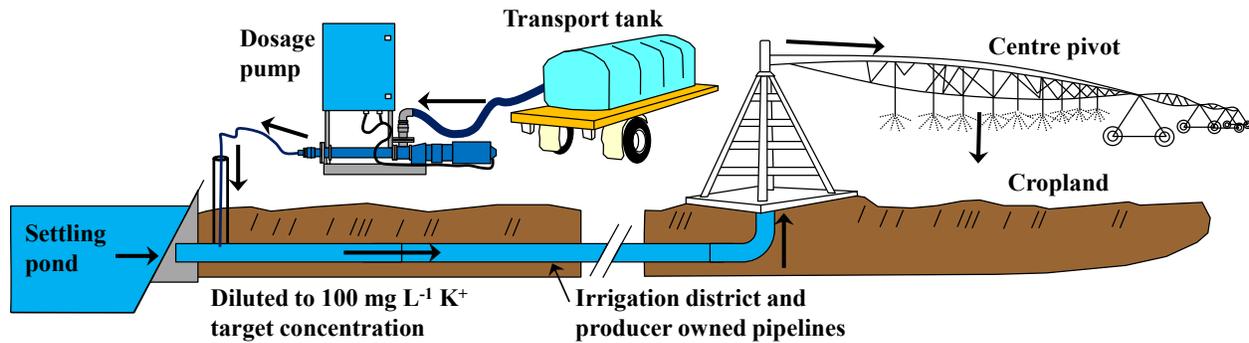
<sup>w</sup> All were centre-pivot systems used in the trials.

Stock solution of KCl (54,400 to 112,000 mg L<sup>-1</sup> K<sup>+</sup>) was transported in a trailer-mounted tank to the pipeline sites. The stock solution was pumped at an appropriate dosage rate through a hose and injection wand inserted into a vertical air-vent pipe at the inlet of each pipeline (Figure 1). The target concentration in the pipelines was 100 mg L<sup>-1</sup> K<sup>+</sup>, which has been used as a lethal concentration in other jurisdictions. Irrigation water in Alberta typically contains on average 2.4 mg L<sup>-1</sup> K<sup>+</sup>. Injection began when one or more pivot systems were started, and ended when the target concentration of KCl in the irrigation water had reached the last pivot and the pivot was turned off. The concentration of K<sup>+</sup> in the water samples collected from the pivots was monitored in the field by measuring electrical conductivity (EC) and comparing to a standard curve of K<sup>+</sup> concentration versus EC. The injection rate was adjusted to allow for different flows through the pipeline as the irrigation systems were turned on and off. After injection was completed, the pipeline inlet gates were closed and the KCl-treated water held in the pipelines for 24 to 48 h.

After the hold period, the pipelines were opened and the pivots turned on and KCl-treated water was purged from the pipelines and irrigated onto cropland. The pivots were monitored by collecting water samples and measuring EC until irrigation water at the pivots reached background conditions.

Water samples were collected at the centre pivots to determine when the target concentration of K<sup>+</sup> was reached during the injection phase and when background conditions were reached during the purging phase. Soil samples (0 to 2.5 cm and 0 to 15 cm) were collected before and after the application of KCl-treated water. Soil moisture samples were also collected from the single

Pipeline A field. Soil moisture samples (0 to 120 cm) were collected at the start and end of the trial in an area of field that was not irrigated during the trial. Plant samples were collected from an alfalfa (*Medicago sativa* L.) field irrigated from Pipeline B, and this was the only opportunity to collect plant samples during this study.



**Figure 1 Schematic diagram showing the main components of the KCl-injection arrangement.**

### *Small-plot Study*

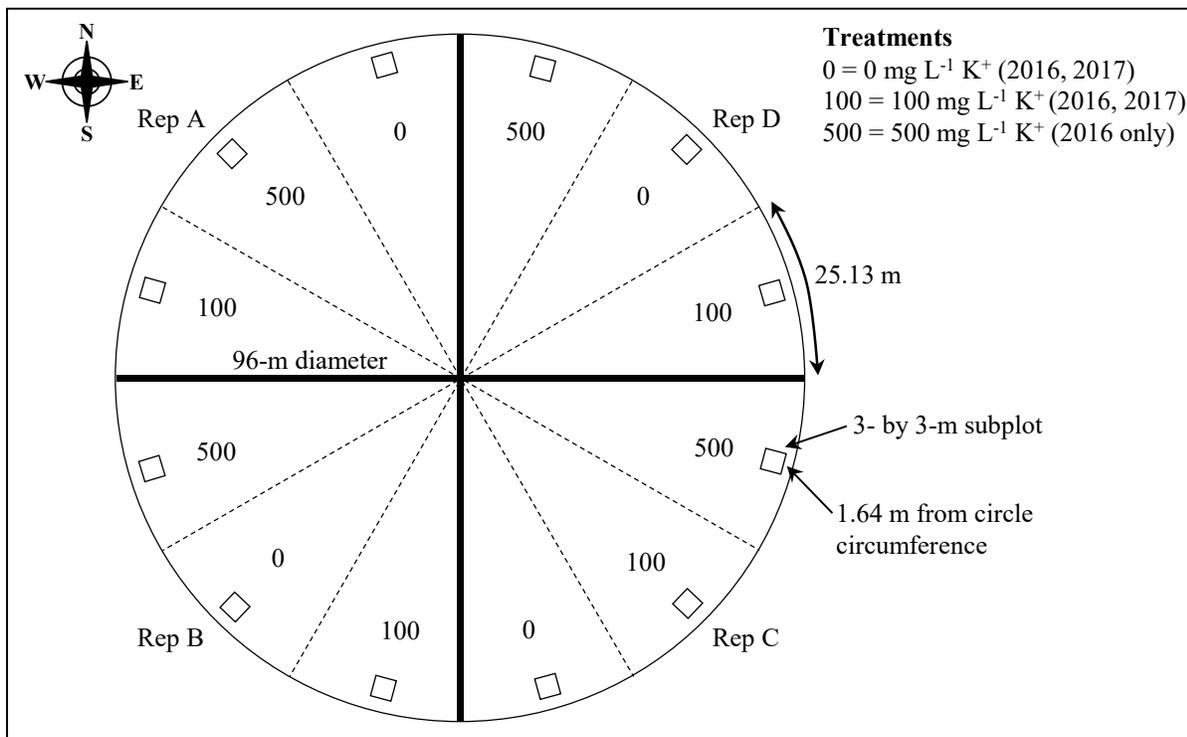
The study was carried out at the Alberta Agriculture and Forestry Irrigation Technology Centre east of Lethbridge, Alberta, on a 0.74-ha circular field with a 55-m long, single-span, centre-pivot system. The pivot discharge was measured at 301 L min<sup>-1</sup> with the end guns turned off. In both years (2016 and 2017), six-row, semi-dwarf barley (*Hordeum vulgare* L. var. Amisk) was seeded at the site.

The experiment was a randomized block design of 12 plots, consisting of three treatments and four replicates (Figure 2). The treatments were three application rates of K<sup>+</sup> in irrigation water: 0, 100, 500 mg L<sup>-1</sup> (0T, 100T, 500T, respectively). In 2016, all three treatments were applied. However, based on the results from Pipeline A, it was decided that 500T was not realistic in terms of expected loads of KCl that would be applied to fields. Therefore, only untreated irrigation water was applied to the 500T plots in 2017. This provided an opportunity to assess the fate of the residual K<sup>+</sup> and Cl<sup>-</sup> from the 2016 applications. A 3- by 3-m subplot was located at the centre and near the outer perimeter of each plot. The distance between subplots was calculated such that the treatment concentration in the irrigation water could change to the required concentration before travelling over the next subplot. Soil and plant samples were collected from the subplots.

A fertigation pump was used to inject KCl stock solution (103,022 to 108,642 mg L<sup>-1</sup> K<sup>+</sup>) into the centre pivot. For the control treatment, the fertigator was turned off and only untreated irrigation water was applied to these plots. For the other two treatments, the fertigator was adjusted to inject enough KCl stock solution to provide a 100 mg L<sup>-1</sup> (2016 and 2017) or 500 mg L<sup>-1</sup> (2016) K<sup>+</sup> concentration in the centre pivot and delivered through the nozzles. The actual K<sup>+</sup>

concentrations achieved in the irrigation water was determined by water sampling and lab analysis. The application concentration for 100T ranged from 70 to 182 mg L<sup>-1</sup> with a mean of 105 mg L<sup>-1</sup>. The application concentration of K<sup>+</sup> for 500T ranged from 439 to 568 mg L<sup>-1</sup> with a mean of 485 mg L<sup>-1</sup> in 2016. The treatments were applied three times each in 2016 and 2017. Additional irrigation events were carried out, without treatments, to meet crop water requirements.

Soil samples were collected in September 2016 (0–2.5 cm, 0–15 cm, 15–30 cm, and 30–60 cm) and in September 2017 (0–2.5 cm, 0–15 cm, 15–30 cm, 30–60 cm, 60–90 cm, 90–120 cm, and 120–150 cm). Soil samples were analyzed for EC, extractable K<sup>+</sup>, and extractable Cl<sup>-</sup>. Crop samples were not collected in 2016 because the treatments were applied late in the growing season. Crop samples were collected in 2017 at the silage stage for yield and nutrient content.



**Figure 2** The experimental design of the small-plot study.

## Key Findings

### *Potash Preparation (Objective 1)*

- Lab-bench trial results showed that plastic and brass irrigation nozzles were not affected by high concentration of KCl. Plus, manufacture specifications for polyvinyl chloride pipe with

ethylene propylene diene terpolymer seals are resistant to KCl. Therefore, KCl solution is not expected to damage or degrade irrigation infrastructure.

- The lab trials were successfully scaled up to prepare larger batches of dissolved KCl using commercial granulated potash. Mixing 0.3 kg potash per 1 L of water generated a concentrated stock solution of about 120,000 mg L<sup>-1</sup> K<sup>+</sup>, and most impurities could be removed or filtered from solution. A reverse pumping method was used during the mixing process, and a filtration unit was used to clarify the final solution.

### ***Pipeline Study (Objectives 2 and 3)***

- Concentrated KCl solution was successfully injected into all five pipelines, and it took 1 to 6 h to treat the pipelines.
- The actual concentration of K<sup>+</sup> achieved was near the target value (i.e., 100 mg L<sup>-1</sup> K<sup>+</sup>) for three of the pipelines. The K<sup>+</sup> concentration was 106 mg L<sup>-1</sup> for Pipeline A, 102 to 105 mg L<sup>-1</sup> for pipeline B, and 89 mg L<sup>-1</sup> for Pipeline C.
- The concentration was consistently high for Pipeline D (122 to 130 mg L<sup>-1</sup> K<sup>+</sup>) and consistently low for Pipeline E (77 to 86 mg L<sup>-1</sup> K<sup>+</sup>).
- It is believed that inaccurate estimates of water flow through Pipelines D and E caused the K<sup>+</sup> concentration to deviate from the desired target concentration.
- The efforts required for pipeline treatment were much greater for the larger pipelines with multiple irrigation systems in terms of coordinating with irrigators and the irrigation districts.
- The area per pivot circle required for a single application of KCl-treated water was relatively small, ranging from <0.4 to 11 ha.
- Based on the concentration of K<sup>+</sup> and the amount of water applied, the application rate of K<sup>+</sup> on the fields ranged from 3 to 29 kg ha<sup>-1</sup>, with a mean of 12 kg ha<sup>-1</sup> among the fields.
- The amount of K<sup>+</sup> from a single application was generally less than what would be expected to be removed by crops grown in southern Alberta. A crop can remove from 16 to 270 kg ha<sup>-1</sup> depending on the crop type.
- The EC of KCl-treated water ranged from 0.52 to 0.84 dS m<sup>-1</sup> among the pivots, with an overall mean of 0.66 dS m<sup>-1</sup>. Water in Alberta with an EC value less than 1 dS m<sup>-1</sup> and a sodium adsorption ratio less than 5 is considered safe for irrigation.
- Extractable K<sup>+</sup> in surface soil was generally unaffected by a single application of KCl-treated water in 11 out of the 18 fields in the five trials.
- However, K<sup>+</sup> concentration in soil was significantly ( $p < 0.05$ ) increased by 6 to 26% in five fields, while two fields had significant decreases.
- Ten fields had significantly higher chloride (Cl<sup>-</sup>) concentrations in the 0- to 2.5-cm soil layer after the application of KCl-treated water. This was also true for the 0- to 15-cm soil layer at eight fields. Two fields had a decrease in Cl<sup>-</sup> concentration after application.
- Soil EC at most of the fields (11 fields) was not affected by the application of KCl-treated water. However, EC was significantly increased at three sites and significantly decreased at four sites.
- It was estimated that the cost of treating these five pipelines by a commercial applicator would be nearly \$5500, based on an application cost of \$0.83 m<sup>-3</sup> of treated water.

- The exposure time of KCl-treated water within individual pivot systems was relatively short (<4 h), which would be insufficient to kill attached mussels. Continuous flow of treated water for several days may be an option, however, this is likely too costly and impractical.

### ***Small-plot Study (Objective 3)***

- Repeated applications of KCl-treated water caused an increase in soil K<sup>+</sup>, Cl<sup>-</sup>, and EC.
- Residual K<sup>+</sup> remained in the top soil layer (0 to 15 cm); whereas, Cl<sup>-</sup> leached deeper into the 30- to 60-cm soil layer.
- Repeated applications of KCl-treated water had no effect on the yield and tissue quality of barley harvested at the silage stage.

### **Conclusions**

- Commercial production of dissolved potash for wide-spread use, if required, would likely require additional improvements on larger-scale preparation and efficiencies. Other considerations would include proper disposal of residual waste material, proper storage of KCl solution, safe transportation of product, and spill prevention and containment. Prepared KCl solution should not be stored at less than 0° C. Some of the residual material will contain amines, which are used as an anti-caking additive, and are considered toxic to marine life.
- The pipeline trials demonstrated that it is technically feasible to treat irrigation district pipelines with KCl-treated water to control invasive mussels if they should become established in the irrigation infrastructure.
- However, with more than 900 pipelines within the 13 irrigation districts in Alberta, treatment on a large scale may be logistically challenging.
- Accurate flow values for pipelines during injection will be required to achieve a target concentration of K<sup>+</sup> in water.
- The variable-rate dosing pump used in the trials was suitable for the application of injecting KCl solution into district pipelines. Considerations for pumps include matching pump size to pipeline size, power supply, and thoroughly cleaning of pumps of KCl solution after use. Additional work is required to assess how best to meter flow and to automate flow measurements with pump control systems.
- The 24- and 48-h hold periods used for the purpose of this study are expected to be too short for effective control of mussels in pipelines. Based on literature<sup>1</sup>, 5 to 6 d may be more realistic for effective control. This may be problematic if irrigation systems and access to livestock and domestic water is not available for this length of time, depending on growing conditions and time of year. Likely, early or late in the growing season (or even after harvest) would be the opportune times to treat pipelines.
- To treat pipelines with potash will require extensive coordination among the applicators, irrigation districts, and water users, particularly if longer hold times (i.e., >2 d) are required for effective treatment. Timing of pipeline treatment will need to consider cropping systems and irrigation demand.
- Frequent drainage of pivot systems and exposure to high temperatures in summer and sub-zero temperatures in winter may be sufficient to prevent the buildup of attached mussels within pivot systems. Options should be investigated on how to manage shell fragments in water to prevent nozzles from plugging.

- The application rate of  $K^+$  from a single application of KCl-treated water on cropland was relatively low compared to crop removal, and will not adversely affect soil and crop quality.
- Careful management of distribution within a field and crop uptake are expected to prevent  $K^+$  accumulation in soil from repeated applications of KCl-treated water.
- Also, operating pivots at 100% speed would minimize the application rate of KCl.
- The control system of the fertigation unit used in the small-plot study was inconsistent in delivery of injection volumes, and re-calibration was required each time the volume control was changed. Performance of pumps will need to be assessed if the treatment of individual irrigation systems is determined to be a viable option.

# List of Contents

Acknowledgements .....	iii
Executive Summary .....	iv
List of Contents .....	xii
List of Tables .....	xiv
List of Figures .....	xv
1 Introduction .....	1
1.1 Irrigation in Alberta .....	1
1.2 Invasive Dreissenid Mussels .....	1
1.3 Potential for the Spread of Invasive Mussels .....	4
1.4 Control of Invasive Mussels .....	4
1.5 Potash .....	6
1.5.1 Potassium .....	6
1.5.2 Chloride .....	8
1.5.3 Safety with Potash .....	9
1.6 Concerns with Potash .....	9
1.6.1 Grass Tetany .....	9
1.6.2 Soil Quality .....	10
1.7 Research Objectives .....	11
2 Preparation of Potassium Chloride Solution .....	12
2.1 Potash Source .....	12
2.2 Preliminary Lab-bench Tests .....	12
2.3 Large-scale Mixing .....	14
3 Pipeline Field Study .....	18
3.1 Introduction .....	18
3.2 Methods .....	18
3.2.1 Study Sites .....	18
3.2.2 Injection of KCl Solution .....	24
3.2.3 Purging of KCl-treated Water .....	31
3.2.4 Water Sampling and Analysis .....	32
3.2.5 Soil Sampling and Analysis .....	35
3.2.6 Plant Sampling and Analysis .....	39
3.2.7 Weather Data .....	40
3.2.8 Statistical Analysis .....	40
3.3 Results and Discussion .....	41
3.3.1 Weather .....	41
3.3.2 Injection of KCl .....	41
3.3.3 Purging of KCl-treated Water .....	47

3.3.4 Soil Chemistry .....	48
3.3.5 Soil Moisture .....	51
3.3.6 Plant Tissue .....	52
3.3.7 Considerations for In-field Irrigation Systems .....	52
4 Small-plot Study .....	54
4.1 Introduction .....	54
4.2 Methods .....	54
4.2.1 Study Site .....	54
4.2.2 Experimental Design .....	54
4.2.3 Field Activities .....	56
4.2.4 Laboratory Analyses .....	60
4.2.5 Weather Data .....	60
4.2.6 Statistical Analyses .....	61
4.3 Results and Discussion .....	61
4.3.1 Weather .....	61
4.3.2 Pre-treatment Soil Characteristics .....	61
4.3.3 Application of KCl .....	62
4.3.4 Effects of KCl Application on Soil Chemistry .....	64
4.3.5 Effects of KCl Application on Crop Yield and Nutrient Content .....	67
5 Conclusions .....	69
5.1 Potash Preparation for Injection (Objective 1) .....	69
5.2 Pipeline Study (Objectives 2 and 3) .....	69
5.3 Small-plot Study (Objective 3) .....	70
6 References .....	71
7 Appendices .....	78
Appendix 7.1 Muriate of Potash .....	79
Appendix 7.2 Pest Management Regulatory Agency (PMRA) annotated experimental label .....	80
Appendix 7.3 Signage used at the pipeline trial sites .....	84
Appendix 7.4 Irrigation pipelines used in the pipeline study .....	85
Appendix 7.5 Pipeline fields .....	88
Appendix 7.6 Soil description at the five irrigation district pipeline trials .....	92
Appendix 7.7 Calculation of stock solution volumes used during the pipeline trials ....	95
Appendix 7.8 Chronological order of main events during each pipeline trial .....	96
Appendix 7.9 Centre-pivot systems used in the pipeline trials .....	102
Appendix 7.10 Amount of water and actual concentrations of potassium (K <sup>+</sup> ), chloride (Cl <sup>-</sup> ), and electrical conductivity (EC) applied at the small-plot site in 2016 and 2017 .....	103

## List of Tables

Table 3.1	Technical details on pipelines used in the 2016 and 2017 field trials .....	19
Table 3.2	Sites at each of the pipeline trials .....	26
Table 3.3	Details of potash-treated water injection for each of the pipeline trials .....	28
Table 3.4	Weather stations nearest the pipeline inlets .....	40
Table 3.5	Weather data for the periods the pipeline trials were conducted .....	42
Table 3.6	Time required to treat the pipelines and the final mean potassium ( $K^+$ ) concentration in the treated water achieved as measured at the pivots .....	43
Table 3.7	Mean concentration of water quality parameters in settling-pond water during the injection phase and after the hold periods.....	43
Table 3.8	Mean concentration ( $n = 3$ ) of potassium in the centre pivots at the end of the injection phase and hold periods.....	45
Table 3.9	Water applied during the purging phase, calculated application rate of potassium ( $K^+$ ), and the areas that received KCl-treated water during the purging (from Positions C to D) and injection (from Positions B to C) phases ....	48
Table 3.10	Mean ( $n = 3$ ) electrical conductivity (EC) of KCl-treated water at the centre pivots immediately prior to purging of the water on cropland.....	49
Table 3.11	Mean ( $n = 10$ ) concentrations of soil chemistry parameters in the fields prior to (pre) and after (post) potash-treated water application .....	50
Table 3.12	Mean ( $n = 4$ ) gravimetric soil moisture content at Pipeline A Site 4 field in July 2016 .....	51
Table 3.13	Mean ( $n = 10$ ) total elemental content of alfalfa tissue collected at Pipeline C Site 3 in June 2017.....	52
Table 4.1	Field tasks carried out at the small-plot study in 2016 and 2017.....	57
Table 4.2	Growing season precipitation and temperature data for the potash small-plot study in 2016 and 2017 .....	62
Table 4.3	Pre-treatment mean values ( $n = 3$ ) of soil chemical properties according to the intended treatment .....	63
Table 4.4	Mean ( $n = 4$ ) potassium and chloride cumulative loads applied at the small-plot study in 2016 and 2017.....	64
Table 4.5	Mean ( $n = 4$ ) extractable potassium ( $K^+$ ), extractable chloride ( $Cl^-$ ), and electrical conductivity (EC) in soil at the small-plot site in September 2016.....	65
Table 4.6	Mean extractable potassium ( $K^+$ ), extractable chloride ( $Cl^-$ ), and electrical conductivity (EC) in soil at the small-plot site in September 2017 .....	66
Table 4.7	Mean ( $n = 4$ ) barley dry-matter yield and plant tissue nutrient content in 2017 .....	68

## List of Figures

Figure 1.1	Images showing (a) the comparison between zebra and quagga mussels, and (b) invasive mussels attached to a boat propeller .....	2
Figure 2.1	Potash used was (a) special standard grade low sodium, and preliminary dissolution trials involved the use of a (b) grinder to prepare the solid potash...	12
Figure 2.2	Preparation of KCl solution showing (a) filtration methods, (b) dissolution of potash, and (c) comparison of filtered solutions .....	13
Figure 2.3	Investigation into the effect of a concentrated KCl solution on brass and plastic irrigation sprinkler nozzles .....	14
Figure 2.4	Preparation of potassium chloride (KCl) stock solution for injection into irrigation pipeline field trial .....	15
Figure 2.5	Potash mixing equipment showing (a) the mixing tank, (b) trash pump used to mix the solution, (c) settled insoluble particles, (d) the storage tank, and (e) the final filtration unit.....	16
Figure 3.1	Approximate location of the pipeline sites (indicated by stars) used for the potash injection trials in 2016 and 2017 .....	19
Figure 3.2	Pipeline A in the Eastern Irrigation District used for the July 2016 field trial ...	20
Figure 3.3	Settling ponds at (a) Pipeline A, (b) Pipelines B and C, (c) Pipeline D, and (d) Pipeline E .....	21
Figure 3.4	Pipelines B and C in the Eastern Irrigation District used for the June 2017 field trials .....	22
Figure 3.5	Pipeline D in the Taber Irrigation District used for the September 2017 field trial .....	23
Figure 3.6	Pipeline E in the St. Mary River Irrigation District used for the September 2017 field trial.....	25
Figure 3.7	Schematic diagram showing the main components of the KCl-injection arrangement .....	27
Figure 3.8	The KCl-injection configuration at the (a) Pipeline A inlet in 2016, and (b and c) the nozzle end of the injection wand .....	27
Figure 3.9	Schematic diagram of the injection wand and MACE meter sensor configuration when inserted into the district-owned pipeline .....	28
Figure 3.10	Injections pumps used at (a) Pipeline A and at (b) Pipelines B, C, D, and E .....	29
Figure 3.11	Typical positions and movement of the centre pivots during the pipeline trials .....	30
Figure 3.12	MACE meter equipment at (a) Pipeline D, (b) Pipeline B, and (c) Pipeline C, with the latter being the irrigation district owned flow-metering station .....	31
Figure 3.13	Water sampling at (a) Site 2 and at (b) Site 3 during the Pipeline A trial in 2016 .....	32
Figure 3.14	Water sampling at (a) Pipeline A settling pond, (b) from a centre pivot-valve at Pipeline B Site 4, and (c) from a drop-down nozzle at Pipeline D Site 11 .....	33
Figure 3.15	Meters used for in-field measurement of K <sup>+</sup> concentration in water samples: (a) WTW Multi3500i EC meter, (b) Horiba LAQUAtwin K <sup>+</sup> probe, and (c) Oakton <sup>®</sup> EcoTestr .....	35
Figure 3.16	Soil sampling at the field sites for chemical analysis .....	37
Figure 3.17	Soil sampling Pipeline D fields in September 2017 showing (a) a transect	

	of sampling points, (b) sampling with a Dutch auger, and (c) other soil-sampling equipment .....	38
Figure 3.18	Change in potassium ( $K^+$ ) concentration with time at the Pipeline A Site 4 in July 2016 .....	46
Figure 4.1	Location of the small-plot study at (a) the Irrigation Technology Centre near Lethbridge, Alberta, and (b) the single-span, centre-pivot system at the plot site .....	55
Figure 4.2	Schematic of the centre-pivot system .....	55
Figure 4.3	Experimental design of the small-plot study .....	56
Figure 4.4	Images showing the (a) centre pivot and fertigator pump, and (b) control knob on the fertigator pump .....	58
Figure 4.5	The small-plot site showing (a) a rain gauge and (b) water sampling .....	59

# 1 Introduction

## 1.1 Irrigation in Alberta

Irrigation in Alberta is essential for high agricultural production and crop diversity. The irrigation conveyance network also 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 supplies water for several other uses including livestock production, wildlife habitat, and recreational activities such as fishing, boating, and camping at irrigation reservoirs. Irrigation infrastructure in Alberta includes 13 irrigation districts, 57 reservoirs, and about 7900 km of conveyance works (GoA 2018a). The irrigation district infrastructure is valued at \$3.66 billion (i.e., replacement cost). Approximately 675,300 ha of land were irrigated in the province in 2017, of which 81% of this area was within the 13 irrigation districts (GoA 2018a).

In recent years, the irrigation industry has been concerned with the threat of aquatic invasive mussels being introduced into Alberta. Invasive mussels were introduced into the Great Lakes in late 1980s and are now present throughout much of North America, with invasive mussels as close as Manitoba and Montana. The introduction of invasive mussels to the irrigation infrastructure will likely compromise the function and conveyance capabilities of the irrigation network in the province. Alberta is currently free of invasive mussels, and therefore, the potential negative effects of invasive mussels on the province's irrigation infrastructure is not known. The Government of Alberta (GoA) understands the value of the irrigation industry, and is working with the irrigation industry to ensure an uncompromised water supply for water users, while maintaining the economic benefits provided to local communities.

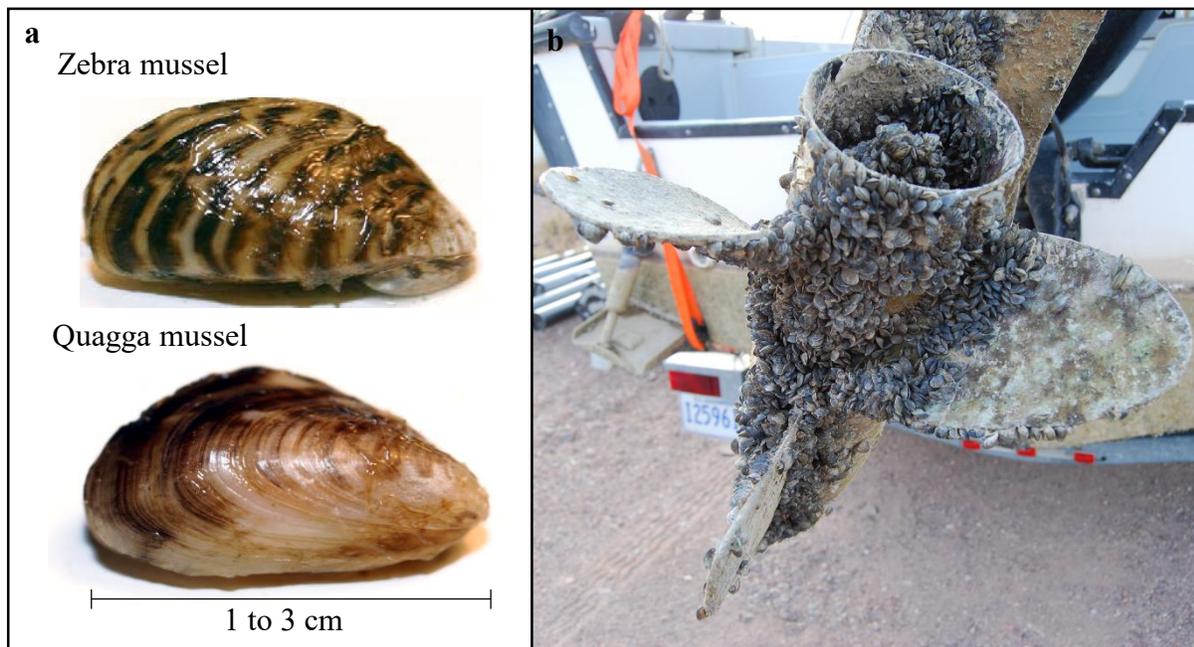
## 1.2 Invasive Dreissenid Mussels

Invasive dreissenid mussels in North America include zebra (*Dreissena polymorpha* (Palla 1771)) and quagga (*Dreissena bugensis* (Andrusov 1897)) mussels, and they both originated from the Ponto-Caspian region in southeastern Europe. These small, freshwater molluscs are filter feeders — ingesting small planktonic algae and zooplankton. A zebra mussel can filter up to 1 L of water per day (GoA 2018b). Zebra mussels have a triangular carbonate shell with dark striped rings, maturing to 3 cm in size (Figure 1.1a). The Quagga mussels have a rounded stripped carbonate shell with shaded concentric rings, maturing to 2 to 5 cm in size, with an average life span of 3 to 5 yr. Detailed descriptions of dreissenid mussels can be found in Mackie and Claudi (2010). Quagga mussels can inhabit greater depths than zebra mussels because they are tolerant of colder temperatures (Spidle et al. 1995; Mills et al. 1996). Generally, quagga mussel population densities are far greater than zebra mussel populations (Karatayev et al. 2015).

Dreissenid mussels are dioecious; however, fertilization occurs externally in the surrounding water with eggs expelled by the females, and sperm expelled by males. Dreissenid mussels reproduce rapidly — a single female can release up to one million eggs per spawning season (Benson et al. 2018a). Optimal spawning temperature for zebra mussels range from 14 to 16° C. Quagga mussels can begin reproduction at lower temperatures (Mackie and Claudi 2010). A

water temperature of 28° C can cause significant mortality, and 32 to 35° C is considered lethal for dreissenid mussels (Benson et al. 2018b).

Within 3 to 5 d after fertilization, veligers (larvae) are formed and remain free-floating for up to a month. Optimum temperature for larval development range from 20 to 22° C. Late stage veligers will sink and settle out of the water column, signalling the beginning of the juvenile stage, which includes releasing carbonate secretions, which forms the shell. Dreissenid mussels use byssal threads to attach to most hard surfaces, often completely covering solid objects and surfaces (Figure 1.1b). Dreissenid mussels are sexually mature by the time they reach 8 to 10 mm in shell length. If water temperature is high enough, larvae born in the spring can develop to reproductive size by the fall. However, most adults are not mature enough for reproduction until the following spring (Mackie and Claudi 2010).



**Figure 1.1** Images showing (a) the comparison between zebra and quagga mussels, and (b) invasive mussels attached to a boat propeller (Left image credit: Dave Brenner, Michigan Sea Grant; Right image credit: United States National Park Service).

There are several factors that affect the establishment and growth of dreissenid mussels including calcium, pH, temperature, oxygen, algae source, phosphorus, nitrogen, conductivity, salinity, total dissolved solids, and total suspended solids. Mackie and Claudia (2010) reviewed the literature and reported criteria to determine potential levels of infestation of zebra and quagga mussels in North America. For example, calcium concentration of 12 to 15 mg L<sup>-1</sup> or less would result in little potential for larval development. Whereas, concentrations greater than 30 mg L<sup>-1</sup> calcium has high potential for massive infestations. Optimum pH is 8.2 to 8.8; though moderate

potential for nuisance infestation can occur in water with pH values from 7.8 to 8.2 or 8.8 to 9.0. Dissolved oxygen would need to be 7 mg L<sup>-1</sup> or greater for nuisance infestations to occur. Chlorophyll *a*, as an indicator of food supply, is optimal from 2.5 to 8 mg L<sup>-1</sup>. Based on water chemistry and physical parameters, lakes and reservoirs in Alberta are generally conducive to the establishment and growth of dreissenid mussels should they be introduced (Paterson Earth & Water Consulting 2018; personal communication, Ron Zurawell, Alberta Environment and Parks, Edmonton, Alberta).

Further, in 2012, Fisheries and Oceans Canada conducted a risk assessment for zebra mussels in Canada (DFOC 2013; Therriault et al. 2013). Zebra and quagga mussels were found to pose a high risk to most regions of western Canada. The probability of survival (habitat suitability) was determined primarily based on calcium concentrations, which indicated that most watersheds in the prairies were highly suitable for survival and establishment of zebra mussels.

Since 2013, the GoA committed to increased protection measures against aquatic invasive species, including invasive mussels. These measures are focused on public education, monitoring, watercraft inspections, rapid response planning, and policy and legislation (GoA 2018c). Invasive mussels are typically introduced to new water bodies on trailered watercraft, and can have significant negative effects on lake ecosystems, as well as on any water infrastructure such as raw-water treatment or conveyance works, e.g., irrigation systems. Effects of invasive mussel introductions are far reaching environmentally, economically, and socially (Mackie and Claudia 2010).

Because of the high filtering capacity of dreissenid mussels, plankton populations can be greatly reduced, resulting in outcompeting native species and changing the ecosystem by increasing light penetration and water transparency (GoA 2018b).

Alberta Environment and Parks conducted an estimate of annual economic cost of invasive dreissenid mussels to Alberta. The report conservatively estimates the total annual cost incurred by the province if invasive mussels are introduced at \$76 million, with \$8.8 million associated with water management structures and \$3.9 million associated with water diversion intakes (Neupane 2013). Paterson Earth & Water Consulting Ltd. (2015) estimates that the irrigation industry in Alberta contributes \$3.6 billion annually to the provincial gross domestic product. Wide-spread infestation of invasive mussels in Alberta's irrigation networks could result in significant negative economic effects due to reduced water supply and increased maintenance costs. It is important to understand that the irrigation infrastructure is highly connective, through reservoirs, canals, and pipelines, and because of this, an infestation of invasive mussels is expected to advance downstream quickly.

Invasive mussel infestations could also negatively affect recreational opportunities afforded by irrigation reservoirs and connected water bodies. The irrigation districts supply water to 22 recreational sites, 20 campgrounds, 29 golf courses, and 58 sport-fishing areas in southern Alberta (AIPA no year).

### 1.3 Potential for the Spread of Invasive Mussels

It is believed dreissenid mussels have been in the Great Lakes since the late 1980s. Hebert et al. (1989) reported the presence of zebra mussels in Lake St. Clair, which connects Lake Huron and Lake Erie, in 1988. Based on the state of the population, they estimated that zebra mussels may have been introduced as early as 1985, and most likely through ballast water discharge from cargo ships. Dreissenids were discovered in Nevada in 2007 and in California in 2008. Invasive mussels were observed in the Red River water basin in the United States in 2009 and in Lake Winnipeg in October 2013.

Invasive mussel distribution and dispersal is related to human population density (Quinn et al. 2014). Human-mediated dispersal is considered the most common transmission vector in North America, specifically recreational boating activities including overland transport of trailered watercraft and water-based equipment. Natural dispersal downstream is also considered a substantial transmission vector in major river systems and can occur rapidly for long distances.

### 1.4 Control of Invasive Mussels

Preventing the arrival and infestation of invasive mussels in a region through education, regulations, and monitoring is considered less costly than trying to manage the presences of mussels. However, if invasive mussels become established, limited control options available include the use of mechanical, biological, and chemical methods. Of these, it was determined that chemical control is likely the most practical option for the large-scale, irrigation conveyance systems in Alberta.

Potential chemical treatments include oxidizing chemicals (chlorine, chloride dioxide, chloramines, ozone, bromine, hydrogen peroxide, potassium permanganate, and ferrate) and non-oxidizing chemicals (molluscicides, ammonium nitrate, copper ions, potassium salts, sodium metabisulfite, flocculation, BioBullets<sup>®</sup>, salinity, and pH adjustment) (Mackie and Claudi 2010). Currently, there are no registered chemical products for the control of mussels in Canada that can be used in Alberta's irrigation infrastructure.

The successful application of a chemical treatment requires a strategy that considers several aspects including timing, frequency, concentration, and application method. The available options for chemical treatment were evaluated for practicality, effectiveness, product availability, cost, environmental risk, and health and safety. Based on this evaluation, it was determined that potassium chloride (KCl) in the form of commercial potash may be the best option for Alberta conditions. The potassium ( $K^+$ ) is toxic to mussels (Mackie and Claudi 2010); is generally nontoxic to fish and other organisms, except for native mussels (Glomski 2015); is economically available in large quantities in the form of potash; and has been used successfully in other jurisdictions.

Evidence suggests  $K^+$  kills zebra mussels by interfering with gill respiration — specifically it elicits an anesthetic effect by paralyzing the mussel, preventing the defense response of shell valve closure (Mackie and Claudi 2010; Sykes and Wilson 2015). Potassium appears to destroy the integrity of the gill epithelium in mussels, leading to asphyxiation (Fisher et al. 1991).

Mackie and Claudi (2010) reported that a commercial applicator in Ontario effectively used KCl to treat closed-loop systems such as fire-protection systems. The applicator found that 100 mg L<sup>-1</sup> K<sup>+</sup> for 2 to 4 d resulted in complete mortality of dreissenid mussels. Under controlled conditions, Waller et al. (1993) found that about 150 mg L<sup>-1</sup> KCl (79 mg L<sup>-1</sup> K<sup>+</sup>) was required to cause a 50% mortality rate in 48 h for zebra mussels. Moffitt et al. (2016), exposed dreissenid mussel veligers to 960 mg L<sup>-1</sup> KCl for less than 24 h and found rapid mortality in three out of four different water sources. The water source in which veligers were resistant had high sodium concentration compared to the other sources. They concluded that water quality can affect the efficiency of KCl as a control treatment for dreissenid mussels. In a separate experiment, Moffitt et al. (2016) found that rapid mortality occurred for attached mussels within 10 d when exposed to 200 mg L<sup>-1</sup> KCl. According to Mackie and Claudi (2010), KCl is less effective at lower temperatures, or lower concentrations, or both, and longer exposure times are required under these conditions.

Millbrook Quarry, an abandoned, isolated quarry lake in Virginia, United States, was tested positive for zebra mussels in 2002 (Fernald and Watson 2014). In early 2006, the lake was treated with KCl to achieve a target concentration of about 100 mg L<sup>-1</sup> K<sup>+</sup>, with measured values ranging from 95 to 155 mg L<sup>-1</sup> K<sup>+</sup>. The treatment period took approximately 3 wk, after which the mussels had been successfully eradicated.

In 2014, zebra mussels were detected in Christmas Lake in Minnesota, United States. The surface area of the lake is 108 ha, and in 2015 a small area of 4.1 ha, where the mussels were originally detected, was barricaded and treated with KCl. Initial results suggested the treatment was effective in that area with 100% mussel mortality. However, subsequent monitoring found mussels elsewhere in the lake, indicating that the presence of mussels was not confined to the treatment area.

Similarly, after zebra mussels were first reported in Lake Winnipeg in 2013, four small harbours were barricaded and treated with KCl in an attempt to eradicate the mussels (DFOC 2014). The harbours were Winnipeg Beach, Balsam Bay, Gimli Harbour, and Silver Harbour, all in the lake's lower South Basin. Dissolved KCl solution was applied to the harbours to achieve a target concentration of 100 mg L<sup>-1</sup> K<sup>+</sup> in May 2014. In June, 100% mortality was confirmed in all four harbours. Unfortunately, zebra mussels had already infected the greater lake (GoM 2014, 2015b) and subsequently have spread throughout Lake Winnipeg, into Cedar Lake, and are in the Red River (GoM 2015a, 2016).

Late in 2016, possible detections of invasive mussels were made in Tiber and Canyon Ferry reservoirs in Montana. So far, Tiber Reservoir is the only waterbody in Montana that has been tested positive for invasive mussel veligers (Montana Government 2018a). Currently, watercraft leaving Tiber and Canyon Ferry reservoirs must be inspected and decontaminated (Montana Government 2018b). Because of the detections in Montana, Parks Canada issued a ban on the use of motorized and trailer-launched watercraft in Waterton Lakes National Park in 2017 (GoC 2018). In 2019, motorized and trailered watercraft will be permitted in Upper and Middle Waterton Lakes, provided watercraft have completed a 90-d sealed quarantine. In July 2018,

SMRID decided to stop boat access to Sherburne Lake, which is 10 km southwest of Grassy Lake, Alberta. This decision was made because boat access was unsupervised at this lake.

## 1.5 Potash

Potash, also known as Muriate of Potash, consists mainly (>95%) of KCl, a metal halide salt. Potash mining is a valuable industry in Canada, and potash is mainly used as a commercial, agricultural-grade fertilizer in solid or aqueous forms. Solid Muriate of Potash is primarily marketed as 0-0-60 fertilizer, containing no nitrogen (N) or phosphorus (P) and is 60% by weight  $K^+$  expressed as potassium oxide ( $K_2O$ ), which is equivalent to about 95% KCl — the chemical form of  $K^+$  in potash. About 95% of potash produced is used as an agricultural fertilizer and the remaining 5% is used in commercial and industrial products (Encanto Potash Corp. no year).

Potassium chloride an odourless and white or colourless crystal, has a molar mass of 74.5513 g  $mol^{-1}$ , a melting point of 770° C, a density of 1.984 g  $cm^3$ , and is readily soluble in water. The solubility of KCl in 100 mL of water is 28 g at 0° C, 31.2 g at 10° C, 34.2 g at 20° C, and 37.2 g at 30° C. The density of a saturated aqueous solution of KCl at 15° C is 1.172 kg  $L^{-1}$ .

Potash is mined from mineral sylvite, and halite evaporates by underground, or dissolution mining, which consists of the injection, circulation, and extraction of a brine solution. Conventional underground mines account for nearly 80% of global KCl capacity, underground solution mines account for about 6%, and the remainder is obtained from natural brines from potassium-rich water bodies (Nutrien 2018a). The potash solution is refined, dewatered, treated with additives, and formed into granular fertilizer. Potash is available as fine pink, granulated white, granulated pink, crystalized white, and pink variants. The pink colour of potash is caused by iron oxides. Canada produces approximately 38% of the global potash supply, and approximately 94% of Canada's production occurs in Saskatchewan (Nutrien 2018a).

Additives in potash constitute only a small portion (<0.4%) of the product's weight, and includes oils and amines as anti-dust and anti-caking agents (Hussein and Donaldson 2017), which helps in the storage and transportation of the agricultural grades of potash. For example, Red Premium Muriate of Potash, produced by Nutrien Ltd., contains 80 to 180 mg  $kg^{-1}$  amine and 1000 to 3000 mg  $kg^{-1}$  oil (Nutrien 2017). The anti-dust agent can be a mixture of paraffinic and naphthenic petroleum distillates, or mineral oil, or both (Nutrien 2017). Amines used are long, carbon-chain ( $C_{15}$ – $C_{20}$ ) molecules. Amines are added to oil and the mixture sprayed onto granular KCl. Amines used for this purpose have an  $LD_{50}$  of 2.4 g  $kg^{-1}$ , and are considered toxic to marine life (Hussein and Donaldson 2017).

### 1.5.1 Potassium

There are four main pools of  $K^+$  in soil as described by Römheld and Kirkby (2010):

**Soil solution  $K^+$ .** This pool is immediately available for uptake by plant roots. However, it represents about 5% of what a crop requires at any given time, and only about 0.1 to 0.2% of total  $K^+$  in soil.

**Exchangeable K<sup>+</sup>.** This pool is held on the negatively charged surfaces of clay and organic matter, and replenishes the soil solution K<sup>+</sup> pool. This pool represents 1 to 2% of total K<sup>+</sup> in soil and is readily available for plant uptake.

**Slowly-exchangeable K<sup>+</sup>.** This pool is released more slowly from lattice wedge sites of weathered micaceous clay minerals, and represents 1 to 10% of total K<sup>+</sup> in soil.

**Structural K<sup>+</sup>.** This pool represents 90 to 98% of total K<sup>+</sup> in the soil and is part of the structure of primary K<sup>+</sup> minerals. This form of K<sup>+</sup> is released very slowly through weathering, replenishing the exchangeable K<sup>+</sup> and slowly-exchangeable K<sup>+</sup> pools.

The four pools differ in plant availability with reversible transfer of K<sup>+</sup> between the pools. Soil K<sup>+</sup> is relatively immobile and most of the plant available K<sup>+</sup> is located in the topsoil. The transfer of K<sup>+</sup> in soil solution to plant roots is mainly through mass flow and diffusion (Tisdale et al. 1993). The amount of K<sup>+</sup> that leaches is small in most soils (Tisdale et al. 1993); however, the amounts leached can be substantial in acidic, coarse-textured soils with low cation exchange capacity and high rainfall (Brady and Weil 2008).

Potassium is an essential nutrient in agricultural systems and is required in plants for a number of functions (Armstrong 1998). After K<sup>+</sup> reaches plant roots through mass flow and diffusion, the cation is absorbed by the epidermal and outer layers of cortical cells and enters the plant mainly through the plasma membrane (Kafkafi et al. 2001). Potassium is required for the activity of more than 80 enzymes (Brady and Weil 2008), and has functions in photosynthesis and respiration (Kafkafi et al. 2001). Potassium also has the important physiological function of osmotic and ionic balance in plants (Kafkafi et al. 2001). Potassium can reduce the loss of water from leaf stomata in lowering cellular water potential (Brady and Weil 2008). This cation is also essential for protein synthesis, nitrogen fixation in legumes, starch formation, translocation of sugars, drought tolerance, winter hardiness, better resistance to certain fungal diseases, and greater tolerance to insect pests (Brady and Weil 2008).

Potassium deficiency is reflected in foliar growth by chlorotic leaves, stunted growth, and defoliation (Armstrong 1998). Generally, tips and edges of older leaves will begin to yellow and then die, and leaf edges of some plants may tear (Brady and Weil 2008). In contrast, luxury consumption of K<sup>+</sup> by plants can occur when there is an excess of K<sup>+</sup> available for uptake (Brady and Weil 2008).

Most soils in Alberta have adequate levels of K<sup>+</sup>, with only about 1.2 million ha of soils with insufficient levels (McKenzie and Pauly 2013). Typically, coarse-textured soils that undergo intensive agricultural operations are at the greatest risk of becoming deficient in K<sup>+</sup>. A minimum of 200 kg ha<sup>-1</sup> in the top 15 cm of the soil is required for adequate growth of most crops in Alberta.

Potassium fertilizers applied to annual crops are more efficient when seed placed or side banded due to the low mobility in soil of K<sup>+</sup>. However, the high salt index of K<sup>+</sup> fertilizers limits the quantity that can be seed placed, and depends on seed type, soil type, and whether or not other fertilizer salts are included. For example, the application of K<sup>+</sup> with canola seed (*Brassica napus* L.), which is a less tolerant crop, should not exceed 14 kg ha<sup>-1</sup> (or 16.8 kg ha<sup>-1</sup> as K<sub>2</sub>O)

(McKenzie and Pauly 2013). Broadcast application of  $K^+$  fertilizer requires about double the rate of application.

### 1.5.2 Chloride

Chloride is the ionic form of chlorine and is an essential nutrient for all living organisms. The majority of  $Cl^-$  in soils originate from salts trapped in parent material, marine aerosols, and volcanic emissions (Tisdale et al. 1993). Factors that determine the amount of  $Cl^-$  available for plants includes  $Cl^-$  in soil solution, atmospheric deposition,  $Cl^-$  in irrigation water, and  $Cl^-$  in manure and commercial fertilizers (Kafkafi et al. 2001; White and Broadley 2001). Deposition values from precipitation can range from 0.5 to 1  $kg\ ha^{-1}$  in the Great Plains and less than 10  $kg\ ha^{-1}$  in coastal areas (Mengal et al. 2009). Most of the  $Cl^-$  in soils exit as soluble salts such as sodium chloride and calcium chloride. Chloride is very soluble and moves readily in soil water. In addition,  $Cl^-$  does not readily form complexes and has little affinity to adsorption on soil components. Because of its solubility and mobility,  $Cl^-$  is often used as a tracer for soil water movement (Vinten et al. 1991; White and Broadley 2001; Dyck et al. 2003) and to trace contaminate sources to groundwater (Manwell and Ryan 2006). Even though  $Cl^-$  can easily leach, accumulations can occur if drainage is restricted (Tisdale et al. 1993).

The uptake of  $Cl^-$  by plant roots is generally an active process that requires energy (Kafkafi et al. 2001). More than 130 chlorinated compounds have been found in higher plants and ferns (Engvild 1986). Biochemical function of  $Cl^-$  in plants includes activation of enzymes and photosynthetic oxygen evolution in the water-splitting system in Photosystem II (Kafkafi et al. 2001). Physiological functions of  $Cl^-$  includes osmotic and anionic balance and stomatal activity and regulation (Xu et al. 2000). Chloride has also been shown to be important for disease suppression in plants, though the mechanisms may not be clearly understood (Tisdale et al. 1993; Xu et al. 2000). Symptoms of  $Cl^-$  deficiency in crops may include reduced leaf growth and wilting, followed by chlorosis, bronzing, and necrosis, and stunted roots with suppression of lateral root development (White and Broadley 2001).

Chloride concentrations in most soils in Canada ranged from 6 to 15  $mg\ kg^{-1}$ , and values less than 15  $mg\ kg^{-1}$  are considered low (A & L Canada Laboratories 2008). However, in Kansas, soils that have less than 4  $mg\ ha^{-1}$   $Cl^-$  in the top 60 cm of soil are considered low for corn (*Zea Mays* L.), sorghum (*Sorghum bicolor* L.), and wheat (*Triticum aestivum* L.) (Mengal et al. 2009). Chloride deficiencies in crops have not been observed in Alberta (McKenzie 1992).

Chloride can also be toxic to some agricultural crops. Chloride accumulation within plants occurs within the cells and intercellular spaces resulting in cell dehydration (Munns 1993) and reduction in photosynthetic activity (Xu et al. 2000). The critical tissue concentration of  $Cl^-$  for toxicity is 4 to 7  $mg\ g^{-1}$  (dry weight) for sensitive plants and 15 to 50  $mg\ g^{-1}$  for tolerant plants (White and Broadley 2001). Symptoms of  $Cl^-$  toxicity may include yellowing of leaves, burning of leaf tips and margins, bronzing, and curling of leaves (Kafkafi et al. 2001).

### 1.5.3 Safety with Potash

The preparation of the KCl solution involves manually handling potash fertilizer and KCl solution. The KCl solution is not considered a dangerous substance according to the Globally Harmonised System, and it is not designated a controlled product under Workplace Hazardous Materials Information Systems (WHMIS). Acute effects of KCl on humans includes irritation to eyes due to mechanical action, with no known significant effects following inhalation. Potassium chloride may cause irritation and dryness of skin following repeat exposures. The ingestion of KCl may cause irritation of the digestive tract with nausea, vomiting, and diarrhea. Potassium chloride LD<sub>50</sub> oral toxicity to rat species is 2600 mg kg<sup>-1</sup>, and sodium chloride LD<sub>50</sub> oral toxicity is 3000 mg kg<sup>-1</sup>. Potassium chloride is not mutagenic; however, it is carcinogenic at concentrations of 1820 mg kg<sup>-1</sup> and teratogenic at concentrations of 310 mg m<sup>-1</sup> (United States National Library of Medicine 2015).

The KCl solution is rated by the Hazardous Material Information System with a health rating of 1, flammability of 0, physical hazards as 0, and instability/reactivity of 0. Potassium chloride is not regulated under the transportation of dangerous goods.

Personal protective equipment recommended when handling potash varies depending on risk assessment, including eye and face protection, hand and body protection with appropriate gloves and clothing, and respiratory protection (Nutrien 2018b).

### 1.6 Concerns with Potash

The introduction of invasive mussels in Alberta's irrigation infrastructure will likely first occur in a reservoir through transportation on watercraft. Mussels established in a reservoir, will be distributed in free-floating veliger form by wind currents and boat wakes, and then propagate downstream, by gravity, through the canals and pipelines. Considering the size of reservoirs in Alberta (120 to 490,180 dam<sup>3</sup>), it is unlikely a mussel infestation can be eradicated. Instead, an ongoing maintenance program for keeping pipelines clear of mussels is a more likely scenario. However, regular treatment of pipelines will result in the application of KCl-treated water onto agricultural soils and crops. Even though potash is primarily used as an agricultural fertilizer, there is some concern that repeated applications of KCl — particularly on soils that do not require added K<sup>+</sup> — may have negative effects on crop quality for livestock feed and on soil quality in terms of salinity.

#### 1.6.1 Grass Tetany

Grass tetany, also known as hypomagnesaemia, is a serious, often fatal metabolic disorder in ruminant livestock caused by low blood magnesium (Mg<sup>2+</sup>) concentration (Grunes et al. 1970). There are a number of factors that can contribute to the development of grass tetany. The cause of the disorder can be as simple as Mg<sup>2+</sup> deficiency in grass feed or more complex with interactions of high K<sup>+</sup> concentrations. Grass forages with low Mg<sup>2+</sup> concentrations or high K<sup>+</sup> concentrations or both tend to promote Mg<sup>2+</sup> deficiencies in ruminants (Robbins and Mayland 1993). Diets with relatively high levels of K<sup>+</sup> compared to Mg<sup>2+</sup>, can interfere with Mg<sup>2+</sup> absorption in the rumen. Research has shown a negative relationship between forage K<sup>+</sup>

concentration and serum  $Mg^{2+}$  concentration (Kemp 1960). The relative ratio of  $K^+$  to  $Mg^{2+}$  plus  $Ca^{2+}$  is used to determine the potential for grass forages to cause grass tetany. A ratio of  $K^+/(Mg^{2+} + Ca^{2+})$  in milliequivalents per kilogram of dry matter of greater than 2.2 represents a higher risk of grass tetany to exposed animals (Robbins and Mayland 1993; Marx 2004; Walker et al. 2006).

The development of grass tetany is most common in older cows that have just given birth. This disorder is usually seen in the spring when livestock graze young, cool-season grasses (Lemus and Rivera 2009). High levels of  $K^+$  and protein in new pasture growth are predisposing causes of grass tetany (Clarke 2011). Potassium concentrations in the rumen can increase when pastures are naturally high in  $K^+$ , pastures are fertilized with excess amount of  $K^+$ , cows are deficient in salt (sodium), and the diet is changed from hay or dry feed to lush pasture (Elliott 2009). Under cooler ( $<7^\circ C$ ) spring conditions, grass roots can temporarily cease to absorb nutrients, and  $K^+$  can accumulate more than  $Mg^{2+}$  and  $Ca^{2+}$  near the roots. Also, the uptake of  $Mg^{2+}$  can be depressed in cold soil when there is inadequate available phosphorus (Rayburn and Matlick 2012). As the soil warms, a rapid uptake of  $K^+$  relative to  $Mg^{2+}$  and  $Ca^{2+}$  can temporarily occur through active root absorption (Grunes and Welch 1989; Elliott 2008). The best course of action is to delay grazing until forage grasses have grown to at least 12 cm in height (Elliott 2008). It is also best not to apply  $K^+$  or nitrogen fertilizer to grass pastures in early spring (Rayburn and Matlick 2012). Grass tetany seldom occurs on pastures with legumes or legumes-grass mixtures, as legumes have higher concentrations of  $Mg^{2+}$  compared to grasses (Grunes and Welch 1989; Rayburn and Matlick 2012). There were 39,430 ha of pasture land in Alberta's 13 irrigation districts in 2017 (GoA 2018a).

### 1.6.2 Soil Quality

As already indicated, potash is a salt, and the application of salts to soils is a concern for soil salinization. Soil salinity can limit vegetative growth in differing soil conditions (Parida and Das 2005; Zhu 2007; Brady and Weil 2008).

In Alberta, soils with electrical conductivity (EC) values greater than  $4 \text{ dS m}^{-1}$  are considered saline or saline-sodic. However, some plants can be adversely affected when EC is near  $2 \text{ dS m}^{-1}$  (Brady and Weil 2008). More specifically, a majority of vegetable crops can be negatively affected when EC is equal to or less than  $2.5 \text{ dS m}^{-1}$  (Machado and Serralheiro 2017). An accumulation of salts in soils will lower the osmotic potential in soil water and this makes it more difficult for plant roots to take up water. As a result, plants exhibit drought-like symptoms leading to reduced yield. Increased salinity can also lead to specific ion toxicity; however, this is more relevant to  $Na^+$  and  $Cl^-$  (Sheldon et al. 2004).

The vast majority of potash produced is used as a crop fertilizer. For a soil in Alberta with a moderately deficient level of  $K^+$  ( $168\text{--}280 \text{ kg ha}^{-1} K^+$  in the top 0–15 cm of soil), a typical fertilizer application may range from 14 to  $88 \text{ kg ha}^{-1} K^+$ , depending on the soil and annual crop type (McKenzie and Pauly 2013). This is equivalent to about 27 to  $168 \text{ kg ha}^{-1}$  of KCl.

Another source of  $K^+$ , as well as total salts, often applied to cropland in Alberta is livestock manure. Eight years of manure analysis in southern Alberta by Olson et al. (2003) showed that

feedlot beef manure contains about 10.8 kg Mg<sup>-1</sup> total K<sup>+</sup> on a wet-weight basis (about 50% water content). A single application of 65 Mg ha<sup>-1</sup> of beef manure would supply about 700 kg ha<sup>-1</sup> K<sup>+</sup>, or the equivalent to 1335 kg ha<sup>-1</sup> of KCl. This amount of K<sup>+</sup> is well in excess of what is typically taken up by crops in Alberta (Canadian Fertilizer Institute 2001). Research has shown that extensive application of livestock manure can increase EC values in soils (Liebhardt and Shortall 1974; Pratt 1984, Hao and Chang 2003, Olson et al. 2003; Miller et al. 2005). In fact, the Agriculture Operation and Practices Act, which regulates confined feeding operations in Alberta, limits a maximum increase of 1 dS m<sup>-1</sup> in surface soil EC from manure application, and no manure application on soils that have more than 4 dS m<sup>-1</sup> (Province of Alberta 2017).

High concentrations of K<sup>+</sup> in soils are considered nontoxic to plants. However, high K<sup>+</sup> concentrations can affect the uptake of other nutrients by plants and induce deficiencies, such as Ca<sup>2+</sup> and Mg<sup>2+</sup> (Tisdale et al. 1993). On the other hand, Cl<sup>-</sup> can be toxic to plants. Non-woody plants generally tolerate excessive levels of soil Cl<sup>-</sup>; whereas, many woody plants and beans are more sensitive (Xu et al. 2000). Critical toxicity concentrations in soil is 4 to 7 g kg<sup>-1</sup> for Cl-sensitive plants and 15 to 50 g kg<sup>-1</sup> for Cl-tolerant plants (Xu et al. 2000). In a pot experiment, Hossain et al. (2010) found that the application of KCl (10 to 50 kg ha<sup>-1</sup>) to soils at different salinity levels (2 to 12 dS m<sup>-1</sup>) had no significant negative effects on rice plants.

Concerns of possible negative effects of potash dust from mines in Saskatchewan on nearby cropland resulted in a field study where dust was applied at different rates. Ballantyne (1974) found that the application of 1.12, 2.24, 4.46, 6.72, and 11.2 Mg ha<sup>-1</sup> potash dust had no significant effect on yield of cereal crops under rain-fed conditions. The K<sup>+</sup> concentration of the dust was 43%. Five years after application of the dust, K<sup>+</sup> had not moved below 48 cm; whereas, Cl<sup>-</sup> was removed from the surface soil and about 50% had leached below 213 cm. Some of the added K<sup>+</sup> displaced exchangeable Ca<sup>2+</sup> and Mg<sup>2+</sup>, which were then leached to lower soil depths.

The accumulation of K<sup>+</sup> and Na<sup>+</sup> in soil may cause degradation of soil structure, and reduced hydraulic conductivity and infiltration in the long-term (Hao and Chang 2002). Clay dispersion will increase with electrolyte cation concentration (Rengasamy 1983).

## 1.7 Research Objectives

The objectives of this 2-yr research project were to

1. Develop and test potash preparation methods and pipeline injection equipment,
2. Determine how to ensure a steady concentration of 100 mg L<sup>-1</sup> of K<sup>+</sup> in irrigation pipelines,
3. Document and assess the irrigation of potash-treated water on soil and crop health, and
4. Confirm economic costs and considerations for treating Alberta's irrigation systems with potash.

This report summarizes the background, methods, and results for Objectives 1 to 3. Objective 4 was achieved through a separate contract, which was supported by the Alberta Innovates funds, and the final report was prepared by Paterson Earth & Water Consulting (2018).

## 2 Preparation of Potassium Chloride Solution

### 2.1 Potash Source

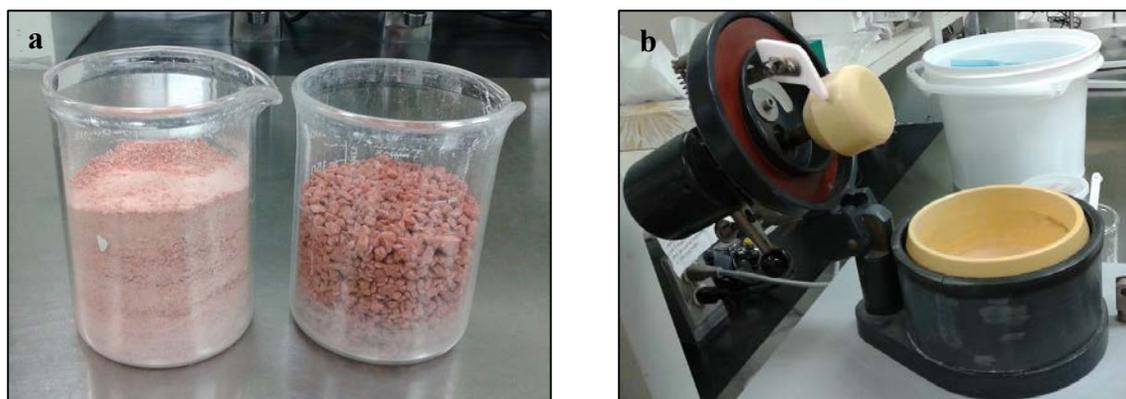
Potash used in this study was supplied by Agrium<sup>®</sup> Inc. (now Nutrien<sup>™</sup>). Agrium marketed four products of Muriate of Potash 0-0-60: granular grade, standard grade, red premium grade, and special standard grade. The product used for this study was the special standard grade, which has relatively low sodium chloride (NaCl) content (product code 2003-2577).

The potash product consisted primarily of KCl with added anti-caking additive agents (organic amines) and anti-dust agents (paraffinic and naphthenic petroleum distillates or mineral oil or both). The red colour of this potash is attributed to insoluble iron oxide compounds. The product had a typical size guide number of 100, with a particle size distribution of 98% by weight retained on a 0.212-mm mesh. The chemical composition of the potash, as provided by Agrium (2015), was 50.4% K<sup>+</sup>, 47.7% Cl<sup>-</sup>, and 1.35% Na<sup>+</sup> (3.43% NaCl). The remainder (0.55%) consisted of calcium, magnesium, bromine, sulphate, organics, water insoluble material, water, and product conditioner (0.004% amine). The complete product data sheet is in Appendix 7.1.

Bulk bags (1000 kg per bag) from Crop Production Services Inc., which was a subsidiary of Agrium, in Lethbridge, Alberta, were purchased at a cost of \$550 per bag. A total of 2000 kg of potash were purchased and used for the project.

### 2.2 Preliminary Lab-bench Tests

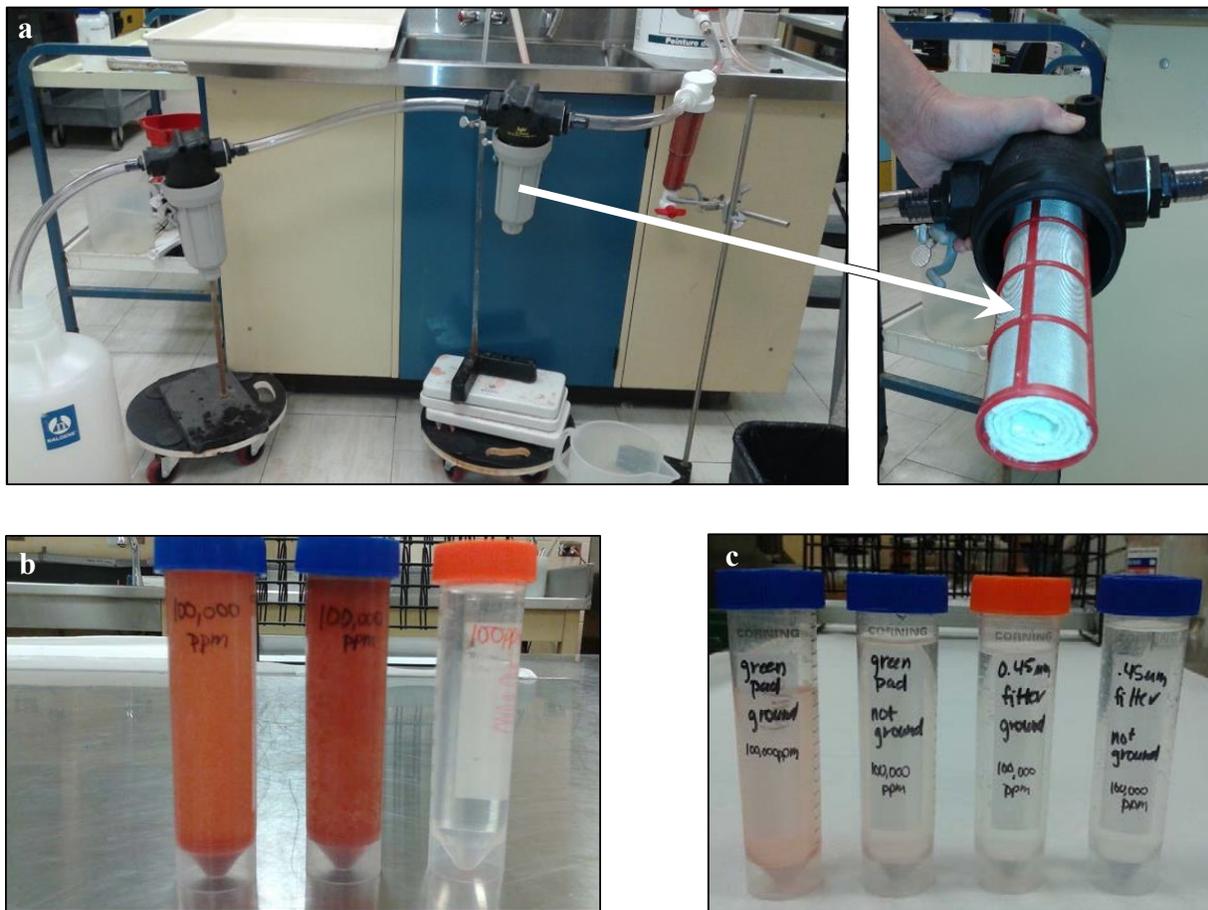
Small-scale investigations into the methodology for dissolving potash was performed at the Alberta Agriculture and Forestry laboratory in Lethbridge. Laboratory trials were performed on granulated white, granulated pink, and powdered pink potash (Figure 2.1a). The granular pink potash was crushed to a fine powder in a soil grinder (Figure 2.1b), and the three forms were evaluated for rate and ease of dissolution.



**Figure 2.1** Potash used was (a) special standard grade low sodium, and preliminary dissolution trials involved the use of a (b) grinder to prepare the solid potash.

The investigations were performed using a polyethylene mixing container to replicate readily available KCl storage materials. The potash forms were mixed with potable water (City of Lethbridge) to saturation, and agitated using manual stirring and bubbling stones. Various dissolution and filtration methods were evaluated for effectiveness (Figure 2.2). The solution was allowed to mix until all granular and powdered forms were dissolved to determine the optimal mixing rate. The powdered potash did not present a noticeable reduction in dissolution time, or increased ease of dissolution. It was determined that to scale up the mixing process, a circulatory pump would work best by drawing solution from near the top and pumping it into the bottom of the mixing container.

Potash anti-caking and anti-dust additives consisting of organic matter and amines were removed by centrifugal separation and filtration, thereby increasing the solution clarity (Figure 2.2). Filtration of the KCl solution using 0.297-mm and 0.106-mm filter screens, 0.45- $\mu$ m filter, filter paper, and absorbent fabric was performed to remove residual flocculates. Filtration materials were evaluated for ease of use, ability to upscale to bulk filtration, and cost. Initial tests showed that unfiltered KCl solution caused a red discoloration on the surfaces of equipment from residue build-up. Clarifying the solution through filtration prevented this problem.



**Figure 2.2 Preparation of KCl solution showing (a) filtration methods, (b) dissolution of potash, and (c) comparison of filtered solutions.**

An investigation into the potential effects of the KCl solution on irrigation equipment was also performed. The irrigation equipment included an impact sprinkler (brass material) and two drop-tube sprinklers (plastic material), which were immersed in a KCl solution of 150,000 mg L<sup>-1</sup> K<sup>+</sup> for a period of 4 d (Figure 2.3). However, it is expected that these pieces of irrigation equipment would be exposed to KCl-treated water for much less than 4 d (perhaps a few hours) and at much lower concentrations during a single treatment. There was no evidence of corrosion, formation of precipitates, clogging, or malfunction was observed following the immersion period. Further, manufacture specifications for polyvinyl chloride pipe with ethylene propylene diene terpolymer seals are resistant to KCl (IPEX 2009, 2013). Therefore, the KCl solution is not expected to damage or degrade irrigation infrastructure.



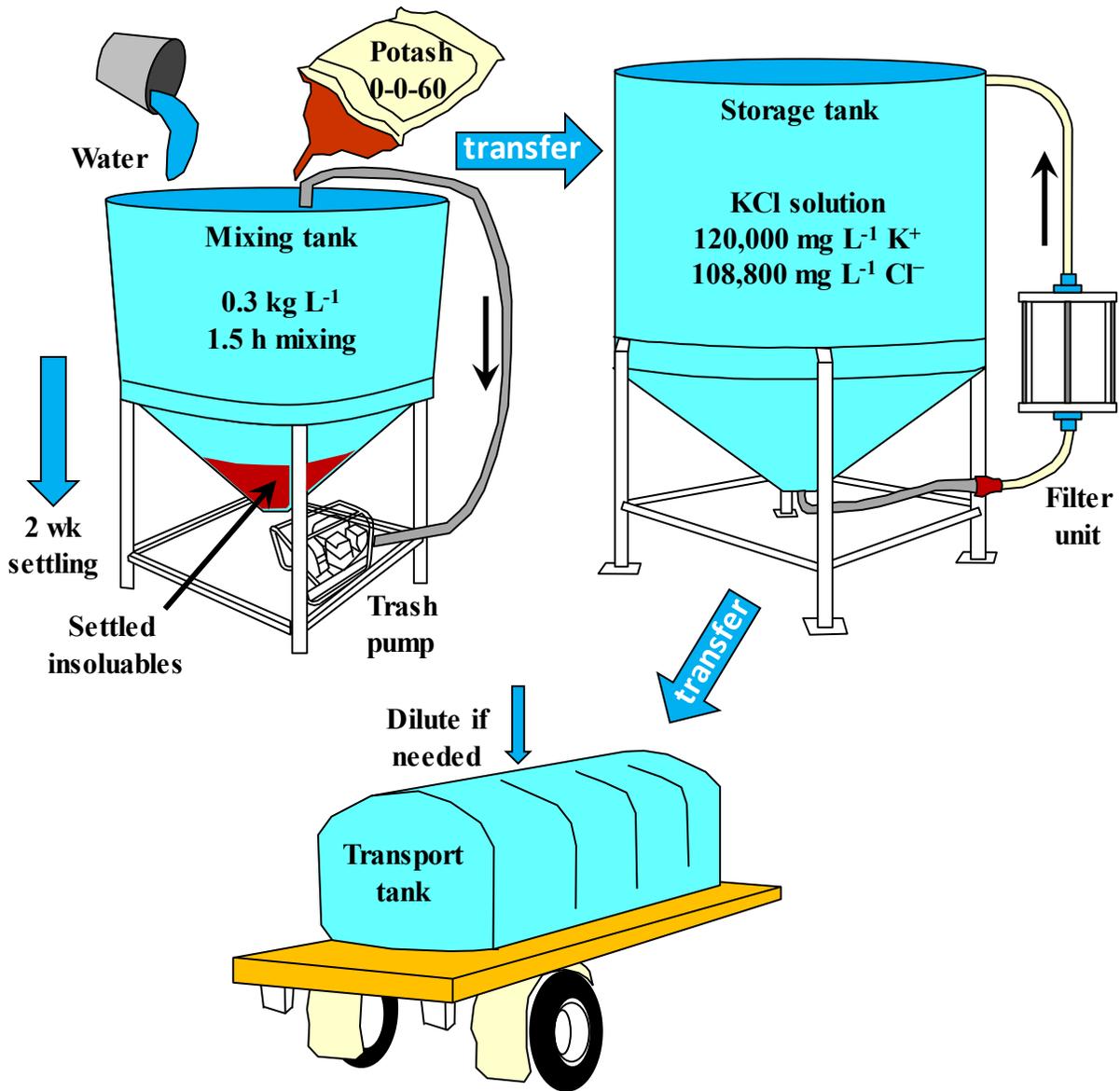
**Figure 2.3 Investigation into the effect of a concentrated KCl solution on brass and plastic irrigation sprinkler nozzles.**

### 2.3 Large-scale Mixing

Lessons learned from laboratory method development were applied to the dissolution of a bulk mass of potash (Figure 2.4). A stock solution of KCl was prepared by dissolving granular potash into potable water at a rate of 0.3 kg L<sup>-1</sup>. The potash was dissolved in batches of 400 to 800 L in a mixing tank (1100 L).

The solution was mixed within the mixing tank (Figure 2.5a) using a 35-kg Wet Jet 5-cm aluminum trash pump, with a Honda GX200 6.5 HP, 196-cm<sup>3</sup> engine (Figure 2.5b). The pump operated at 35,886 L hr<sup>-1</sup> at 3,400 RPM, capable of a maximum suction lift of 7.93 m, and maximum discharge head of 28 m. The pump was thoroughly cleaned between uses to prevent the buildup of KCl precipitates in the unit.

The solution was mixed for 1.5 to 2 h until most of the granular potash was dissolved. During mixing, the trash pump withdrew solution from near the surface and injected the solution into the base of the tank, so to prevent potash granules from plugging the pump. As the potash dissolved, residual flocculants and residue floated to the solution surface. These residues consisted of organics and amines, and were removed by skimming the solution surface by hand throughout the mixing step, and during the settling period. The residue was placed in containers, allowed to partially dry, and then taken to the municipal landfill.



**Figure 2.4 Preparation of potassium chloride (KCl) stock solution for injection into irrigation pipeline field trial.**

After mixing, the solution was left for 2 wk to allow other, insoluble particulates to settle to the bottom and sides of the tank. Following the settling period, the solution was pumped from the mixing tank, leaving behind the settled particulates, and transferred to a 6826-L storage tank (Figure 2.5d). The solution was withdrawn from near the liquid surface to minimize the transfer of particulates. More than one batch was combined in the storage tank. The settled residue at the bottom of the mixing tank was a reddish-brown in colour and was placed into buckets for disposal (Figure 2.5c). The residue was allowed to partially dry and then taken to the municipal landfill.

The amount of residual material generated during the mixing process was not accurately measured. However, it was estimated that several tens of kilograms of material (partially dried) was generated per 1000 kg of potash.



**Figure 2.5 Potash mixing equipment showing (a) the mixing tank, (b) trash pump used to mix the solution, (c) settled insoluble particulates, (d) the storage tank, and (e) the final filtration unit.**

After the mixing and settling steps, the resulting stock solution was relatively clear. However, some fine particulates were visible in the solution. A filtration system was developed to further clarify the stock solution. The custom-built filter consisted of a series of plastic reinforced polypropylene absorbent pads contained within a polyvinyl chloride (PVC) enclosure (Figure 2.5e). The filter and a pump were attached to the storage tank and the stock solution was circulated through the filter (Figure 2.4).

The concentration of the final stock solution was approximately  $120,000 \text{ mg L}^{-1} \text{ K}^+$  and  $108,800 \text{ mg L}^{-1} \text{ Cl}^-$ . Laboratory testing showed that a stock solution of  $120,000 \text{ mg L}^{-1} \text{ K}^+$  was ideal as the KCl solution is near saturation at this concentration. The stock solution can be stored indefinitely, and was not expected to change in concentration providing the storage was moisture and air tight. After the addition of new batches and filtering, the stock solution was sampled and analyzed to confirm the  $\text{K}^+$  concentration, prior to use.

If commercial production of dissolved potash for wide-spread use is required, because of a future mussel infestation, additional improvements on larger-scale preparation and efficiencies would likely be required. Other considerations would include proper disposal of residual waste material, proper storage of KCl solution, safe transportation of product, and spill prevention and containment. A 20% solution of KCl will begin to freeze at about  $-11^\circ \text{C}$  (Hall et al. 1988), and we recommend storage at above  $0^\circ \text{C}$ . The residual material will contain amines, which are used as an anti-caking additive, and are considered toxic to marine life (Hussein and Donaldson 2017).

## 3 Pipeline Field Study

### 3.1 Introduction

The purpose of this study was to assess methodology to treat underground irrigation pipelines with KCl at a target concentration of  $100 \text{ mg L}^{-1} \text{ K}^+$ , which is a lethal concentration used by other jurisdictions (Mackie and Claude 2010; Fernald and Waterson 2014; DFOC 2014). Because potash is not registered as a pesticide to control mussels in Canada, a research authorization was obtained from the Pest Management Regulatory Agency (PMRA) of Health Canada (Research Authorization Number 0005-RA-17) in order to undertake this field study. An annotated experimental label was provided by PMRA (Appendix 7.2). The experimental label stated several precautions for using potash as a pesticide including avoidance of breathing potash dust, wearing personal protection equipment (e.g., goggles or face shield, dust mask, appropriate clothing), good hygiene practices, and apply treated water only when drift to off-target sites will not occur (Appendix 7.2). As required by the research authorization, the injection sites and the entrances to the fields that received potash-treated water had warning signs posted during the trials (Appendix 7.3).

Because, potash is likely the most practical chemical option to control invasive mussels in Alberta, steps have been taken by Alberta Environment and Parks to apply to PMRA to register potash for the control of mussels. A pre-registration process has been completed, and Alberta Environment and Parks is currently preparing the required information and data to submit an application for registration.

After the research authorization was granted by PMRA, the Eastern Irrigation District (EID) obtained a temporary amendment approval from Alberta Environment and Parks under the *Environmental Protection and Enhancement Act* to apply KCl to irrigation pipelines in 2016. In 2017, Alberta Agriculture and Forestry obtained a similar approval from Alberta Environment and Parks (Approval Number 390487-00-00). As part of the Alberta Environment and Parks approval process, a public notice was issued in local media outlets in the areas where the trials were conducted.

A professional applicator possessing a provincial aquatic certification oversaw the application of the KCl solution to pipelines and subsequent discharge onto the agricultural cropland.

### 3.2 Methods

#### 3.2.1 Study Sites

Five irrigation-district pipelines were selected for the study: three in the EID (Pipelines A, B, and C), one in the Taber Irrigation District (TID) (Pipeline D), and one in the St. Mary River Irrigation District (SMRID) (Pipeline E) (Table 3.1; Figure 3.1; Appendix 7.4). In order to protect the confidentiality of the landowners, the pipelines were named using single letters (A, B, etc.), and the actual nomenclature used by the irrigation districts are not used in this report.

**Table 3.1 Technical details on pipelines used in the 2016 and 2017 field trials.**

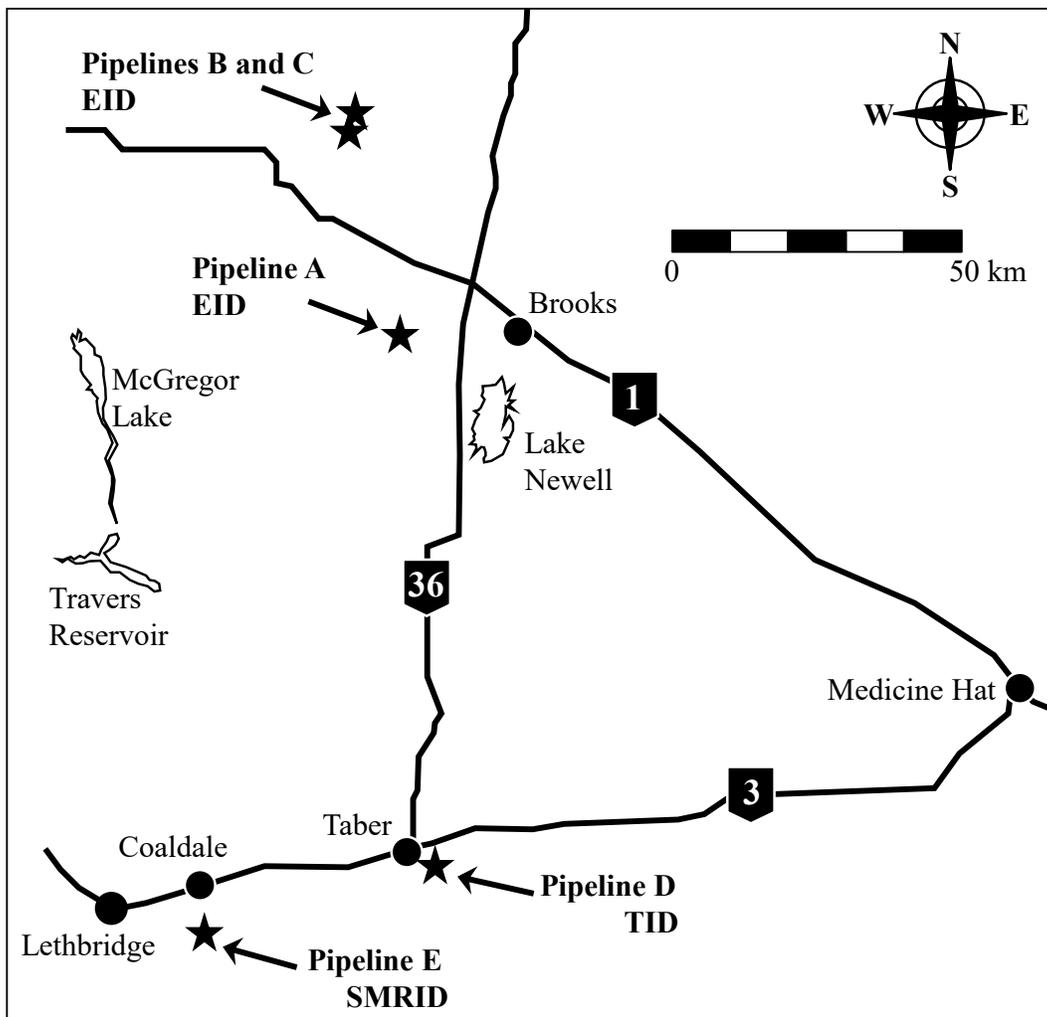
Pipeline <sup>z</sup>	District <sup>y</sup>	Total length <sup>x</sup> (km)	Total volume <sup>x</sup> (m <sup>3</sup> )	Pipe diameter at inlet (m)	Number of irrigation systems on pipeline	Number of irrigation systems used <sup>w</sup>	Number of participating producers in the project	Date of trial
A	EID	2.9	207	0.307	1	1	1	Jul 4–7, 2016
B	EID	5.7	950	0.623	7	3	3	Jun 7–9, 2017
C	EID	4.3	779	0.623	5	2	1	Jun 20–21, 2017
D	TID	10.8	3489	1.072	23	9	7	Sep 12–13, 2017
E	SMRID	7.3	1180	0.772	7	6	3	Sep 19–20, 2017

<sup>z</sup> Actual names of the pipelines were not used for reporting purposes.

<sup>y</sup> EID = Eastern Irrigation District; TID = Taber Irrigation District; SMRID = St. Mary River Irrigation District.

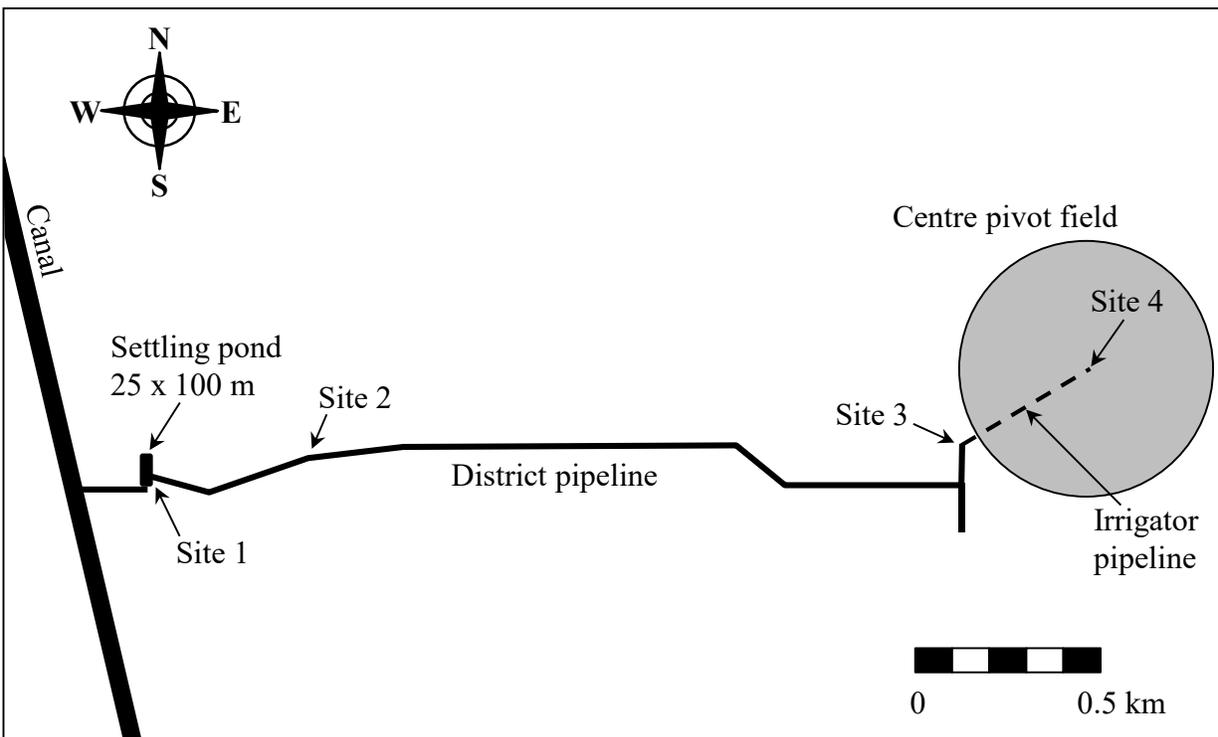
<sup>x</sup> Includes district- and producer-owned pipelines.

<sup>w</sup> All were centre-pivot systems used in the trials.



**Figure 3.1 Approximate location of the pipeline sites (indicated by stars) used for the potash injection trials in 2016 and 2017.**

**Pipeline A.** Pipeline A was approximately 10 km west of Brooks, Alberta within the EID (Figure 3.1). The pipeline was supplied by water from a settling pond, which in turned was supplied by water conveyed through a 237-m long pipeline from a nearby canal (Figure 3.2, 3.3a). Pipeline A extend east from the settling pond for 2386 m and then split into a north spur (122 m long) and a south spur (128 m long). Most of the district pipeline had an inside diameter of 30.71 cm. The north spur serviced one, low-pressure, drop-tube centre-pivot system through the irrigator’s pipeline, which was 410 m long (25.89-cm inside diameter). The south spur did not supply an irrigation system. The pipeline length from the settling pond to the centre of the pivot was 2918 m and the total volume was 207 m<sup>3</sup>, not including the south spur, which had a volume of 2.88 m<sup>3</sup>. The pivot system, with an end gun, irrigated approximately 40.5 ha of land. Canola was grown on the field in 2016. The field was under long-term agricultural use including livestock grazing and crop production.



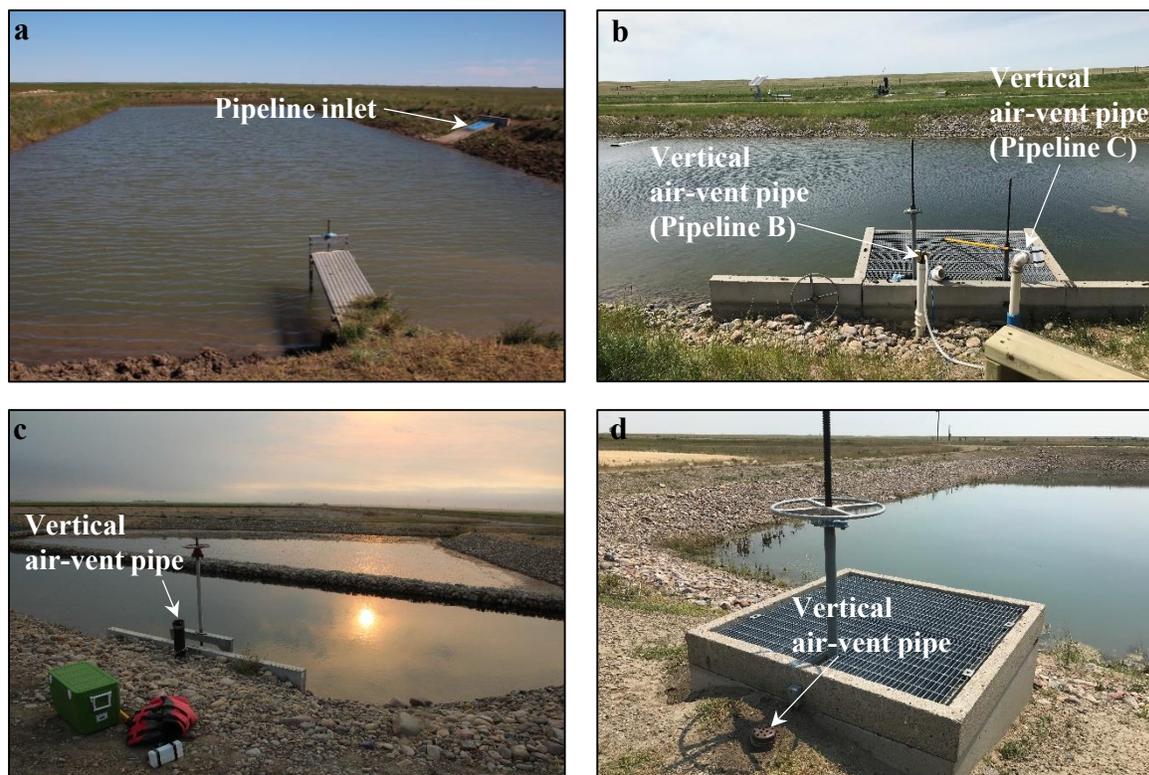
**Figure 3.2 Pipeline A in the Eastern Irrigation District used for the July 2016 field trial.**

**Pipeline B.** Pipeline B was approximately 45 km northwest from Brooks, Alberta, within the EID (Figure 3.1). A settling pond, which was connected to an adjacent canal, supplied water to the district pipeline (Figure 3.3b). The pipeline provided water to seven irrigation systems, and all seven were centre-pivot systems. Of these pivots, three were used in the trial, designated Sites 2, 3, and 4, and the settling pond was designated as Site 1 (Figure 3.4). Pipeline B was more than

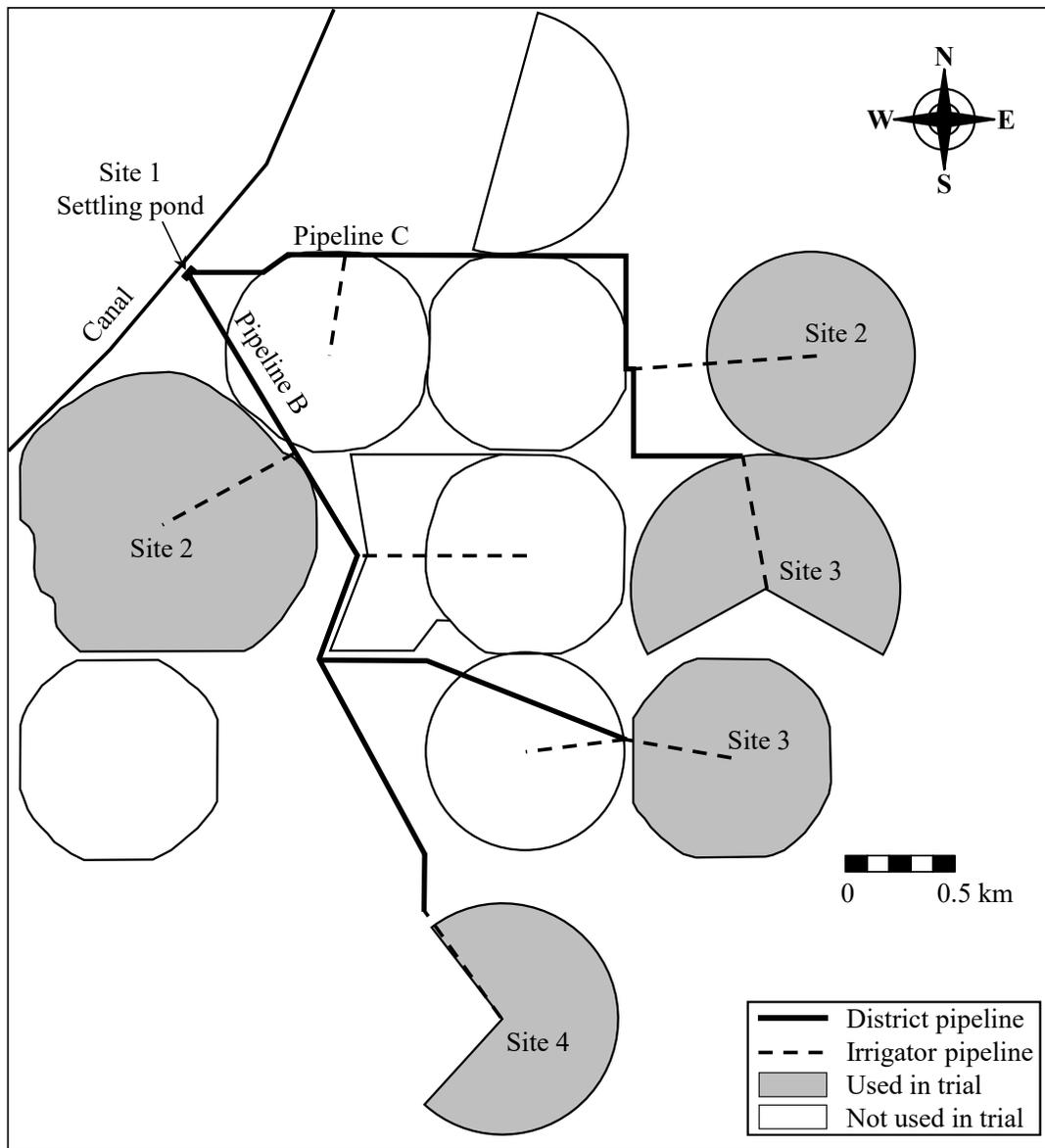
four times larger than Pipeline A, with a total volume of 950 m<sup>3</sup>, including the producer-owned supply lines to the three pivots used in the trial (Table 3.1).

**Pipeline C.** Pipeline C was adjacent and north of Pipeline B (Figure 3.1), and was supplied with water from the same settling pond through a separate inlet (Figure 3.3b). This pipeline supplied water to five irrigation systems, which were all centre-pivot systems. Two of the pivot systems were used in the field trial and these were designated as Sites 2 and 3 (Figure 3.4). The total volume of this pipeline, including the supply lines to the two pivots, was 779 m<sup>3</sup>, about 18% smaller than Pipeline B (Table 3.1).

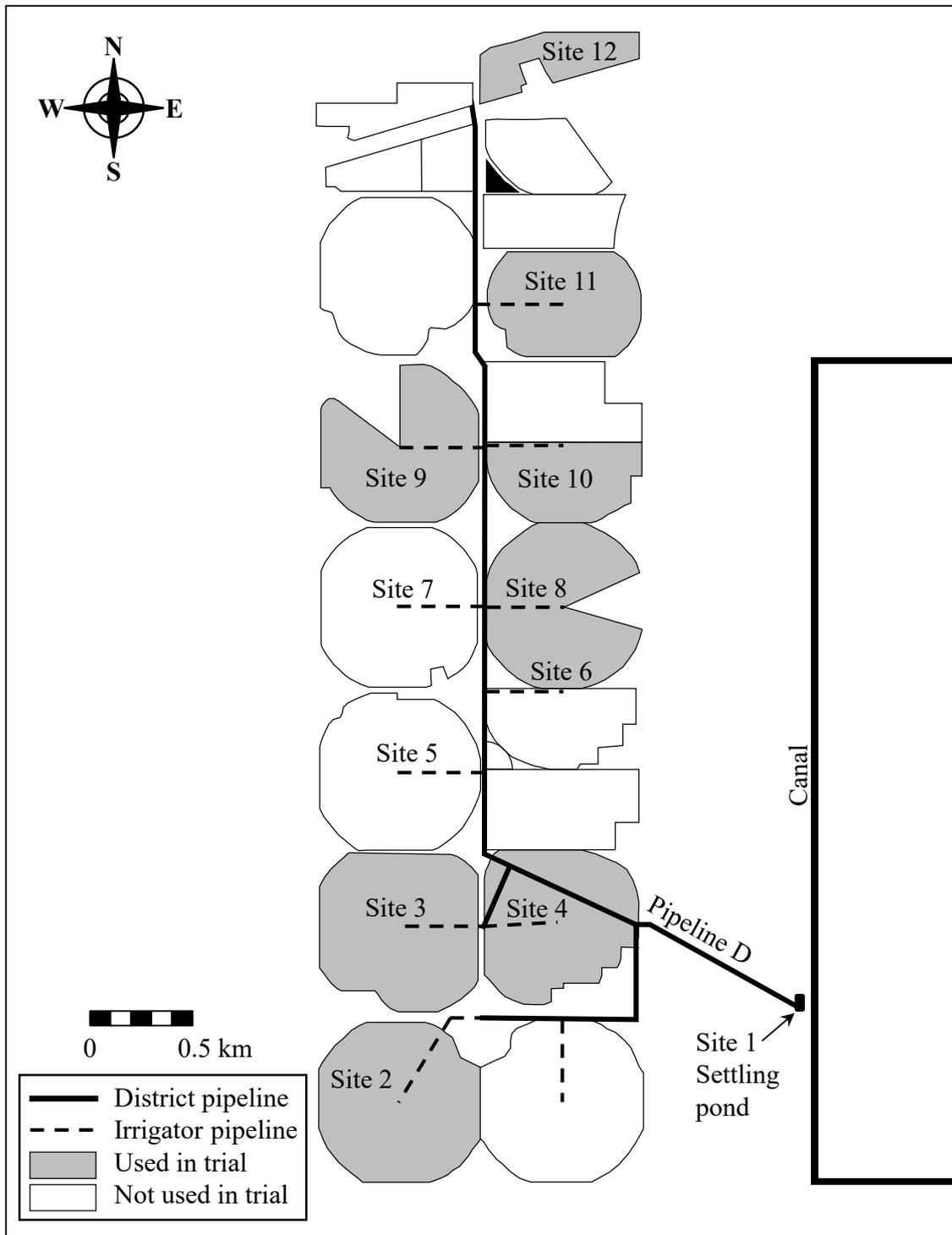
**Pipeline D.** Pipeline D was approximately 4.5 km east-southeast from Taber, Alberta within the TID (Figure 3.1). The pipeline was supplied with water from a settling pond with a gabion wall (Figure 3.3c). The pipeline supplied water to 14 irrigation centre pivots (including one small corner pivot adjacent to Site 5) and nine side-roll systems (Table 3.1). Of these systems, nine centre pivots were used in the trial and these were designated Sites 2 to 4, 6, and 8 to 11, with the settling pond designated as Site 1 (Figure 3.5). Site 12, which had a side-roll irrigation system, was only used during the purging phase to purge the district pipeline after the turnout to Site 11. Sites 5 and 7 were withdrawn the day before the trial started. This was the largest of the pipelines used in the study, with a volume nearly 17 times larger than Pipeline A (3489 m<sup>3</sup>; Table 3.1).



**Figure 3.3** Settling ponds at (a) Pipeline A, (b) Pipelines B and C, (c) Pipeline D, and (d) Pipeline E.



**Figure 3.4 Pipelines B and C in the Eastern Irrigation District used for the June 2017 field trials.**



**Figure 3.5 Pipeline D in the Taber Irrigation District used for the September 2017 field trial.**

**Pipeline E.** Pipeline E was approximately 7 km south of Coaldale, Alberta within the SMRID (Figure 3.1). Water was supplied to the pipeline from a settling pond (Figure 3.3d), which was adjacent to a canal. The pipeline inlet was along the north side of the settling pond. The pipeline supplied water to seven centre-pivot systems, of which six pivots were used during the trial (Figure 3.6). The settling pond was designated as Site 1 and the pivots used in the trial were designated as Sites 2 to 7 (Figure 3.6). Pipeline E was comparable in size to Pipeline B, being about 1.24 times larger (1180 m<sup>3</sup>; Table 3.1).

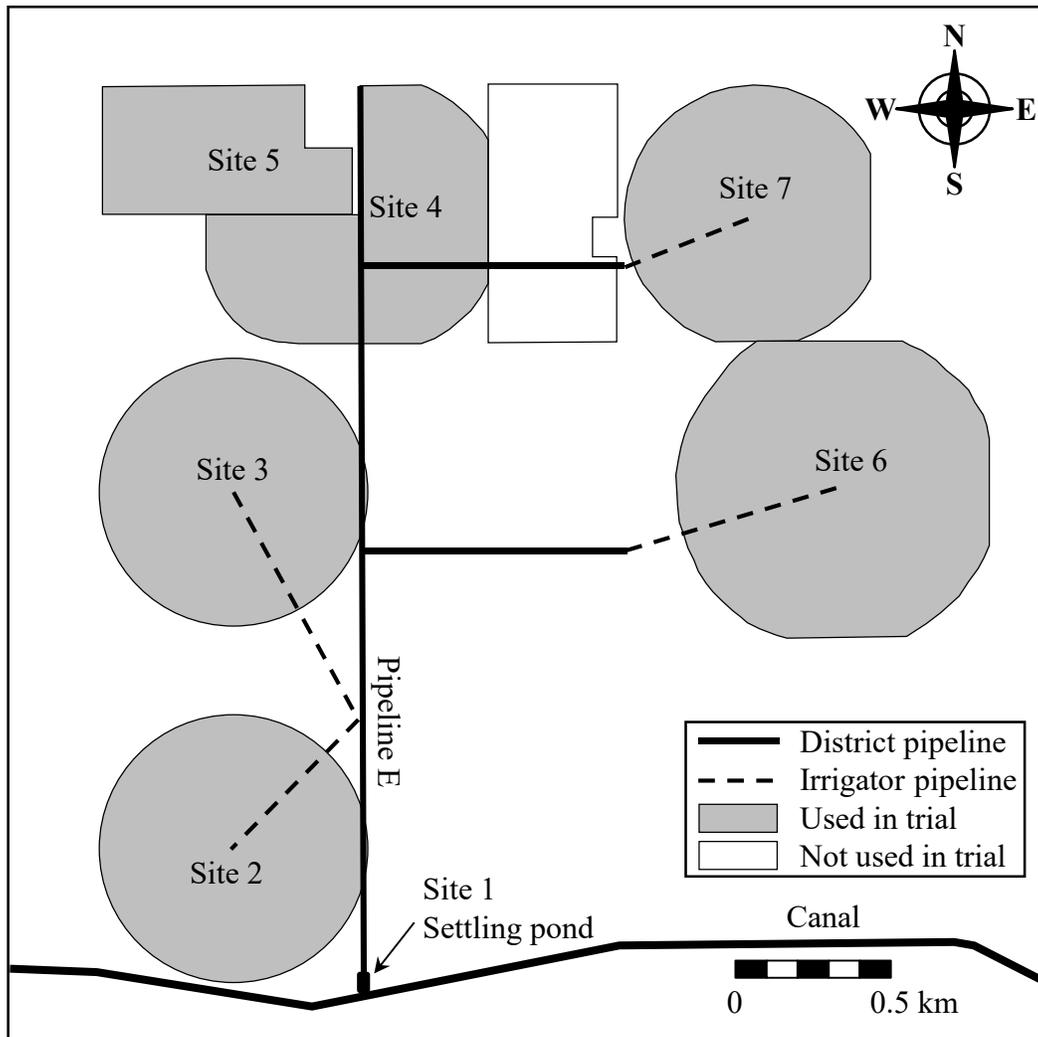
**Irrigated Fields.** There was a total of 21 irrigated fields among the five pipelines that were used and received an application of KCl-treated water. A wide range of crops were grown among the fields including forages, cereals, canola, potato (*Solanum tuberosum* L.), sugar beet (*Beta vulgaris* L.), and dry bean (*Phaseolus vulgaris* L.) (Table 3.2). The fields varied in size from 16 to 108 ha. For Pipelines D and E, many of the fields had been harvested at the time of the trials. Several pivot fields were divided into more than one crop (Table 3.2; Appendix 7.5). For example, Pipeline B, Site 4 field was a partial (three quarters) circle divided into four crops. The south portion was a pasture, the southeast portion had ryegrass (*Eymus Canadensis* L.), the northeast portion had corn (*Zea Mays* L.), and the north portion had wheat (*Triticum aestivum* L.).

### 3.2.2 Injection of KCl Solution

The KCl stock solution was transported in a 1300-L, trailer-mounted tank to the pipeline sites. A pump was used to inject the solution through a hose and injection wand inserted down a vertical air-vent pipe at the inlet of each pipeline (Figures 3.7 and 3.8a). For all the pipeline trials, the original stock solution was diluted and the final concentrations ranged from 54,400 to 112,000 mg L<sup>-1</sup> K<sup>+</sup> (Table 3.3). Two spill kits were available in case of accidental release of KCl solution.

The injection wand was an Acrylonitrile Butadiene Styrene (ABS) pipe with four holes drilled to distribute the stock solution within the pipeline (Figure 3.8b,c). The four holes were positioned on one side of the wand, and the wand was orientated in the air vents so the holes faced the direction of water flow (i.e., downstream) (Figure 3.9). The holes were drilled into the wand at angles so the upper two holes directed the KCl solution upward and to the right and left, and the lower two holes directed the KCl solution downward and to the right and left. The length of the wand varied depending on the length of the air-vent pipe. The injection end of the wand was lowered to the bottom of the pipelines (Figure 3.9).

For the Pipeline A trial, the KCl stock solution was injected using a 12-volt diaphragm pump (Delavan Ag Pumps Inc. Powerflo series 2200-301 Model) at a fixed rate of 3.11 L min<sup>-1</sup> (Figure 3.10a). Prior to the trial, water flow in the pipeline was measured at 58 L s<sup>-1</sup> by the irrigation district staff (using a strap-on Panametrics PT 878 meter) when the single pivot was operating including the end-gun nozzle. Based on this flow value and the capacity of the pump, the stock solution was diluted to 112,000 mg L<sup>-1</sup> K<sup>+</sup> in order to achieve the target concentration of 100 mg L<sup>-1</sup> K<sup>+</sup> in the pipeline. The final concentration after dilution was confirmed by laboratory analysis.



**Figure 3.6 Pipeline E in the St. Mary River Irrigation District used for the September 2017 field trial.**

**Soils.** Soil information for the five pipeline areas was obtained from the Agricultural Region of Alberta Soil Inventory Database (Alberta Soil Information Centre 2018) and is summarized in Appendix 7.6.

**Table 3.2 Sites at each of the pipeline trials.**

Pipeline	Site	Site type	Crop grown in year of trial	Field size <sup>z</sup> (ha)	
A	1	settling pond	not applicable	–	
	2	turn out	not applicable	–	
	3	turn out	not applicable	–	
	4	pivot field	canola	40.5	
B	1	settling pond	not applicable	–	
	2	pivot field <sup>y</sup>	wheat (N½), alfalfa (S½)	108.0	
	3	pivot field	alfalfa	52.7	
	4	pivot field <sup>x</sup>	pasture (S), ryegrass (SE), corn (NE), wheat (N)	48.9	
C	1	settling pond	not applicable	–	
	2	pivot field <sup>y</sup>	wheat (N½), canola (S½)	56.1	
	3	pivot field <sup>w</sup>	alfalfa (E), faba bean (W)	61.0	
D	1	settling pond	not applicable	–	
	2	pivot field	dry bean <sup>v</sup>	51.8	
	3	pivot field	wheat <sup>v</sup>	58.3	
	4	pivot field	cereal <sup>v</sup> (N½), sugar beet (S½)	54.2	
	6	pivot field	wheat <sup>v</sup> (S½)	28.3	
	8	pivot field	sugar beet (N½)	24.0	
	9	pivot field	wheat <sup>v</sup> (E½)	29.5	
	10	pivot field	sugar beet	29.1	
	11	pivot field	potato <sup>v</sup>	38.8	
	12	side roll	alfalfa	16.2	
	E	1	settling pond	not applicable	–
		2	pivot field	tame pasture	54.6
3		pivot field	tame pasture	54.6	
4		pivot field	canola <sup>v</sup>	39.5	
5		pivot field	wheat <sup>v</sup>	29.5	
6		pivot field	wheat <sup>v</sup>	69.3	
7		pivot field	wheat <sup>v</sup>	49.8	

<sup>z</sup> Irrigated areas for Pipelines A, D, and E fields were provided by the irrigation districts. The irrigated areas for Pipelines B and C fields were estimated using Google™ Earth.

<sup>y</sup> KCl-treated water was applied only to the wheat portion of the field.

<sup>x</sup> KCl-treated water applied to the ryegrass portion of the field.

<sup>w</sup> KCl-treated water applied to the alfalfa portion of the field.

<sup>v</sup> Crops had been harvested at the time of the pipeline trial.

alfalfa (*Medicago sativa* L.)

bean (*Phaseolus vulgaris* L.)

canola (*Brassica napus* L.)

corn (*Zea Mays* L.)

faba bean (*Vicia faba* L.)

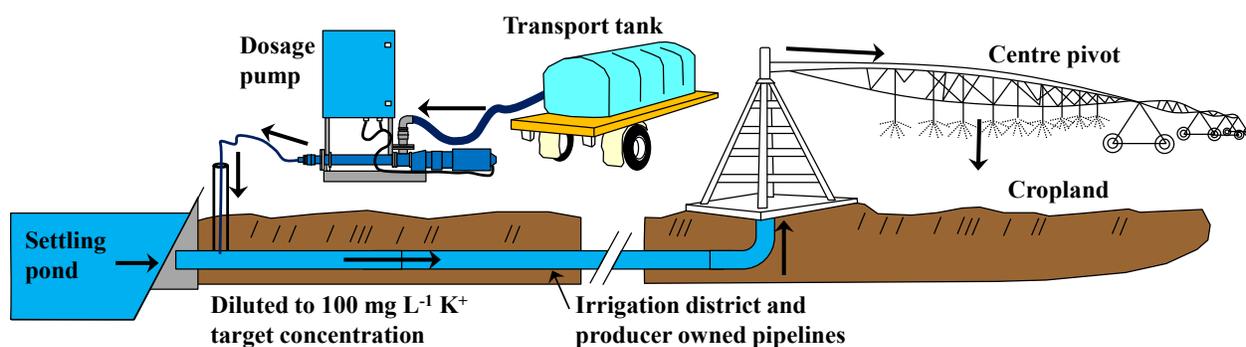
oat (*Avena sativa* L.)

potato (*Solanum tuberosum* L.)

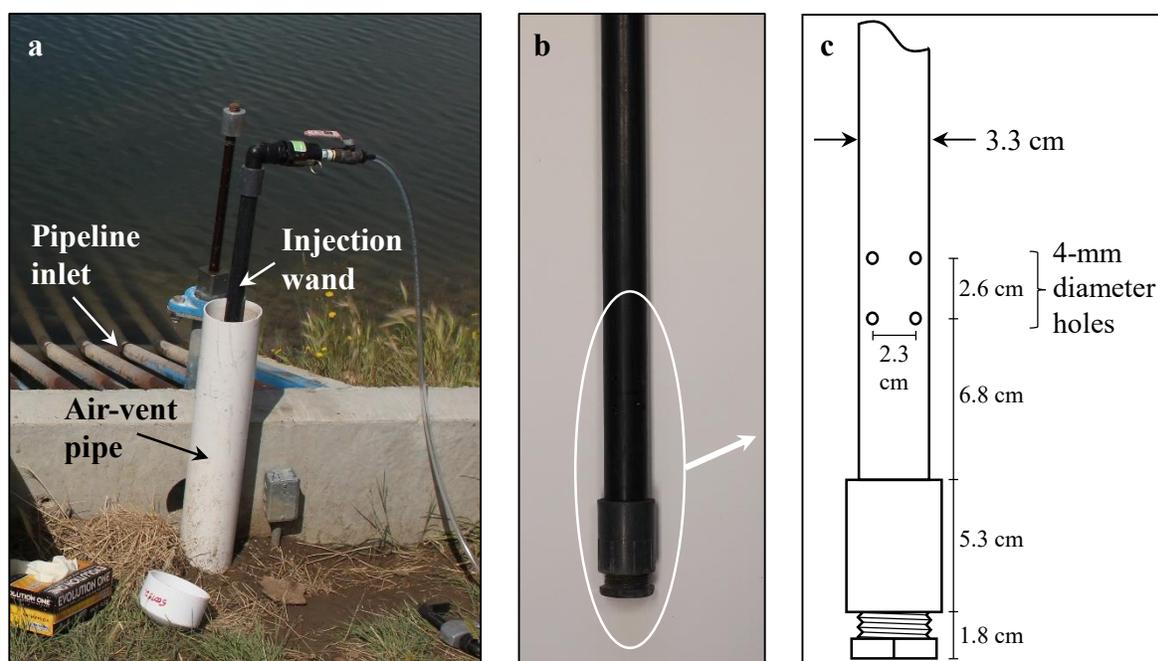
sugar beet (*Beta vulgaris* L.)

wheat (*Triticum aestivum* L.)

ryegrass (*Eymus Canadensis* L.)



**Figure 3.7** Schematic diagram showing the main components of the KCl-injection arrangement.



**Figure 3.8** The KCl-injection configuration at the (a) Pipeline A inlet in 2016, and (b and c) the nozzle end of the injection wand.

For the other four pipeline trials, a variable-rate custom dosing/metering pump was used to inject the stock solution (Figure 3.10b). The pump was a Moyno Compact C Pump, driven by a Nord Drivesystems NordBloc two-stage helical in-line gear system, and the system was driven by a 0.75 KW three-phase inverter duty AC induction Black Max Vector Duty Motor with a programmable logic controller. Electrical power was provided from a portable gas generator (Honda EU7000ISC). Pipelines B to E had two or more irrigation systems, and as the individual irrigation systems were turned on and off, the injection rate of the pump was manually adjusted. This variable-rate pump was not available when the Pipeline A trail was carried out.

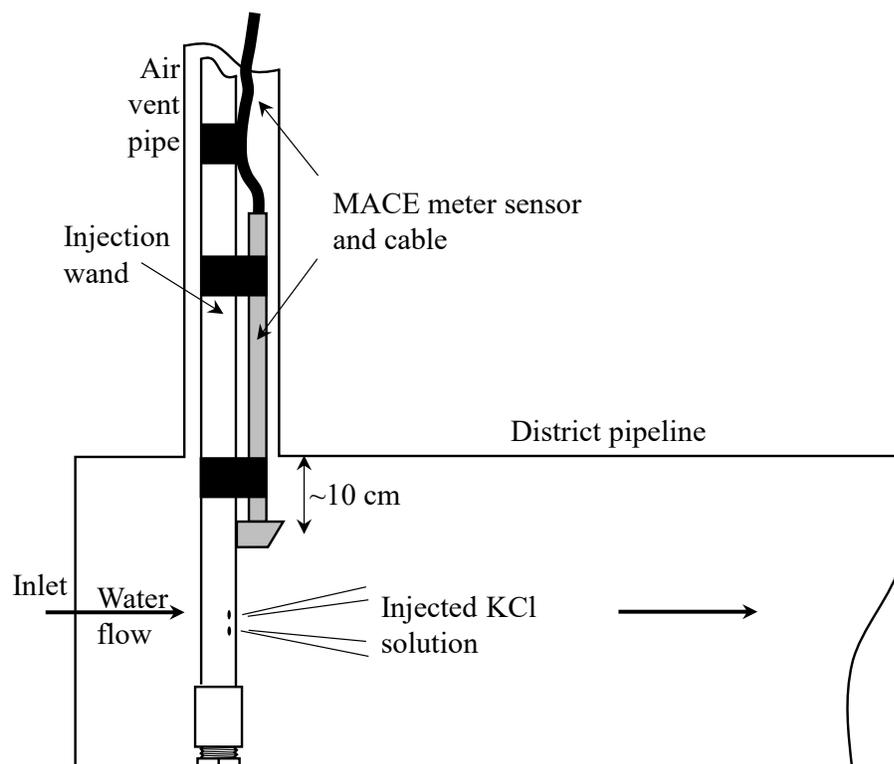
**Table 3.3 Details of potash-treated water injection for each of the pipeline trials.**

Pipeline	K <sup>+</sup> in stock solution (mg L <sup>-1</sup> )	Stock solution used (L)	KCl load injected (kg)	Duration of injection (min)	Duration potash solution was held in pipeline <sup>z</sup> (h)	Flow measurement method
A	112,000	345	73.7	111	48 (45.5)	pivot rate measured
B	74,261	1481	209.7	161	48 (46.9)	EID MACE meter at inlet <sup>y</sup>
C	78,850	1105	166.1	139	24 (26.8)	AAF MACE meter at inlet <sup>y</sup>
D	107,900	3871	796.3	363	24 (17.4)	pivot rate measured
E	54,400	3031	314.5	147	24 (20.9)	pivot rate assumed

<sup>z</sup> The values in parentheses are the actual number of hours from the time injection stopped to when the first pivot was turned on to begin purging.

<sup>y</sup> The EID (Eastern Irrigation District) MACE meter was permanently insulated near the pipeline inlet. The AAF (Alberta Agriculture and Forestry) MACE meter was attached to the injection wand.

The injection phase began by turning on one or more pivots to initiate flow in the pipeline. Shortly after water flow started, the pump was turned on and the KCl stock solution injected at the appropriate rate. After KCl-treated water reached each pivot along the pipeline, and the concentration had peaked and stabilized, the pivots were turned off. How long it took to turn off a pivot depended on the producer. Usually the pivots continued for 10 to 20 min during which time KCl-treated water was applied to the fields (Figure 3.11).



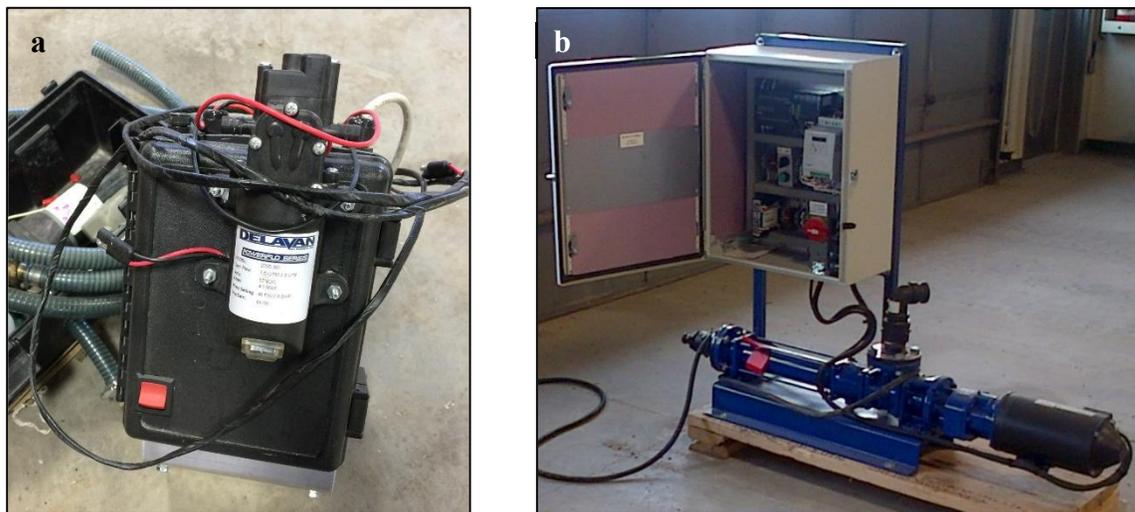
**Figure 3.9 Schematic diagram of the injection wand and MACE meter sensor configuration when inserted into the district-owned pipeline.**

After the last pivot had reached a stable  $K^+$  concentration and was turned off, the injection pump was turned off and the pipeline inlet gate closed. The duration of injection ranged from 111 to 363 min among the five pipelines (Table 3.3). The inlet gates of the settling ponds were also closed to prevent KCl entering the canal in the event KCl-treated water leaked from the pipelines and into the settling ponds. The KCl-treated water was then held in the pipeline for approximately 24 or 48 h (Table 3.3). The hold time was changed from 48 h (Pipelines A and B) to 24 h (Pipelines C, D, and E) because prior to the Pipeline C trial, one of the producers requested that the irrigation system be unavailable for only 1 d. After injection was completed, the dosing pump was thoroughly flushed with untreated water to remove residual KCl.

The amount of stock solution used was determined by recording the duration between adjustments to the injection rate of the pump (Appendix 7.7). The start and final volumes in the stock solution transport tank were also recorded; however, using these values to determine the volumes used was considered less accurate.

The position of the pivots at various stages (Figure 3.11) during the trials were generally recorded with a global positioning system (GPS) unit. However, for Pipeline E, wooden stakes were placed in the ground under the pivot and a few metres (10 to 20 m) from the centre. Then the distances from the centre to the stakes and between the stakes were measured.

Detailed order of events during each pipeline trial are summarized in Appendix 7.8.



**Figure 3.10** Injections pump used at (a) Pipeline A and at (b) Pipelines B, C, D, and E.

As indicated above, Pipeline A had one flow value, which was determined prior to the trial. As a result, actual flow in the pipeline was not measured during the Pipeline A trial. For the other four pipelines, which all had more than one pivot system, changes in flow were measured or estimated in order to adjust the injection rate of the pump. Water flow at the inlets of Pipelines B to E was measured with a flow meter using a Doppler sensor (MACE AgriFlow® XCi) (Figure

3.12a). The meter sensor was attached to the injection wand and inserted through the vertical air vents with the wand and into the water (Figure 3.9). The base of the wand was placed on the bottom of the pipelines, and the flow meter sensor was positioned about 10 cm from the top of the pipelines. Even though this MACE meter was used for these four pipelines, the basis for determining flow, which was needed in order to adjust the dosing pump, varied among the pipelines (Table 3.3), to evaluate the effectiveness of methods and technology. Pipelines B and C had built-in MACE meters owned by the irrigation district (Figure 3.12c). During the Pipeline B trial, the district MACE meter was used to determine when to adjust the pump. During the Pipeline C trial, the MACE meter sensor attached to the injection wand was used instead. In addition, the irrigation districts also measured or provided a flow value for each pivot system (Appendix 7.9). For Pipelines D and E, flow values provided for each pivot were used to estimate flow at the inlet of the pipelines during the trials.

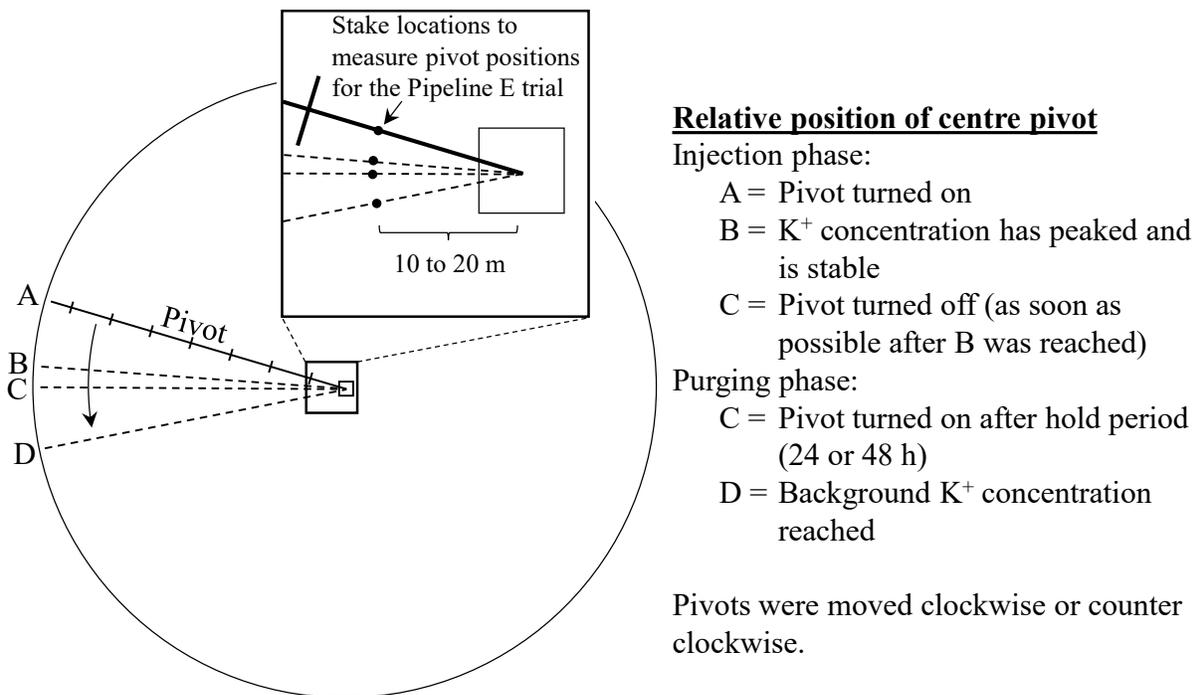


Figure 3.11 Typical positions and movement of the centre pivots during the pipeline trials.



**Figure 3.12 MACE meter equipment at (a) Pipeline D, (b) Pipeline B, and (c) Pipeline C, with the latter being the irrigation district owned flow-metering station.**

### 3.2.3 Purging of KCl-treated Water

After the hold period, and after the  $K^+$  concentration in the settling ponds were confirmed to be at background conditions (i.e., no measurable increase due to leakage from the pipeline), the pivot or pivots were turned on, the pipeline inlet gates were opened, and the KCl-treated water in the pipelines purged and irrigated onto the fields. Once the water at the pivots had returned to background conditions, the position of the pivots were recorded (Figure 3.11). At most sites, the pivot was operated in the same direction as during the injection phase, i.e., either clockwise or counter clockwise. However, the reverse direction was used during the purging phase at some sites, and these included Pipeline B Sites 2, 3, and 4; Pipeline D Site 6; and Pipeline E Sites 3 and 5. Further, the producers were asked to run the pivots at 100% speed during the purging phase; however, some pivots were operated at slower speeds, for example, due to uneven surface conditions in the field. Operating pivots at 100% speed would result in the lowest application rate of  $K^+$ .

### 3.2.4 Water Sampling and Analysis

**Injection Phase.** For nearly all of the pipeline trials, water samples were collected at the settling ponds and at the centre pivots. The exception was for Pipeline A, where samples were also collected at two, above-ground turnout valves (Sites 2 and 3) between the settling pond (Site 1) and the centre pivot (Site 4) (Figures 3.2 and 3.13).

At the start of KCl stock solution injection into the pipelines, the settling ponds were sampled every 10 min until the dosing pump stopped. Grab samples were taken using a pole and sampling bottle (Figure 3.14a). The sampling bottle was rinsed three times before collecting a sample. These samples were placed in a cooler with ice and sent to the laboratory for analysis.



**Figure 3.13 Water sampling at (a) Site 2 and at (b) Site 3 during the Pipeline A trial in 2016.**

Estimates were calculated to determine when the KCl-treated water would reach each centre pivot. Based on these estimates, water sampling was started at each pivot about 40 to 50 min prior to the estimated arrival time, and sampled every 10 min. For some pivots, sampling began sooner because the estimated time for the arrival of KCl-treated water was shorter. The electrical conductivity (EC) of these samples were measured in the field and confirmed background conditions. After the EC values began to increase, water samples were collected every 5 min until the EC value appeared to stabilize and was confirmed by measuring the EC of three samples taken in rapid succession (i.e., every 2 min). After a stable EC was confirmed, three laboratory samples were collected and placed in a cooler with ice. At this point, the producer was asked to turn off the pivot. Water samples were collected at the centre of the pivots either from a valve (Figure 3.14b) or from one of the nearby drop-down nozzles using a sampling pole and bottle (Figure 3.14c). Sample bottles were triple rinsed before collecting a final sample.

For the two pipeline trials with hold times of 48 h, water samples were collected from Sites 1, 2, 3, and 4 at Pipeline A and at Sites 1 and 4 at Pipeline B after approximately 24 h. Three samples were collected at each site and taken to the laboratory for analysis.



**Figure 3.14** Water sampling at (a) Pipeline A settling pond, (b) from a centre-pivot valve at Pipeline B Site 4, and (c) from a drop-down nozzle at Pipeline D Site 11.

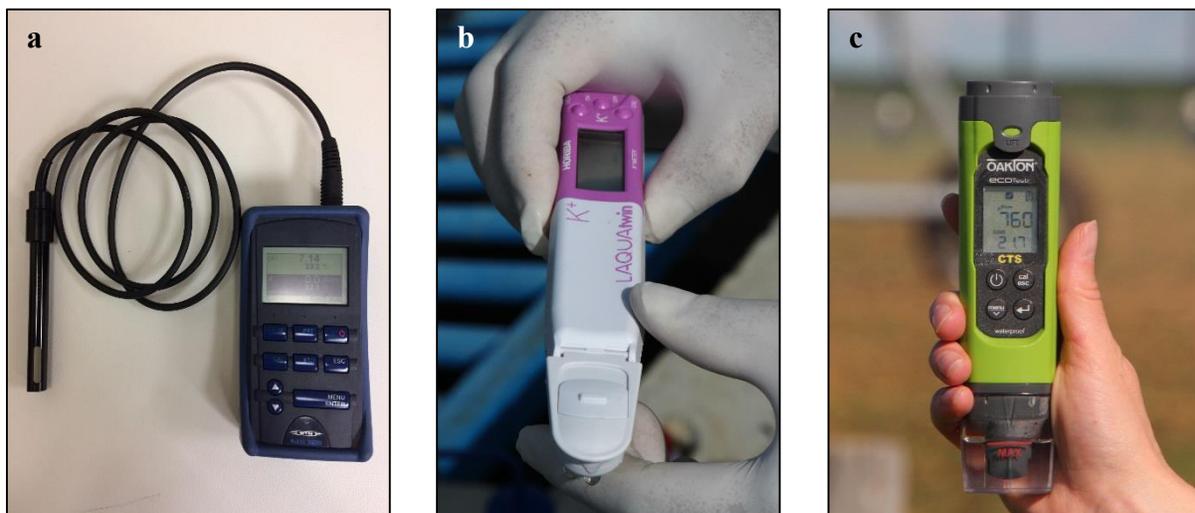
All personnel collecting water samples wore the appropriate personal protective equipment including steel-toed boots, Tyvek<sup>®</sup> coveralls, and eye protection when appropriate. Personal flotation devices were worn when sampling water from the settling ponds.

**Purging Phase.** After the hold periods (i.e., 24 or 48 h) and before the inlet gates were opened, three water samples were collected from the settling pond and the EC value measured in the field to determine if the pond water was still at background concentration (i.e., the KCl solution in the pipeline had not leaked into the settling pond). Three laboratory samples were also collected from the settling ponds at the same time. In all cases, the settling ponds remained at background conditions and no further sampling of the ponds were carried out during the purging phase.

Prior to purging of the KCl-treated water, rain gauges were installed ahead of the pivots. At Pipeline A, five rain gauges were installed in a transect in the direction of travel of the pivot (i.e., roughly perpendicular to the pivot). For Pipelines B and C, five rain gauges were used at each field, and these were placed at every other soil sampling point (Section 3.2.5). For Pipelines D and E, three rain gauges were used, and these were placed at soil sampling Points 1, 10, and 5 or 6. The rain gauges were fixed to wooden laths and the gauges were about 1 m above the ground. After the pivots had passed over the rain gauges, the amount of water collected was recorded, and the results were used to calculate application rates of  $K^+$ .

For Pipeline A, just prior to opening the pipeline inlet and turning on the pivot, three laboratory samples were collected from all four sites. For the other four pipelines, immediately after the pipeline inlet was opened and the pivots turned on, three laboratory water samples were collected at each pivot. These samples represented the 48-h (Pipelines A and B) or 24-h (Pipelines C, D, and E) hold-time concentration of  $K^+$  in the treated water. As the purging phase continued, the water was monitored similarly as described for the injection phase (10-, 5-, and 2-min frequencies) for a decrease in EC and a return to background conditions. After the EC returned to background conditions and was stable, three additional laboratory samples were collected. At this stage, the pivots were either turned off or the irrigator continued to irrigate the field. The positions of the pivots where the irrigation water had returned to background conditions was measured (Figure 3.11). The laboratory samples were placed in coolers with ice and transported to the laboratory for analysis.

**Water Sample Analysis.** In-field measurements of  $K^+$  concentration were carried out using two methods and three different instruments. Samples collected at Pipeline A were analyzed in the field using a WTW Multi3500i EC meter (Xylem Analytics, Weilheim, Germany) and a Horiba LAQUAtwin  $K^+$  probe (HORIBA Instruments Inc., Irvine, California, United States) (Figure 3.15a,b). The calibration of the  $K^+$  probe was checked with standard solutions. Readings from the EC meter were converted to  $K^+$  concentrations using a standard curve previously developed in the laboratory. It was determined from the Pipeline A trial that the Horiba  $K^+$  probe was too sensitive to temperature for use in the field, particularly at cooler temperatures. For the remainder of the pipeline trials, EC measurement was used as the in-field method, and hand-held Oakton<sup>®</sup> EcoTestr meters (OAKTON Instruments, Vernon Hills, Illinois, United States) were used (Figure 3.15c). Water was collected from the settling ponds and used as the matrix in the preparation for the standard curves for the EC meters. The EC readings were adjusted for temperature in the field.



**Figure 3.15 Meters used for in-field measurement of  $K^+$  concentration in water samples: (a) WTW Multi3500i EC meter, (b) Horiba LAQUAtwin  $K^+$  probe, and (c) Oakton® EcoTestr.**

The laboratory water samples were analyzed by the Alberta Agriculture and Forestry laboratory in Lethbridge. Samples were stored at 4° C, filtered ( $\mu\text{m}$  0.45), and analyzed within 24 to 48 h after delivery. All samples were analyzed for EC,  $K^+$ , and  $Cl^-$ . In addition, the samples from Pipeline A were analyzed for calcium ( $Ca^{2+}$ ), magnesium ( $Mg^{2+}$ ), and sodium ( $Na^+$ ). Electrical conductivity was measured using a WTW Multi3500i EC meter and values adjusted to 25° C (APHA 1995a). Flame atomic absorption spectrometry was used to measure  $Ca^{2+}$  (nitrous oxide-acetylene) (APHA 1995b) and  $Mg^{2+}$  (air-acetylene) (APHA 1995c). Potassium and  $Na^+$  were analyzed using the flame emission photometric method (APHA 1995d,e). Chloride was analyzed using the potentiometric method (APHA 1995f). Sodium adsorption ratio (SAR) was calculated for the Pipeline A samples.

**Additional Sites.** In addition to the settling ponds and the centre pivots, water from other sites or turnouts was sampled following the purging of the pipelines to ensure KCl-treated water was no longer in the pipeline systems. The number of additional sites varied from 1 to 13 among the five pipelines. For pipeline A, only the south spur pipe was flushed and tested. There were three cattle watering sites for Pipeline B and four turnouts for Pipeline C. Pipeline D had the most, with 13 domestic turnouts that were flushed and tested. Finally, for Pipeline E, there was four additional sites: two cattle watering turnouts and two turnouts associated with a side-roll irrigation system.

### 3.2.5 Soil Sampling and Analysis

Of the 21 fields that received KCl-treated water, 18 fields were soil sampled. Soil samples were not taken at Pipeline D Sites 11 and 12 and at Pipeline E Site 5, as explained later in this section.

Surface soil samples for chemical analysis were collected from each field prior to and after KCl-treated water application. With some variations, the following procedure was used. After the KCl-treated water had reached a pivot, and the pivot was stopped, soil sampling points were located ahead of the pivot in an area that was not irrigated during the injection phase. A transect of 10 sampling points were located roughly parallel to the pivot with the first point located 5 m from the outer-most pivot wheel track and about 15 m in front of the pivot (i.e., in the direction of travel) (Figure 3.16a). Nine additional points were located towards the centre of the field, with each point 10 m apart. The points were numbered 1 to 10, with Point 1 being the furthest from the centre of the field. Each sampling point was marked with a wire flag and GPS coordinates recorded (Figure 3.17a).

Two sets of soil samples were collected from the sampling points: (1) pre-KCl samples taken on the day of KCl injection into the pipeline, and (2) post-KCl samples taken after the KCl-treated water was applied to the fields following the holding periods of 24 or 48 h. At each sampling point, a composite 0- to 15-cm sample was prepared from either three or five samples (Figure 3.16b,c). The numbers of sample per composite sample was reduced from five to three to save time in the field. A Dutch auger was used to collect the 0- to 15-cm samples (Figure 3.17b). In addition, a single, 0- to 2.5-cm sample was collected using a small hand shovel (Figure 3.17c). All soil samples were air dried and ground (<2 mm).

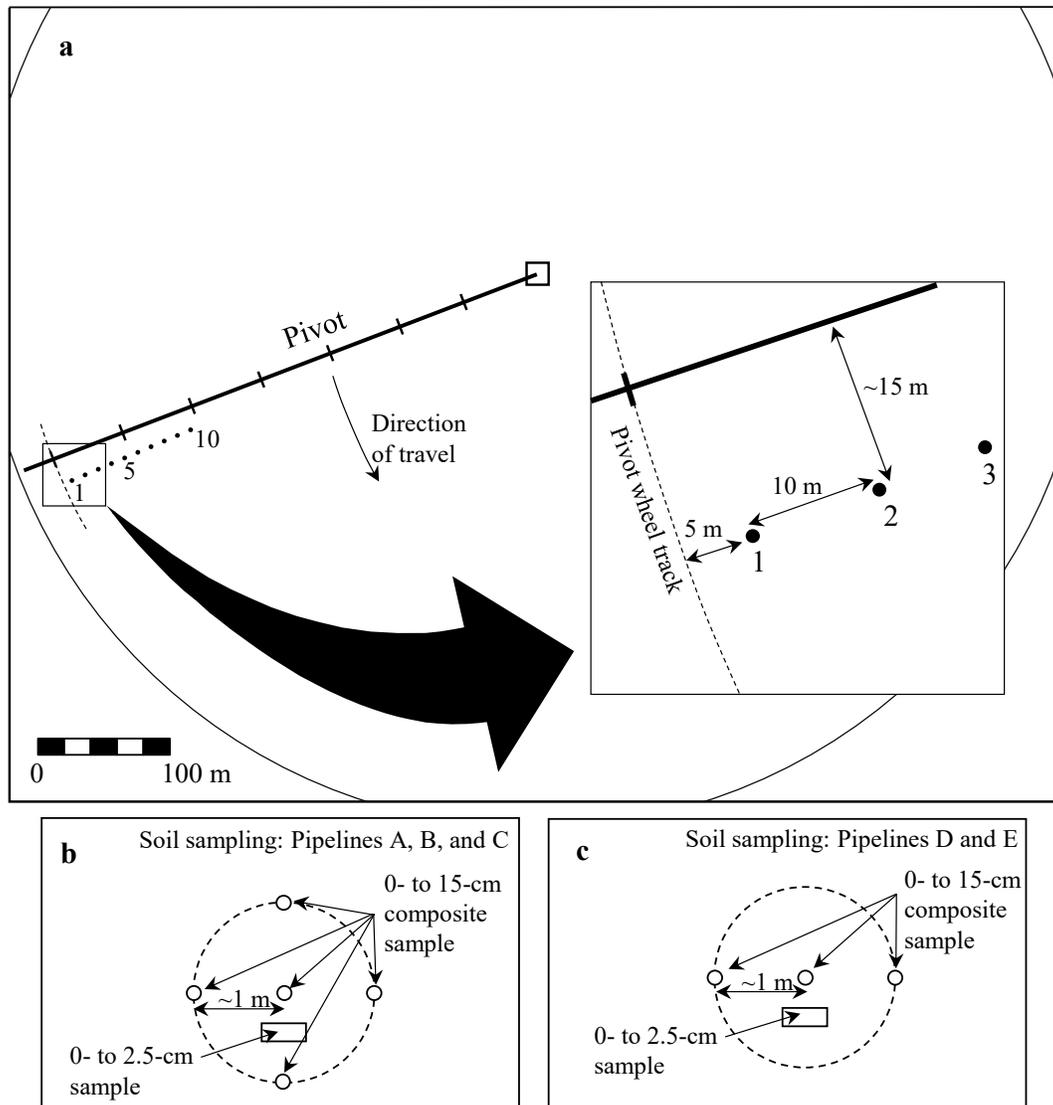
Deviations from the above soil sampling protocol occurred at the following sites.

**Pipeline B Site 2.** The pivot experienced a failure with its GPS system, and this caused the pivot to stop operating several times during the injection phase. During the hold period, the producer moved the pivot in the same direction past the soil sampling points to a location where mechanical repairs were made (Appendix 7.5). During the purging phase, the pivot was started from this new position and moved in the opposite direction and did not reach the soil sampling points. Therefore, a second set of soil sampling points were located near where the pivot started and where KCl-treated water was applied. The results from this set of soil samples was compared to the first set of soil samples where KCl was not applied.

**Pipeline B Site 3.** During the injection phase, the pivot was operated in a counter clockwise direction; whereas, during the purging phase it was operated in the opposite direction. As a result, soil sampling points were located between Positions B and C of the pivot. Therefore, the samples collected after injection received one application of KCl-treated water, and the samples collected after purging received two applications of KCl-treated water.

**Pipeline B Site 4.** This field was divided into four crops: wheat, corn, ryegrass, and pasture. Because of the wet conditions, the trial was only carried out on the ryegrass crop. During the injection phase, the pivot was operated in a counter clockwise direction, and during purging, the pivot moved in the opposite direction. Two soil sampling transects were used at this site: one was between Positions B and C (Area 2), and the second transect was located south of Position B towards Position D (Area 1). At Area 2, the first set of soil samples received one application of KCl-treated water and the second set of samples received two applications. At Area 1, the first set of soil samples did not receive KCl-treated water and the second set of samples received one application.

plied KCl would likely not penetrate through the thatch layer. Therefore, these sam-  
 scarded. Following purging, a second set of soil samples (0- to 15-cm layer only) v  
 ed without removing the thatch layer from two transects: one transect where the KC  
 water was applied (treatment) and the other transect where KCl-treated water was  
 (control). The 0- to 2.5-cm soil samples were not collected at this pasture site beca



**Figure 3.16** Soil sampling at the field sites for chemical analysis.



**Figure 3.17** Soil sampling Pipeline D fields in September 2017 showing (a) a transect of sampling points, (b) sampling with a Dutch auger, and (c) other soil-sampling equipment.

**Pipeline E Site 3.** The pre-KCl soil samples were not collected on the day of injection because the pivot continued to move for 3 h after the water flow was turned off. The pivot was eventually stopped adjacent to an ephemeral slough in the field. To prevent KCl-treated water from entering the slough, prior to purging on September 20, the pivot was moved about 30 m from the slough. After the pivot was repositioned (new Position C), the pre-KCl soil samples were collected. After purging, the post-KCl samples were then collected. Only the 0- to 15-cm layer samples were collected from this site because of the thatch layer.

**Pipeline E Site 5.** During the injection phase, this pivot was operated counter clockwise. The original plan was the producer wanted the pivot operated in the opposite direction during the purging phase. Therefore, the soil sampling points were located on the trailing side of pivot after the injection phase. Unfortunately, at the start of the purging phase, the pivot continued to be operated in a counter clockwise direction, and as a result, moved away from the soil sampling points. The pivot was eventually stopped and reversed; however, it had travelled too far and

reached background conditions before the pivot reached the soil sampling points. The post-KCl samples were not collected and the pre-KCl samples were discarded.

**Soil Chemical Analysis.** The soil chemistry samples were analyzed by the Alberta Agriculture and Forestry laboratory in Lethbridge (samples from Pipelines A, C, and E) and by Exova Canada Inc., in Edmonton (samples from pipelines B and D). In the Alberta Agriculture and Forestry laboratory, soil sub-samples (100 g) were extracted with water using the saturated paste method with vacuum extraction (Janzen 1993). The water extracts were analyzed for EC using a WTW Multi3500i EC meter (APHA 1995a) and for  $\text{Cl}^-$  using a colorimetric method (Technicon Industrial Systems 1986). Extractable  $\text{K}^+$  was determined using the modified Kelowna extraction method (1:10 soil-extractant ratio) (Qian et al. 1994) and  $\text{K}^+$  concentration in the filtrates was determined by flame emission photometry method (APHA 1995d). The same procedures were used by Exova Canada Inc.

**Soil Moisture Samples.** Soil moisture samples were collected from the field used for the Pipeline A trial. These samples were collected from four locations in the north-northeast portion of the field where water was not applied during the trial. Sample locations were marked with a wire pin flag. Samples were collected using a Dutch auger before (July 4) and after (July 7) the trial in 30-cm increments to a depth of 120 cm. Soils were placed into metal tins, covered, and transported to the laboratory. Gravimetric moisture content of the samples was determined by drying in an oven at 105° C for 24 h, and then calculated on a dry-weight basis. Soil moisture samples were not collected at the other pipelines fields either because of weather or crop status, and the change in the hold period from 48 to 24 h.

Soil moisture samples were collected at the Pipeline B fields prior to the injection phase. However, because of rain, the soil become too wet, and as a result, post-trial samples were not collected. The pre-injection soil samples were therefore discarded. Soil moisture samples were also not collected from the fields at Pipelines C, D, and E because the hold time was only 24 h long and most of the fields had been harvested at Pipelines D and E.

### 3.2.6 Plant Sampling and Analysis

There was only one opportunity to collect plant samples. Alfalfa (*Medicago sativa* L.) samples were collected at the Pipeline B Site 3 (Figure 3.4) on June 29, 2017, 8 d after the KCl-treated water was applied to the field. The samples were collected just prior to the alfalfa being harvested by the producer. Two transects of 10 sampling points were located in the field: one transect where KCl-treated water was not applied (i.e., control), and the other transect where KCl-treated water was applied (treatment). At each sampling point, a 0.25 m<sup>2</sup> area was harvested by hand removing all plant material above ground. The samples were placed into perforated paper bags and dried at 35° C. The plant samples were analyzed for the content of total K, nitrogen (N), phosphorus (P), sulphur (S), calcium (Ca), magnesium (Mg), zinc (Zn), boron (B), copper (Cu), iron (Fe), and manganese (Mn). Total N was determined by the macro total Kjeldahl method (AOAC 1990). All the other parameters were determined by dry ashing (muffle furnace at 500° C for 1 h), dissolution in 10%  $\text{HNO}_3$  acid, and inductively coupled plasma optical emission spectrometry (Benton Jones 2001). Samples were analyzed by Down to Earth Labs Inc., Lethbridge, Alberta.

### 3.2.7 Weather Data

Weather data were obtained from the online Alberta Climate Information Service (ACIS) (AAF 2018). The data used were from the nearest ACIS weather stations to the selected pipelines (Table 3.4). Data obtained were for the days the trials were conducted, plus the day prior to each trial. Parameters selected were mean daily temperature, minimum daily temperature, maximum daily temperature, daily precipitation, and mean wind speed at 2 m above ground surface.

**Table 3.4 Weather stations nearest the pipeline inlets.**

Pipeline	Weather station <sup>z</sup>	Latitude (°N)	Longitude (°W)	Elevation (m)	Distance to pipeline inlet (km)
A	Lathom AGCM	50.6004	112.2990	810.00	7.9
B and C	Bassano AGCM	50.8926	112.4652	810.00	13.9
D	Fincastle IMCIM	49.8023	112.0459	803.96	5.1
E	Lethbridge Demo Farm IMCIN	49.6867	112.7449	906.87	9.3

<sup>z</sup> From the online Alberta Climate Information Service (AAF 2018).

### 3.2.8 Statistical Analysis

Statistical comparison of means was performed using SAS software, Version 9.4 for Windows (SAS Institute Inc., Cary, North Carolina, United States).

Most of the soil sampling (for chemistry and moisture) at the sites were paired samples. The exception was Pipeline E Site 2, where two separate transects were taken: one where KCl was applied and one where KCl was not applied. The paired data set for each site and soil layer were first checked for normal distribution of the differences between the pre and post values using PROC UNIVARIATE in SAS software. Paired data sets that were normally distributed were compared using the paired t-test in the PROC TTEST procedure with the PAIRED statement ( $p < 0.05$ ). Paired data sets that were not normally distributed were compared using the Wilcoxon Signed Rank Test in the PROC UNIVARIATE procedure ( $p < 0.05$ ).

The alfalfa tissue chemistry data and the soils data from Pipeline E Site 2 were treated as a comparisons of two independent groups: control and KCl treated. Normality was checked using PROC UNIVARIATE in SAS software using the Shapiro-Wilk test. Equality of variances was checked using the PROC TTEST procedure. For those data sets that met normality and equality of variances conditions, comparisons were made using the Student's t-test (PROC TTEST,  $p < 0.05$ ). For those data sets that were not normally distributed or variances not equal, comparisons were made using the non-parametric Wilcoxon Rank Sum Test in the PROC NPAR1WAY procedure ( $p < 0.05$ ). Because of the small sample size, the EXACT statement was used to obtain exact  $p$ -values for the Wilcoxon test.

### 3.3 Results and Discussion

#### 3.3.1 Weather

Generally, weather conditions were conducive for conducting the pipeline trials. Conditions were relatively dry for four of the trials. The exception was for Pipeline B where rain fell on June 8 and 9 causing wet conditions during purging of the pipeline on June 9 (Table 3.5). Because of lightning and scattered showers on June 9, purging of the pipeline was delayed until late in the afternoon.

#### 3.3.2 Injection of KCl

The injection of the KCl stock solution was carried out successfully at all five pipeline trials. The efforts required for pipeline treatment were much greater for the larger pipelines with multiple irrigation systems in terms of coordination with irrigators and the irrigation districts.

For the four pipeline trials carried out in 2017, not all of the irrigation systems were used in the trials. About half the systems serviced by Pipelines B, C, and D were used, while nearly all of the systems serviced by Pipeline E were used (Table 3.1). There were a number of reasons why irrigators did not participate either in whole or in part. These reasons included not being interested in the project, concerns about possible effects on their crop, interference with crop management practices (e.g., pollination by bees), and unexpected last-minute changes that prevented an irrigator from operating their pivot system(s). The later point occurred for Pipeline D when the landowner of Sites 5 and 7 had to cancel the day before the trial started. Other factors such as limited window-of-opportunities relative to main agronomic activities, including seeding, pesticide application, and harvesting, had to be considered. Any irrigation system not part of the trials had to be identified and isolated by closing inlet valves of the producer-owned supply pipelines. A few pivots on Pipelines B and C were serviced by aboveground supply pipelines, and as a result, the KCl-treated water could not be held in these pipelines during the hold periods. For a similar reason, side-roll irrigation systems were not included. In addition to irrigation systems, other turnouts used for livestock watering or domestic purposes or both had to be identified, which required landowners to be informed, and their concerns addressed. Particularly for some cattle watering turnouts (Pipelines B, C, and E), time was required to flush the turnouts and ensure there was no KCl-treated water remaining in the systems.

The time required to inject the KCl stock solution into the pipelines varied from 1.1 to 6.1 h (Table 3.6). The length of time was a function of the total pipeline volume (Table 3.1) and the number of irrigation systems in operation at a given time. Even though Pipeline E was larger than Pipelines B and C, the time required to treat the former pipeline was about 30 to 40% less time. This was because only two to three pivot systems were operated during the Pipeline B and C trials; whereas, up to five pivots were operated at the same time during the Pipeline E trial. As a result, the flow was higher through Pipeline E. The injection of Pipeline D took about 2.3 to 3.8 times longer to inject the KCl solution compared to the other four pipelines (Table 3.6). This is mainly because Pipeline D was 3 to 17 times larger than the other four pipelines. Even though Pipeline D had a larger number of irrigation systems used in the trial, not all of the irrigation

systems were operated at the same time in order accommodate the limited number of field staff to monitor the pivots (Appendix 7.8).

**Table 3.5 Weather data for the periods the pipeline trials were conducted.**

Date	Precipitation (mm)	Mean temperature (°C)	Minimum temperature (°C)	Maximum temperature (°C)	Mean wind speed (km h <sup>-1</sup> )
<i>Pipeline A (2016)<sup>z</sup></i>					
July 4	10.8	15.3	10.9	23.9	11.9
July 5	0	14.2	7.0	20.6	8.4
July 6	2.0	14.2	7.3	21.7	8.9
July 7	0	16.7	6.6	24.8	7.7
<i>Pipeline B (2017)<sup>y</sup></i>					
June 6	0	15.6	3.7	23.5	12.6
June 7	0.1-	17.5	5.3	27.5	12.1
June 8	26.7	19.3	8.6	30.2	14.0
June 9	9	14.4	8.5	18.8	10.0
<i>Pipeline C (2017)<sup>y</sup></i>					
June 19	0	14.9	8.1	21.4	9.0
June 20	0.1	18.7	9.8	27.4	9.8
June 21	0.1	13.3	7.1	20.0	11.4
<i>Pipeline D (2017)<sup>x</sup></i>					
Sep. 11	0	21.0	10.4	31.9	13.6
Sep. 12	0	18.4	12.6	22.5	12.2
Sep. 13	0.6	10.8	6.9	14.9	14.4
<i>Pipeline E (2017)<sup>w</sup></i>					
Sep. 18	0	12.4	6.2	18.0	14.7
Sep. 19	0	8.9	0.3	16.0	14.8
Sep. 20	0	9.0	2.1	15.3	19.4

<sup>z</sup> Lathom AGCM weather station; 50.6004°N, 112.2990°W, 810.00 m elevation (AAF 2018).

<sup>y</sup> Bassano AGCM weather station; 50.8926°N, 112.4652°W, 807.00 m elevation (AAF 2018).

<sup>x</sup> Fincastle IMCIM weather station; 49.8023°N, 112.0459°W, 803.96 m elevation (AAF 2018).

<sup>w</sup> Lethbridge Demo Farm IMCIN weather station; 49.6867°N, 112.744°W, 906.87 m elevation (AAF 2018).

The background concentration of  $K^+$  in the settling ponds was consistently less than the detection limit of  $3.91 \text{ mg L}^{-1}$  for all five pipelines (Table 3.7). This was also true for  $Cl^-$  at pipelines D and E and just slightly above the detection limit ( $9.93 \text{ mg L}^{-1}$ ) at the other three pipelines. The EC values were less than  $0.40 \text{ dS m}^{-1}$ . These values are comparable to mean values for irrigation water samples ( $n = 1079$ ) collected for 9 yr in southern Alberta ( $K^+ = 2.4 \text{ mg L}^{-1}$ ,  $Cl^- = 7.7 \text{ mg L}^{-1}$ ,  $EC = 0.40 \text{ dS m}^{-1}$ ; unpublished data, Alberta Agriculture and Forestry).

**Table 3.6 Time required to treat the pipelines and the final mean potassium ( $K^+$ ) concentration in the treated water achieved as measured at the pivots.**

Pipeline	Number of pivot systems	Treatment time (h)	Final $K^+$ concentration ( $\text{mg L}^{-1}$ )
A	1	1.1	106
B	3	2.7	102–105
C	2	2.3	89
D	9	6.1	122–130
E	6	1.6	77–86

At the end of the hold periods (24 and 48 h), the concentration of  $K^+$ ,  $Cl^-$ , and EC in the settling ponds did not change from background conditions (Table 3.7). Therefore, after the injection phase and after the pipeline inlet valves were closed, it can be concluded that there was no measurable leakage of KCl-treated water from the pipelines into the settling ponds during the hold periods. This provided reassurance that the KCl-treated water could be safely contained within district-owned pipelines for at least 48 h. This is important because exposure time, along with  $K^+$  concentration and temperature, is an important factor in controlling mussels. For the purpose of this study, KCl-treated water was only held for 1 to 2 d. However, a recent review suggests that in southern Alberta, KCl-treated water at a concentration of  $115 \text{ mg L}^{-1} K^+$  may need to be held for 5 to 6 d to achieve 100% mortality (Paterson Earth & Water Consulting 2018). This may be problematic if irrigation systems and access to livestock and domestic water is not available for this length of time, depending on growing conditions and time of year. Likely, early or late in the growing season (or even after harvest) would be the opportune times to treat pipelines.

**Table 3.7 Mean concentration of water quality parameters in settling-pond water during the injection phase and after the hold periods.**

Pipeline	Potassium			Chloride			Electrical conductivity		
	Injection n = 14–20	24 h n = 3	48 h n = 3	Injection n = 14–20	24 h n = 3	48 h n = 3	Injection n = 14–20	24 h n = 3	48 h n = 3
	----- ( $\text{mg L}^{-1}$ ) -----			----- ( $\text{mg L}^{-1}$ ) -----			----- ( $\text{dS m}^{-1}$ ) -----		
A	<3.91	<3.91	<3.91	10.6	10.6	10.6	0.34	0.34	0.34
B	<3.91	<3.91	<3.91	14.2	14.2	14.2	0.38	0.38	0.37
C <sup>z</sup>	<3.91	<3.91	na <sup>y</sup>	14.2	14.2	na	0.37	0.39	na
D <sup>z</sup>	<3.91	<3.91	na	<9.93	<9.93	na	0.23	0.24	na
E <sup>z</sup>	<3.91	<3.91	na	<9.93	<9.93	na	0.24	0.24	na

<sup>z</sup> KCl-treated water was only held in these pipelines for 24 h.

<sup>y</sup> na = not applicable.

The target concentration of  $100 \text{ mg L}^{-1} \text{ K}^{+}$  was generally achieved in Pipelines A, B, and C (Table 3.6). In contrast, the final concentrations were consistently greater than the target for Pipeline D, and were consistently less than the target for Pipeline E.

A key factor in treating pipelines is to have accurate values of water flow in the pipeline at the point of injection. The flow changes as pivots, as well as end arms and end guns, are turned on and off, and changes in flow requires adjusting the injection rate of stock solution. During the trials, different methods were used to estimate the flow. For Pipelines B and C, a MACE flow meter was used at the inlet. For Pipelines D and E, the flow was estimated by calculation using the flow values of the pivots during when a particular set of pivots were in operation. Each time a pivot was turned on or off, the flow was re-calculated and the injection pump re-adjusted accordingly. It is believed the target concentration was not achieved for Pipelines D and E because the flow values provided for the pivots were not accurate. Some of the values used may have been the rated flow value for the pivots as opposed to an actual measurement with a flow meter. However, flow meters are generally only accurate to within 2% (personal communication, Lloyd Healy, AAF, Lethbridge). Even a couple of percentage points, either consistently too high or too low, would result in a cumulative effect among several pivots supplied by the same pipeline, easily resulting in being 10 to 30% above or below the target concentration.

The concentration of  $\text{K}^{+}$  achieved at each pivot by the end of the injection phase remained reasonably constant during the 24-h or 48-h hold periods. For Pipelines A, B, C, and E, the concentration was essentially unchanged (Table 3.8). However,  $\text{K}^{+}$  concentration at the Pipeline D pivots was consistently less after the 24-h hold period by about 9% on average. This small decrease may have been caused by diffusion. The injection phase for Pipeline D ended before the whole pipeline could be treated with KCl because the stock solution was depleted. Likely, there would have been enough stock solution if the target concentration was met rather than over applying by 22 to 30%. At the time injection was stopped, KCl-treated water had reached Sites 9 and 10 but not Site 11 (i.e., still at background conditions). However, 24 h later, when the Site 11 pivot was first turned on and water samples collected, the concentration was  $111 \text{ mg L}^{-1} \text{ K}^{+}$  (Table 3.8), suggesting that diffusion occurred during the hold period. It is estimated that about 1 km of district-owned pipeline (i.e., downstream from the Site 11 pivot turnout; Figure 3.5) had not received KCl-treated water when injection stopped. This represents about 14% of the total length of the district-owned pipeline. Diffusion into this portion of the pipeline during the 24-h hold period may explain the overall decrease in KCl concentration in the pipeline.

The change from background concentration ( $<3.91 \text{ mg L}^{-1}$ ) to maximum concentration of  $\text{K}^{+}$  at the pivots occurred in a relatively short period of time. The time required for this change to occur ranged from 5 to 20 min with an average of about 12 min among the pivots. For example, it took about 15 min to reach the maximum concentration at the Pipeline A pivot (Figure 3.18). The time required to change from background to maximum concentration was not affected by the size of the pipeline system (data not shown).

The total amount of KCl injected into the five pipelines was estimated at about 1560 kg (Table 3.3, Appendix 7.7). At the time of the trials, the cost of commercial potash fertilizer used was  $\$550 \text{ Mg}^{-1}$ . Therefore, the total cost of the potash used was \$858. However, the amount of potash required would have been slightly higher as a small percentage of potash does not dissolve into

solution. This cost would only represent a small portion of the total cost of treating irrigation pipelines. Additional costs would include the cost of preparing the potash solution, travel and setup costs, time required to coordinate with irrigation districts and landowners, and time required to inject the KCl into pipelines. There would also be the cost of capital equipment and facilities. Paterson Earth & Water Consulting (2018) reported that it costed about \$0.83 m<sup>-3</sup> of water to treat Lake Winnipeg harbours in 2014 with dissolved potash by a contracted applicator. The total volume of the five pipelines used in this study was 6605 m<sup>-3</sup> (Table 3.1). Based on the Lake Winnipeg cost, the cost of treating the five pipelines would be nearly \$5500. There are more than 900 pipelines in Alberta's 13 irrigation districts, and to treat all of these pipelines once may cost about \$1.1 million (Paterson Earth & Water Consulting 2018). Paterson Earth & Water Consulting (2018) also suggested that this cost estimate may be conservative.

**Table 3.8 Mean concentration (n = 3) of potassium in the centre pivots at the end of the injection phase and hold periods.**

Pipeline	Site	Injection phase (mg L <sup>-1</sup> )	24 hr (mg L <sup>-1</sup> )	48 hr <sup>z</sup> (mg L <sup>-1</sup> )
A	4	106	104	106
	2	105	ns <sup>y</sup>	105
B	3	102	ns	122
	4	103 <sup>x</sup>	104	104
C	2	89	93	
	3	89	90	
D	2	128	123	
	3	125	104	
	4	127	116 <sup>w</sup>	
	6	130	119	
	8	127	111	
	9	123	111	
	10	122	119	
E	11	ns <sup>y</sup>	111	
	2	85	85 <sup>u</sup>	
	3	77	76	
	4	85	80	
	5	85	83	
	6	85	85	
	7	86	78	

<sup>z</sup> Hold times for Pipelines C, D, and E were only 24 h.

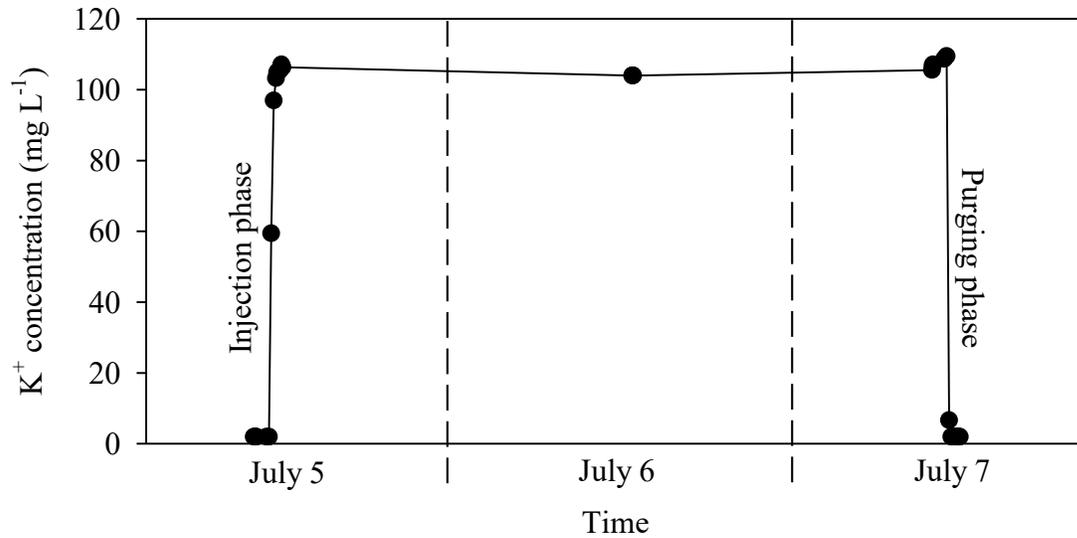
<sup>y</sup> ns = not sampled.

<sup>x</sup> n = 4.

<sup>w</sup> n = 1.

<sup>v</sup> The water in the pivot was still at background conditions at the time injection was stopped.

<sup>u</sup> n = 2.



**Figure 3.18 Change in potassium (K<sup>+</sup>) concentration with time at the Pipeline A Site 4 in July 2016.**

The dosing pump used for Pipelines B to E worked well in the field and is suitable for this type of application. There was some initial manufacturing and programming problems with the new pump, and these were corrected prior to the trials. Also, a suitable generator (\$5100) was required to accommodate the electrical current requirements of the pump. Calibration tests confirmed the pump accurately dispensed required volumes. A key learning in operating pumps for dispensing concentrated KCl solution is they need to be well flushed with ordinary water after each use to prevent the build-up of KCl precipitates. Also, as with any pump, sub-zero temperatures need to be avoided. The pump and control system that was purchased (\$15,000) was designed to accommodate a wide range of flow values (0.1 to 2 m<sup>3</sup> s<sup>-1</sup>) and pipeline sizes (0.3 to 1.2 m diameter). An option for irrigation districts or commercial applicators is to have several pumps of different sizes, using smaller, less expensive pumps for smaller pipelines, as was used for Pipeline A, and larger pumps for larger pipelines. Districts may choose to install permanent pumps on pipelines or use portable pumps, or a combination. Alternatively, districts may rely on commercial operators to supply pumping capabilities.

Another consideration is that some modification at pipeline inlets may be required in order to insert an injection tube. All five pipelines used in the study had vertical air vent pipes at the inlets, and only minor, inexpensive modifications were needed to accommodate the injection process.

In this study, the pump was adjusted manually to change the injection rate as the flow changed in the pipeline, caused by pivots being turned on and off. Ideally, a meter monitoring the flow in the pipeline would be electronically connected to the pump's control system, resulting in automatic adjustments to the injection rate as the flow changes. This arrangement was not tested in our study, as additional programming of the pump's control system was required for this capability, and this was not achievable prior to the field trials in 2017.

### 3.3.3 Purging of KCl-treated Water

Purging of the KCl-treated water held in the pipelines was successful for all five pipelines. The amount of irrigated water applied to fields during purging ranged from 3 to 24 mm, depending on the pivot (Table 3.9). The concentration of  $K^+$  at the centre pivots after the hold periods, but before purging, ranged from 76 to 123 mg L<sup>-1</sup>, with an average of 101 mg L<sup>-1</sup> (Table 3.8). Based on the concentration of  $K^+$  and the amount of water applied, the application rate of  $K^+$  on the fields ranged from 3 to 29 kg ha<sup>-1</sup>, with a mean of 12 kg ha<sup>-1</sup> among the fields for the five pipeline trials (Table 3.9). In all cases, only a small proportion of each field (<0.4 to 11 ha) received KCl-treated water, with most sites less than 5 ha. The above range of application rates is based on the  $K^+$  concentrations at the start of purging. The application rate would have decreased during the latter part of the purging phase as the irrigation water returned to background conditions. The return to background conditions occurred as quickly as the increase in  $K^+$  concentration occurred during the injection phase (Figure 3.18).

As indicated above, the area that received KCl-treated water during the purging phase (i.e., from Position C to D; Table 3.9; Figure 3.11) was generally small compared to the size of the fields (Table 3.2). The proportion of field area that received KCl-treated water ranged from 1 to 20%. However, during the injection phase, KCl-treated water was also applied to the field from when maximum  $K^+$  concentration was reached and until the pivot was turned off (i.e., from Position B to C). This represented another 0.09 to 3.2 ha (Table 3.9). Together, 2 to 26% of field area received KCl-treated water, with a mean of 11%. In addition, some KCl-treated water (less than target concentration) was applied to a relatively small area as the pivots approached Position B; however, this was not measured in terms of land area.

The amount of  $K^+$  applied to the fields was generally less than what would be expected to be removed by crops typically grown in southern Alberta. In comparison, the annual removal of  $K^+$  by harvested crops can range from 16 to 26 kg ha<sup>-1</sup> for cereal grains, from 11 to 17 kg ha<sup>-1</sup> for oilseed crops, from 30 to 48 kg ha<sup>-1</sup> for pulse crops, and from 114 to 279 kg ha<sup>-1</sup> for forage crops (Canadian Fertilizer Institute 2001). Harvested sugar beet and potato can remove 133 and 201 kg ha<sup>-1</sup>, respectively (Canadian Fertilizer Institute 2001).

Considering the relatively low application rates of  $K^+$  and the small application areas for a single treatment, the accumulation of  $K^+$  in soil from repeated treatments could be avoided by managing the distribution of applications throughout the field and with annual crop removal. For example, if the area that receives KCl-treated water is one-eighth the area of the field, then eight treatments could be applied before applying more than once on the same area. And likely, eight treatments would occur during two or more years. Also, operating pivots at 100% during purging is recommended in order to apply the lowest application rate of  $K^+$ .

The EC of KCl-treated water immediately prior to purging of the water on cropland ranged from 0.52 to 0.84 dS m<sup>-1</sup> among the pivots, with an overall mean of 0.66 dS m<sup>-1</sup> (Table 3.10). In comparison, the EC of untreated irrigation water ranged from 0.24 to 0.39 dS m<sup>-1</sup> in the settling ponds (Table 3.7). Therefore, the injection of KCl stock solution into the pipelines to achieve a target concentration of 100 mg L<sup>-1</sup>  $K^+$  increased EC values by about two times. However, water

in Alberta with EC values less than 1 dS m<sup>-1</sup> and sodium adsorption ratios less than 5 is considered safe for irrigation (GoA 2018d).

**Table 3.9 Water applied during the purging phase, calculated application rate of potassium (K<sup>+</sup>), and the areas that received KCl-treated water during the purging (from Positions C to D) and injection (from Positions B to C) phases.**

Pipeline	Site	Water applied (mm) <sup>z</sup>	Land area (Position C to D) <sup>y,x</sup> (ha)	K <sup>+</sup> application rate (kg ha <sup>-1</sup> ) <sup>w</sup>	Land area (Position B to C) <sup>v,x</sup> (ha)
A	4	5.5	4.95	6	2.54
	2	na <sup>u,t</sup>	2.84 <sup>t</sup>	–	na
B	3	5.8	0.99	7	1.07
	4	3.2	9.58	3	0.80
C	2	4.2	6.10	4	1.19
	3	7.0	10.93	6	1.69
D	2	13.7	2.21	17	1.91
	3	15.7	3.92	16	na
	4	21.3	na	25	na
	6	24.3	1.93	29	0.09
	8	na	1.32 <sup>t</sup>	–	na
	9	10.0	2.91	11	0.62
	10	13.7	0.80	16	0.68
E	2	15.5	0.58	13	0.25
	3	17.3	<1 <sup>s</sup>	13	<1 <sup>s</sup>
	4	12.0	0.43	10	0.38
	5	7.3	4.50	6	3.20
	6	11.0	3.74	9	2.05
	7	13.3	2.34	10	0.68

<sup>z</sup> Mean values (n = 2 to 5) from the rain gauge data.

<sup>y</sup> The area that received KCl-treated water during the purging phase (Figure 3.11).

<sup>x</sup> Determined using Google Earth Pro and the measured positions of the pivots.

<sup>w</sup> Based on K<sup>+</sup> concentration in the water at the start of the purging phase (Table 3.8).

<sup>v</sup> The area that received KCl-treated water during the latter portion of the injection phase (Figure 3.11), i.e., during the time K<sup>+</sup> changed from background concentration to maximum concentration and until the pivot was turned off (i.e., between Positions B and C).

<sup>u</sup> na = not available.

<sup>t</sup> Rain gauges were not installed. The pivot was set to apply about 6 mm.

<sup>s</sup> Approximate estimates.

### 3.3.4 Soil Chemistry

Generally, a single application of KCl-treated water on the fields had no significant effect on extractable K<sup>+</sup> in surface soil layers at most of the fields (Table 3.11). However, K<sup>+</sup> concentration was significantly increased by 6 to 26% at five fields. These included Pipeline B Site 4, Pipeline C Site 3, Pipeline D Sites 2 and 4, and Pipeline E Site 6. At Pipeline D Site 2, a significant increase occurred in the 0- to 2.5-cm layer but not in the 0- to 15-cm layer. At

Pipeline B Site 4, significant increases occurred in both soil layers. For the other three fields, significant increases occurred in the 0- to 15-cm layer but not in the 0- to 2.5-cm layer. An increase in the 0- to 2.5-cm layer but not in the 0- to 15-cm layer can be expected, but not the opposite. Considering the time frame between the pre- and post-soil samplings (i.e., 24 to 48 h) and the amount of water applied during purging, it was expected that the applied  $K^+$  would likely remain in the first few centimetres of soil. In contrast, two sites had a significant decrease in  $K^+$  concentration in the post samples compared to the pre samples: Pipeline B Site 3 (0- to 2.5-cm layer) and Pipeline D Site 10 (0- to 15-cm layer). The amount of  $K^+$  applied to the fields was generally less than what would be expected to be removed by crops typically grown in southern Alberta. In addition, the amount of  $K^+$  applied was small compared to the existing  $K^+$  content in the soil. This likely made it difficult to detect a significant difference relative to field variability, and the significant effects may be largely due to field variability. Further to this, there was no consistent tendency (i.e., increase or decrease) between the pre and post samples that were not significantly different.

**Table 3.10 Mean (n = 3) electrical conductivity (EC) of KCl-treated water at the centre pivots immediately prior to purging of the water on cropland.**

Pipeline	Site	EC (dS m <sup>-1</sup> )	Pipeline	Site	EC (dS m <sup>-1</sup> )	Pipeline	Site	EC (dS m <sup>-1</sup> )
A	4	0.75	D	2	0.70	E	2	0.56
B	2	0.77	D	3	0.62	E	3	0.52
B	3	0.84	D	4	0.67 <sup>z</sup>	E	4	0.54
B	4	0.77	D	6	0.68	E	5	0.55
C	2	0.73	D	8	0.65	E	6	0.56
C	3	0.71	D	9	0.65	E	7	0.53
			D	10	0.68			

<sup>z</sup> n = 1.

Of the 18 fields sampled, 10 had significantly higher  $Cl^-$  concentrations in the 0- to 2.5-cm soil layer after the application of potash-treated water (Table 3.11). This was also true for the 0- to 15-cm soil layer at eight of the fields. Unlike  $K^+$ , the amount of  $Cl^-$  added was relatively large compared to the existing  $Cl^-$  content in soil, and this allowed for the detection of significant increases. These increases from pre- to post-soil samples ranged from 21% to more than 400%. In contrast, two sites (Pipeline B Sites 2 and 4) had a significant decrease in  $Cl^-$  concentration in the post samples compared to the pre samples. The amount of water applied during purging on these two fields was 6 and 3 mm, respectively, and would likely not result in leaching. However, the fields during the Pipeline B trial were relatively wet from rain (Table 3.5) and this may have contributed to some downward movement. At another site (Pipeline D Site 3), the concentration of  $Cl^-$  significantly decreased in the 0- to 2.5-cm layer; whereas, the concentration significantly increased in the 0- to 15-cm soil layer. At this site, about 16 mm of water was applied during purging (Table 3.9) and this may have been enough to leach  $Cl^-$  from the 0- to 2.5-cm layer deeper into the 0- to 15-cm layer.

**Table 3.11 Mean (n = 10) concentrations of soil chemistry parameters in the fields prior to (pre) and after (post) potash-treated water application.**

Pipeline	Site	Soil layer (cm)	Electrical conductivity <sup>z</sup>		Extractable potassium <sup>y</sup>		Extractable chloride <sup>z</sup>	
			Pre ----- (dS m <sup>-1</sup> )	Post <sup>x</sup> -----	Pre ----- (mg kg <sup>-1</sup> )	Post <sup>x</sup> -----	Pre ----- (mg kg <sup>-1</sup> )	Post <sup>x</sup> -----
A	4	0–2.5	0.76	0.78	800	780	16	22*
		0–15	0.83	0.89	586	592	15	21*
B	2	0–2.5	1.12	0.73*	911	894	27	14*
		0–15	0.83	0.73*	639	615	20	16*
	3	0–2.5	0.72	0.90*	798	670*	9	21*
		0–15	0.68	0.91*	331	377	8	14*
	4	0–2.5	1.06	0.80	576	644*	16	19
		0–15	1.51	1.28*	537	595*	28	25
4 <sup>w</sup>	0–2.5	1.35	0.83*	793	760	48	24*	
0–15	1.73	1.70	733	699	56	49		
C	2	0–2.5	0.72	0.91*	478	499	9	46*
		0–15	1.51	1.51	377	397	26	25
	3	0–2.5	0.86	0.81	886	863	13	27*
		0–15	1.01	0.93	506	536*	17	18
	2	0–2.5	1.34	1.06	396	497*	19	36*
		0–15	1.97	2.10	333	348	27	35*
3	0–2.5	1.01	0.91*	371	350	47	37*	
	0–15	0.96	1.01	289	294	34	41*	
D <sup>v</sup>	4	0–2.5	0.76	0.90*	432	475	6	15*
		0–15	0.64	0.80*	319	396*	5	10*
	6	0–2.5	1.27	1.00	1021	942	43	33
		0–15	1.36	1.21	971	984	36	42
	8	0–2.5	0.89	0.96	456	474	12	25*
		0–15	0.70	0.75	377	359	6	18*
9	0–2.5	1.61	1.46	750	683	138	113	
	0–15	1.04	1.04	324	301	62	61	
10	0–2.5	0.66	0.72	349	336	8	16*	
	0–15	0.57	0.60	269	242*	5	7	
E <sup>t</sup>	2	0–2.5	1.53	1.34	762	794	46	52
		0–15	ns <sup>u</sup>	ns	ns	ns	ns	ns
	3	0–2.5	1.24	1.14	490	474	31	30
		0–15	ns	ns	ns	ns	ns	ns
	4	0–2.5	0.92	0.78	649	632	15	22*
		0–15	0.56	0.46*	358	327	7	12*
	6	0–2.5	1.14	1.11	403	440	78	80
		0–15	0.58	0.59	198	222*	16	23*
	7	0–2.5	1.62	1.71	973	1015	54	73*
		0–15	4.36	4.38	588	583	47	50

<sup>z</sup> Determined using the saturated paste extraction method.

<sup>y</sup> Determined using the modified Kelowna extraction method.

<sup>x</sup> Post-mean concentrations followed by an asterisk (\*) are significantly different ( $p < 0.05$ ). Comparisons were conducted either by the paired t-test or by the Wilcoxon Signed Rank Test for most sites, except for Pipeline E Site 2 for which the t-test (EC) and Wilcoxon Rank Sum Test (K and Cl) were used.

<sup>w</sup> Two transects were sampled at Site 4. For the above first transect, the pre samples did not receive KCl-treated water and the post samples received one application. For the above second transect, the pre samples received one application of KCl-treated water and the post samples received two applications.

<sup>v</sup> Sites 11 and 12 were not soil sampled.

<sup>u</sup> ns = not sampled.

<sup>t</sup> Site 5 was not soil sampled.

For 11 of the fields, the application of KCl-treated water did not affect soil EC (Table 3.11). Significant effects on EC did occur in seven fields; however, the effect was not consistent, with EC increasing in three fields and decreasing in four fields. Therefore, the apparent significant effect on EC may be due to field variability.

### 3.3.5 Soil Moisture

The mean soil gravimetric moisture content in the unirrigated portion of the Pipeline A Site 4 canola field was slightly less on July 7 compared to July 4. The overall soil profile (0–120 cm) mean moisture content was 21.5% on July 4 and 20.7% on July 7 (Table 3.12). Similar observations were observed for the 0- to 30-cm, 30- to 60-cm, and 90- to 120-cm soil layers; whereas, the 60- to 90-cm soil layer had slightly higher moisture content on July 7. There were no statistically significant differences in soil moisture between the two sampling dates for the four soil layers. Under the conditions of the pipeline trial, halting of irrigation during the 48-h hold time did not pose a risk to significant soil moisture depletion. However, other conditions may cause a higher risk of moisture depletion, and this will depend on crop type, growth stage, weather conditions, soil type, and duration of hold time. For the current study, a maximum of 48 h was used as a hold time, and this was believed to be a minimum time required to treat attached mussels in pipelines. However, as indicated above, in southern Alberta, KCl-treated water may need to be held for 5 to 6 d in pipelines to achieve 100% mortality of invasive mussels (Paterson Earth & Water Consulting 2018). Not being able to irrigate for this length of time during peak water demand by crops would be a concern to irrigators. Treating pipelines during periods of less demand would need to be considered, such as early or late in the irrigation season.

Soil moisture samples were not collected at the Pipeline B sites because of the wet conditions from rainfall (Table 3.5). Soil moisture samples were not collected at the Pipeline C sites because the KCl-treated water was held for only 24 h, and based on the results from Pipeline A, it was felt that this time was too short to measure any noticeable change. This was also true for Pipelines D and E, and furthermore, most of fields for these two pipelines had been harvested at the time of the trials.

**Table 3.12 Mean (n = 4) gravimetric soil moisture content at Pipeline A Site 4 field in July 2016.**

Soil layer (cm)	Moisture content — July 4 (%) <sup>z</sup>	Moisture content — July 7 (%) <sup>z</sup>	Paired t-test
0–30	20.9 ± 5.6	19.9 ± 5.0	ns <sup>y</sup>
30–60	21.2 ± 1.3	18.8 ± 3.1	ns
60–90	21.2 ± 2.8	22.1 ± 4.2	ns
90–120	22.5 ± 2.2	22.0 ± 3.1	ns
0–120	21.5 ± 2.1	20.7 ± 2.5	ns

<sup>z</sup> Expressed on a dry-weight basis.

<sup>y</sup> ns = not significant ( $p < 0.05$ ).

### 3.3.6 Plant Tissue

There was no significant effect ( $p < 0.05$ ) caused by the application of KCl-treated water on the nutrient content of the alfalfa crop at Site 3, Pipeline C (Table 3.13). The concern with the application of  $K^+$  to a crop used for livestock feed is the possibility of causing grass tetany (or hypomagnesemia), which is the result of low  $Mg^{2+}$  content in blood. High levels of  $K^+$  in feed can reduce the absorption of  $Mg^{2+}$  by cattle, and alfalfa can accumulate high levels of  $K^+$  (Marx 2004). The mean K:(Mg+Ca) ratio in the control and treatment alfalfa samples was  $1.6 \pm 0.2$  and  $1.8 \pm 0.3$ , respectively. A feed ration should have a K:(Mg+Ca) ratio less than 2.2 (Marx 2004). Therefore, a one-time application of KCl-treated water did not affect the nutrient quality of the alfalfa crop under the conditions of this trial. This is not surprising as the  $K^+$  concentration in the 0- to 15-cm layer increased by only 6% (Table 3.11). Plus, the time between KCl application and tissue sampling was only 8 d, and this may not have been enough time for plant uptake.

**Table 3.13 Mean (n = 10) total elemental content of alfalfa tissue collected at Pipeline C Site 3 in June 2017.**

Treatment	N	P	K	S	Ca	Mg	Zn	B	Cu	Fe	Mn
	----- (g kg <sup>-1</sup> ) -----						----- (mg kg <sup>-1</sup> ) -----				
Control	25.4	1.4	20.0	2.7	9.7	3.1	9.22	32.0	7.39	67.3	16.4
KCl <sup>z</sup>	25.1	1.4	21.0	2.8	9.9	3.1	8.70	32.0	6.06	68.5	17.5
	ns <sup>y</sup>	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

<sup>z</sup> KCl-treated water was applied on June 21, 2017 and the crop samples collected on June 29, 2017.

<sup>y</sup> ns = not significant ( $p < 0.05$ ). The Wilcoxon Rank Sum Test was used for the Zn and Cu and the Student's t-test was used for the other parameters.

### 3.3.7 Considerations for In-field Irrigation Systems

This study focused on the treatment of irrigation district pipelines using KCl-treated water. The ability to fill large pipelines with treated water and then close the pipelines to allow enough exposure time is likely key to an effective method of killing mussels and minimizing treatment costs. Continuous flow with treated water beyond a single pipeline volume would greatly increase the amount of potash used and the cost of treatment.

While KCl-treated water can be held in district pipelines and producer-owned service pipelines, this is not the case for aboveground pivot systems, which are the most common irrigation systems used in Alberta. About 84% of the irrigated land within the 13 districts is irrigated with centre-pivot systems (GoA 2018a). During the pipeline trials, after KCl-treated water reached the pivot systems, the pivots were turned off and the treated water in the pivots drained through the nozzles by gravity emptying the aboveground pipe. The exposure of the pivot systems to KCl-treated water was relatively short. Based on the times reported in Appendix 7.8, exposure ranged from less than 10 min to more than 3.8 h, with a mean of 1.7 h among 20 irrigation systems. As indicated in Subsection 3.3.2, an exposure time of 5 to 6 d with  $100 \text{ mg L}^{-1} K^+$  may be required to achieve 100% mortality under Alberta conditions.

If invasive mussels should become attached inside centre pivots, long-term exposure to  $K^+$  would require continuous flow of KCl-treated water through the system for several days. This can only occur when the district pipelines are not closed and being treated. When the district pipelines are not being treated and are supplying regular water, individual pivots could be treated with KCl using fertigation technology. This would also apply to irrigation systems directly supplied from canals and not by district pipelines. Fertigation equipment would have to deliver consistently accurate amounts of KCl water, which may not always be the case, as discovered in the small-plot study (Subsection 4.2.3). Also, accurate flow values of pivots would need to be measured.

However, continuous water flow through pivots with KCl-treated water may not be practical or cost effective. For example, the pivot system supplied by Pipeline A had a measured flow of  $58 \text{ L s}^{-1}$ . At this rate, the total volume of water through the pivot would be 30,067,200 L, if operated continuously for 6 d. To treat this amount of water with  $100 \text{ mg L}^{-1} K^+$ , would require about 7690 kg of potash. At  $\$550 \text{ Mg}^{-1}$ , which was the price of bulk potash fertilizer at the time of the trials, it would cost more than  $\$4000$  just for the potash to treat the pivot once. The cost of obtaining dissolved KCl or employing custom applicators would likely cost more. Fertigation is fairly common in southern Alberta (King 2017), however, some irrigators may need to purchase fertigation equipment if they choose to treat their own systems. Also, operating a pivot continuously for 5 to 6 d does occur, but is not typical, depending on crop-water demand. And operating for this length of time, a pivot would travel around a field two to six times (AARD 2013), depending on the speed of the pivot. The application of the KCl-treated water volume in the above example would result in an application of  $74 \text{ kg ha}^{-1} K^+$  if applied evenly on a 40.5 ha field, which was the size of the field at Pipeline A. This would result in higher application rates of  $K^+$  during a single treatment than observed during the pipeline trials, and the whole field would receive KCl rather than just a small portion.

The risk of invasive mussels becoming established within pivot systems may be less than in underground pipelines, which are generally full of water throughout the irrigation season. In contrast, pivots are frequently drained of water as they are turned on and off, and can remain empty for extended periods of time, such as during periods of extended precipitation and outside of the irrigation season. During sunny, summer days, the temperature inside pivot pipes, when empty, likely can become quite high. A temperature of  $28^\circ \text{ C}$  can cause significant mortality, and  $32$  to  $35^\circ \text{ C}$  is considered lethal for invasive mussels (Benson et al. 2018b). Also, irrigation systems would experience sub-zero temperatures during winter, and any live mussels would be killed by freezing.

One concern often expressed is the issue of dislodged shells after mussels die in pipelines and potentially plugging irrigation systems and nozzles. Potential solutions have not been tested in Alberta. Physically cleaning or replacing nozzles may be one option. Another option is to use screens at the point where water enters irrigation systems. Pivots in Alberta typically have screens installed, and whether existing screens can accommodate shell material would have to be assessed. Frequent cleaning may be required depending on the concentration and size of shell material in the water.

## 4 Small-plot Study

### 4.1 Introduction

For the pipeline study trials, KCl-treated water was only applied once to each field. However, it is anticipated that in real-world scenarios, KCl will likely be applied more than once per year and applied annually to ensure pipelines remain free of invasive mussels. The purpose of the 2-yr (2016–2017) small-plot study was to determine the effects of repeated application of KCl-treated irrigation water on soil chemistry and crop quality.

### 4.2 Methods

#### 4.2.1 Study Site

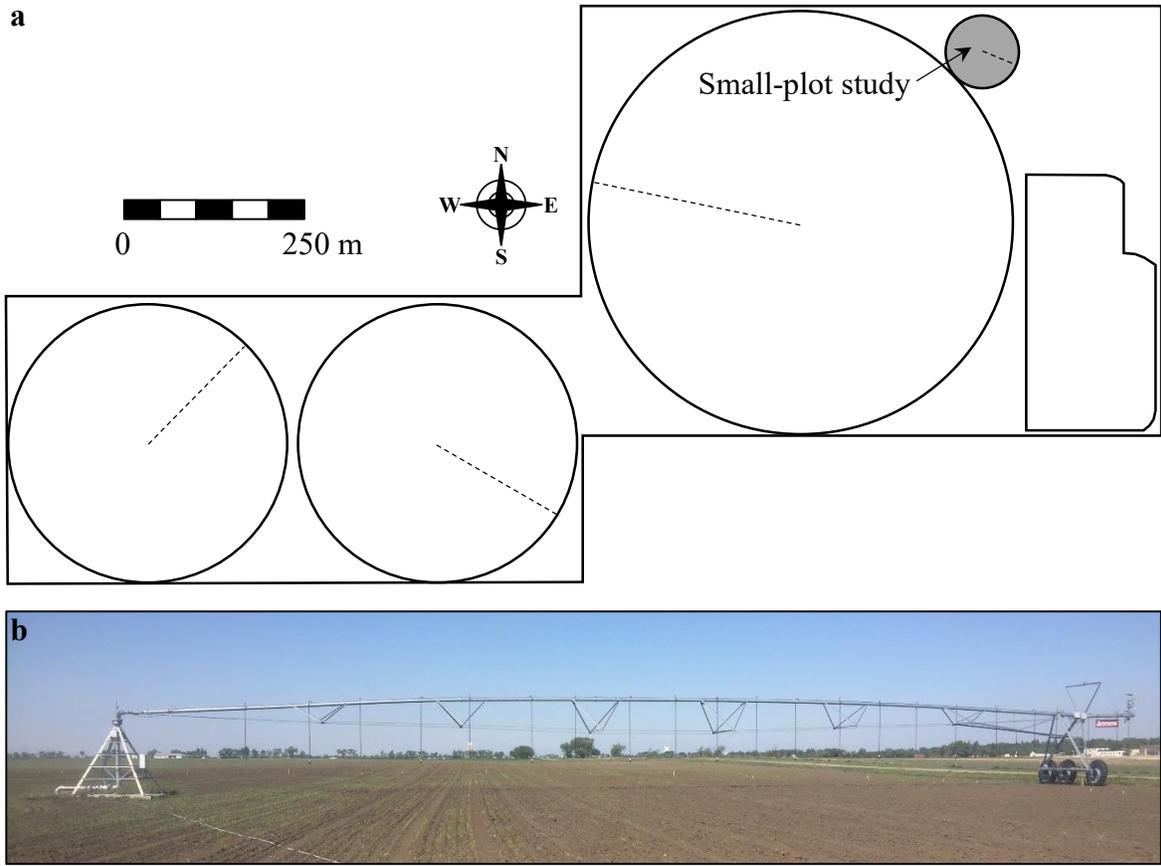
The study was carried out at the Alberta Agriculture and Forestry Irrigation Technology Centre (NE of LSD 15-35-8-21 W4; 49.690172° latitude, -112.737494° longitude) east of Lethbridge, Alberta, Canada (Figure 4.1a). The 0.74-ha circular field had a previously installed 55-m long single-span, centre-pivot system (Zimmatic®, Lindsay™ Corporation, Omaha, Nebraska, United States) (Figure 4.1b). The total pipe volume of the pivot was 1063 L. The pivot span had 23 drop tubes and two end guns (Figure 4.2), and the end guns were not used when the treatments were applied. The pivot discharge was measured at 301 L min<sup>-1</sup> with the end guns turned off. The pivot was supplied with water by an underground water supply pipeline.

The site was in the Mixedgrass Natural Subregion. Soil at the site was an Orthic Dark Brown Chernozem with a LET5/U11 soil landscape model designation (Alberta Soil Information Centre 2018; Polygon 5865). The dominant soil series (80%) was Lethbridge with Coaldale as a significant (20%) soil series. The Lethbridge soil series has a medium textured sediment loam, silt loam, and very fine sandy loam parent material deposited by aeolian and fluvial processes. The Coaldale soil series has a fine textured clay, silty clay, and sandy clay fluvial deposited parent material. The landscape model is undulating low relief.

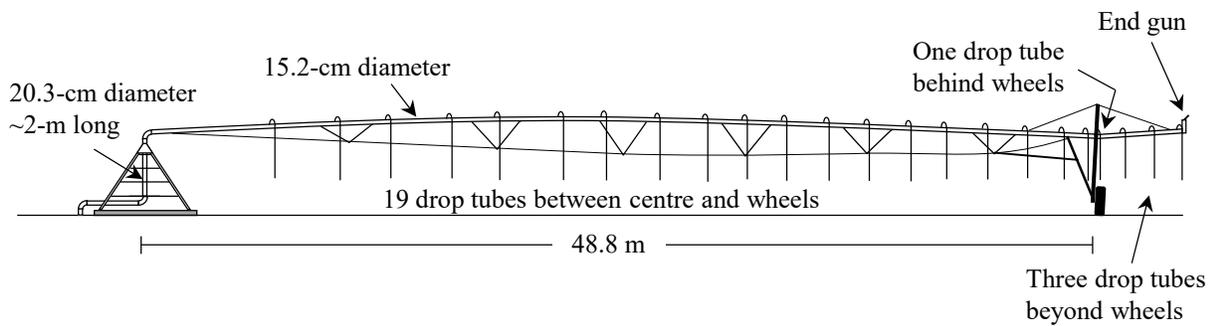
#### 4.2.2 Experimental Design

The experiment was a randomized block design of 12 plots, consisting of three treatments and four replicates (Figure 4.3). The treatments were three application rates of K<sup>+</sup> in irrigation water: 0, 100, 500 mg L<sup>-1</sup> (0T, 100T, and 500T, respectively). In 2016, all three treatments were applied. Based on the results from Pipeline A, it was decided that 500T was not realistic in terms of expected loads of KCl that would be applied to fields. Therefore, in 2017, only untreated irrigation water was applied to the 500T plots. This provided an opportunity to study the fate of residual K<sup>+</sup> and Cl<sup>-</sup> from the 2016 applications.

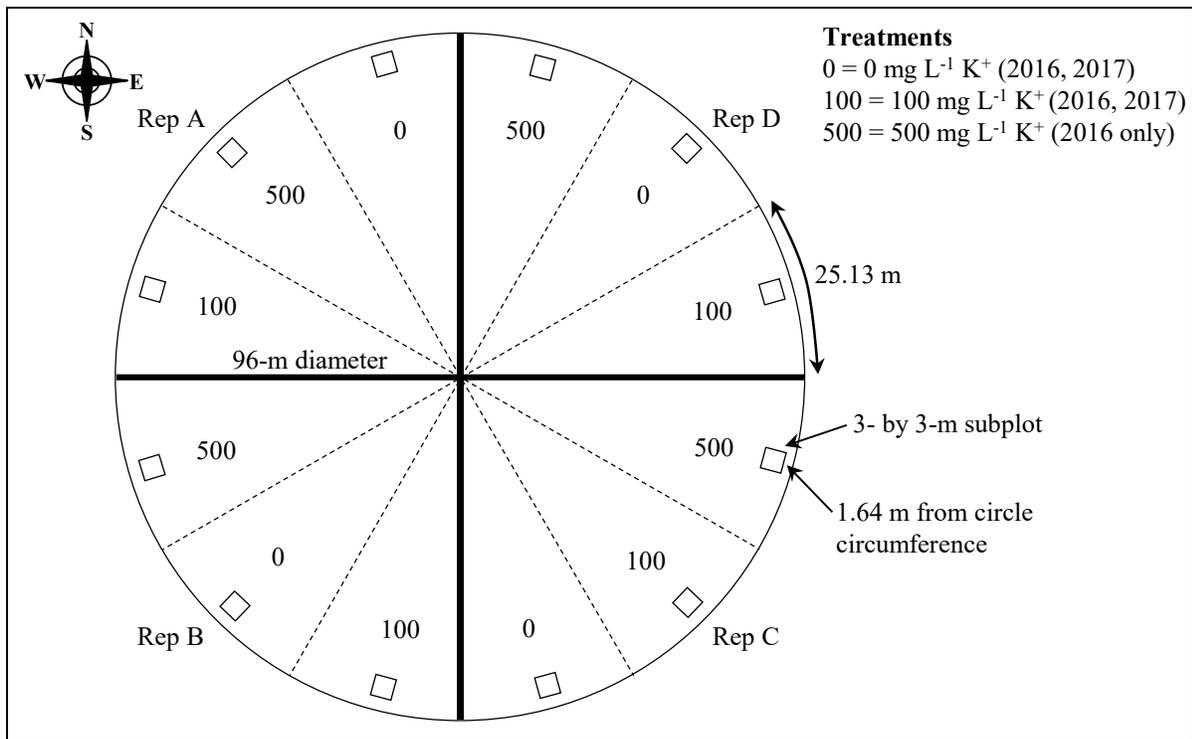
The 12 plots were wedge-shaped, with a maximum width of about 25 m at the perimeter of the field (Figure 4.3). A 3- by 3-m subplot was located at the centre and near the outer perimeter of each plot. The distance between subplots was large enough so the treatment concentration in the irrigation water could change before travelling over the next subplot. Soil and plant samples were collected from the subplots.



**Figure 4.1** Location of the small-plot study at (a) the Irrigation Technology Centre near Lethbridge, Alberta, and (b) the single-span, centre-pivot system at the plot site.



**Figure 4.2** Schematic of the centre-pivot system.



**Figure 4.3 Experimental design of the small-plot study.**

#### 4.2.3 Field Activities

In 2015, a sugar beet crop was grown at the site. After the sugar beet crop was harvested in 2015, the site was disked and spiked in the fall (Table 4.1). In spring 2016, the plot area was prepared using a cultivator with a harrow attachment and tilled to a depth of about 12 cm in April followed by vertical tillage (Table 4.1).

In both years (2016 and 2017), six-row, semi-dwarf barley (*Hordeum vulgare L.* var. Amisk) was seeded at the site (Table 4.1). A blend of nitrogen and phosphorus fertilizer was applied with the seed. Weed control was carried using commercial herbicides. Untreated irrigation water (i.e., regular irrigation) was applied to the plots three times in 2016 and twice in 2017, with about 25.4 mm applied per application. On June 23, 2016, only the Replicate B plots received irrigation water.

The entire barley crop was swathed in late August, and then combined in early September 2016. A total grain yield of about 6100 kg was harvested from the plot area. In 2017, the crop was swathed and combined in late August.

**Table 4.1 Field tasks carried out at the small-plot study in 2016 and 2017.**

Date	Field activity
<i>2016 crop year</i>	
Oct. 26–28, 2015	Tilled (disked and spiked)
Apr. 13, 2016	Tilled (cultivator with harrows)
Apr. 18, 2016	Tilled (vertical tilled with packers)
Apr. 29, 2016	Seeded barley <sup>z</sup>
May 27, 2016	Subplots soil sampled <sup>y</sup>
May 31, 2016	Herbicide application (tank mix of Axial <sup>®</sup> and Enforcer <sup>®</sup> M) <sup>x</sup>
June 8, 2016	Irrigated all plots (25.4 mm applied)
June 23, 2016	Irrigated Replicate B (25.4 mm applied)
July 8, 2016	Irrigated all plots (25.4 mm applied)
Aug. 16, 2016	Irrigated all plots (25.4 mm applied)
Aug. 5, 2016	Irrigated all plots (treatments applied)
Aug. 16, 2016	Irrigated all plots (treatments applied)
Aug. 31, 2016	Crop swathed
Sep. 6, 2016	Crop combined
Sep. 16, 2016	Irrigated all plots (treatments applied)
Sep. 20, 2016	Soil samples collected from subplots
Sep. 28, 2016	Herbicide application (tank mix of Aim <sup>®</sup> , Koril <sup>®</sup> , and Roundup <sup>®</sup> ) <sup>w</sup>
Nov. 10, 2016	Tilled (vertical tilled with packers)
<i>2017 crop year</i>	
Mar. 3, 2017	Tilled (vertical tilled)
May 12, 2017	Pre-season application of glyphosate (Roundup WeatherMIX <sup>®</sup> ) <sup>y</sup>
May 15, 2017	Seeded barley <sup>u</sup>
June 12, 2017	Herbicide application (tank mix of Axial <sup>®</sup> and Enforcer <sup>®</sup> M) <sup>x</sup>
June 23, 2017	Irrigated all plots (25.4 mm applied)
July 7, 2017	Irrigated all plots (25.4 mm applied)
July 11, 2017	Irrigated all plots (treatments applied)
July 17, 2017	Irrigated all plots (treatments applied)
July 20, 2017	Irrigated all plots (treatments applied)
July 26, 2017	Plant samples collected from subplots
Aug. 21, 2017	Crop swathed
Aug. 25, 2017	Crop combined
Sep. 27, 2017	Soil samples collected from subplots

<sup>z</sup> Six-row, semi-dwarf barley (*Hordeum vulgare* L. var. Amisk) was used. The seed was treated with Vibrance<sup>®</sup> Quattro fungicide and seeded at a rate of 137 kg ha<sup>-1</sup>, with a row spacing of 17.8 cm. Banded fertilizer blend of 50-20-0 (N-P-K) at a rate of 155 kg ha<sup>-1</sup> product was applied during seeding and about 10 cm below the seed.

<sup>y</sup> The 0- to 2.5-cm soil layer samples were collected on June 2, 2016.

<sup>x</sup> Axial<sup>®</sup> (1235 mL ha<sup>-1</sup>) and Enforcer<sup>®</sup> M (1235 mL ha<sup>-1</sup>), with a tank mixture application of 98.8 L ha<sup>-1</sup>.

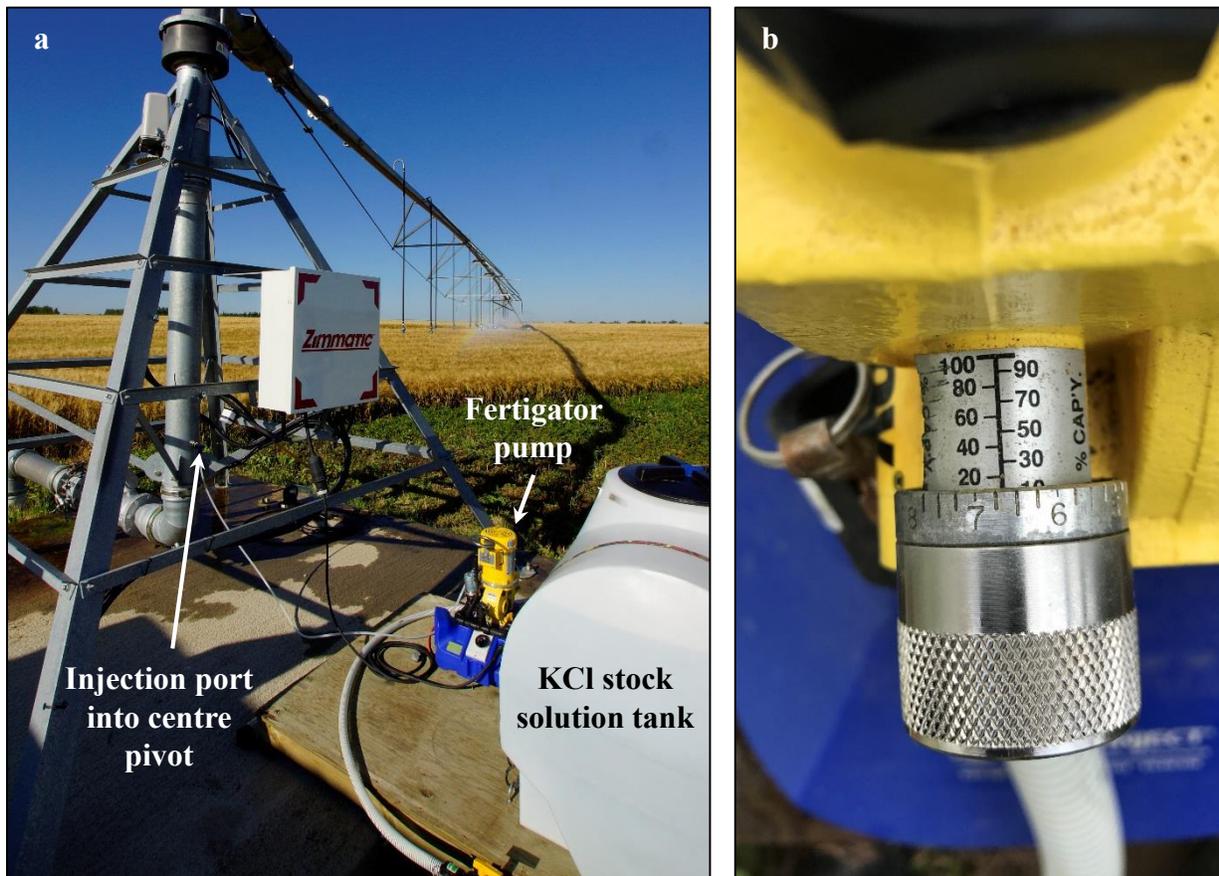
<sup>w</sup> Aim<sup>®</sup> (37 mL ha<sup>-1</sup>), Koril<sup>®</sup> (593 mL ha<sup>-1</sup>), and Roundup<sup>®</sup> (2471 mL ha<sup>-1</sup>), with a tank mixture application of 16.2 L ha<sup>-1</sup>.

<sup>v</sup> Roundup WeatherMIX<sup>®</sup> (1656 mL ha<sup>-1</sup>), with a tank mixture application of 98.8 L ha<sup>-1</sup>.

<sup>u</sup> Amisk variety was used. The seed was treated with Dividend-Vibrance<sup>®</sup> Quattro fungicide and seeded at a rate of 137 kg ha<sup>-1</sup>, with a row spacing of 22.9 cm. Commercial fertilizer nitrogen (40 kg ha<sup>-1</sup> N) and phosphorus (20 ha ac<sup>-1</sup> P) was applied at seeding.

**KCl Application.** A fertigation pump (Milton Roy A Series Metering Pump model MR11X0002) was used to inject KCl stock solution into the centre pivot (Figure 4.4a). The KCl stock solution was held in a 700-L storage tank at the field site. The concentration of K<sup>+</sup> in the

prepared potash stock solution ranged from 103,022 to 108,642 mg L<sup>-1</sup> among the six application dates. For the control treatment, the fertigator was turned off. For the other two treatments, the fertigator control knob (Figure 4.4b) was adjusted to inject sufficient KCl stock solution to provide a 100 mg L<sup>-1</sup> (2016 and 2017) or 500 mg L<sup>-1</sup> (2016) K<sup>+</sup> concentration in the centre pivot and delivered through the nozzles. The injection rates were determined based on a flow of 301 L min<sup>-1</sup> through the pivot system and the actual K<sup>+</sup> concentration in the stock solution for a given application date. The actual K<sup>+</sup> concentrations achieved in the irrigation water were determined by water sampling and analyzing the samples in the laboratory. The application concentration for 100T ranged from 70 to 182 mg L<sup>-1</sup> with a mean of 105 mg L<sup>-1</sup> (Appendix 7.10). The application concentration of K<sup>+</sup> for 500T ranged from 439 to 568 mg L<sup>-1</sup> with a mean of 485 mg L<sup>-1</sup> in 2016. The pivot was operated in a clockwise direction. For each application of treatments, the last plot irrigated was a control plot to ensure the pivot was purged of KCl-treated water before turning off the pivot.



**Figure 4.4 Images showing the (a) centre pivot and fertigator pump, and (b) control knob on the fertigator pump.**

It was discovered that the oil level in the pump must be maintained at full in order for the fertigator to work properly. It was also discovered that the control knob (Figure 4.4b) was not very accurate in terms of reproducing a set injection volume relative to the scale on the knob

(i.e., too coarse). Therefore, as the pivot moved from one plot to the next and the fertigator was re-adjusted to either the 100T or 500T treatment, water samples were collected from the first drop-down tube to check the KCl concentration (by measuring EC) and adjustments were made as needed before the pivot reached the next subplot.

The treatments were applied three times in 2016 (August 5, August 16, and September 16) and three times in 2017 (July 11, 17, and 20). It took about 7 h to apply one set of treatments, i.e., for the pivot to travel around the site once. The pivot was set to apply 25.4 mm of water. To determine the actual amount of water applied, a manual rain gauge was placed in each of the subplots (Figure 4.5a). The amount applied ranged from 12 to 20 mm, with an overall mean value ( $n = 68$ ) of 14.5 mm per application (Appendix 7.10).

**Water Sampling and In-field Analysis.** The drop tube nearest to the centre of the pivot was modified so that water samples could be collected (Figure 4.5b). Water samples were obtained while the pivot was operating and progressing clockwise around the site. One water sample was obtained from each plot when the pivot was positioned midpoint over the subplot. Samples were collected in 500-mL polyethylene bottles. A portion of each sample was measured in the field using an EC meter to determine the  $K^+$  concentration. Either a WTW Multi3500i EC meter or an Oakton<sup>®</sup> EcoTestr were used to measure EC (Figure 3.15a,c). Standard curve equations were developed and used to convert EC values to  $K^+$  concentration.

The remainder of each sample was poured into a lab sample bottle (after rinsing three times) and placed on ice in a cooler, and transported to the lab at the Lethbridge Agriculture Centre.



**Figure 4.5** The small-plot site showing (a) a rain gauge and (b) water sampling.

**Soil Sampling.** Soil samples were collected twice from each of the subplots in 2016: once in May (pre-treatments) and a second time in September (post-treatments) (Table 4.1). In each subplot, five cores were collected in three increment layers (0–15 cm, 15–30 cm, 30–60 cm) by hand using a Dutch auger, and a composite sample was prepared for each layer. One soil core sample location was at the centre of the subplot while the remaining four were radially distributed around the centre. A topsoil sample (0–2.5 cm) was also obtained using a rectangular steel frame and hand shovel. Soil samples were air-dried and ground (2-mm sieve).

The subplots were also soil sampled in September 2017 (Table 4.1). Two core samples were collected in increments of 0 to 15, 15 to 30, 30 to 60, 60 to 90, 90 to 120, and 120 to 150 cm using a truck-mounted, hydraulic-powered core tube. Composite samples were prepared for each soil layer. In addition, a single sample from the 0- to 2.5-cm soil layer was collected as described for the 2016 samples. The soil samples were air dried and ground (2-mm sieve).

**Plant Sampling.** Plant samples were collected at the silage or green-feed stage (about 65% moisture) on July 26, 2017. At each subplot, a 0.25-m<sup>2</sup> area was harvested by hand, and all of the above ground material was placed in a perforated, paper bag. These samples were used to determine dry-matter yield. A second, smaller sample was collected for plant-tissue analysis. All samples were placed in a drying room at 35° C for 2 d. The 0.25-m<sup>2</sup> samples were weighed after drying.

Crop samples were not collected in 2016 because of the late application of the treatments (Table 4.1).

#### 4.2.4 Laboratory Analysis

Water and soil samples were analyzed by the AAF laboratory in Lethbridge. Water samples were analyzed for K<sup>+</sup>, Cl<sup>-</sup>, and EC as described in Section 3.2.4.

Soil samples were analyzed for extractable K<sup>+</sup>, extractable Cl<sup>-</sup>, and EC as described in Section 3.2.5. In addition, the soil samples collected in spring 2016 were analyzed for extractable ammonium nitrogen (NH<sub>4</sub>-N), extractable nitrate nitrogen (NO<sub>3</sub>-N), and extractable phosphate phosphorus (PO<sub>4</sub>-P). Extractable NH<sub>4</sub>-N and NO<sub>3</sub>-N were determined using the 2-M KCl extraction (1:10 soil-extractant ratio) method and the NO<sub>3</sub>-N and NH<sub>4</sub>-N in the filtrates were measured on an autoanalyzer (Maynard and Kalra 1993; methods 4.2 and 4.3). Extractable PO<sub>4</sub>-P was determined using the modified Kelowna extraction method (1:10 soil-extractant ratio) (Qian et al. 1994) and the PO<sub>4</sub>-P in the filtrates was measured using the molybdate/antimony/ascorbic acid colorimetric method (Technicon Industrial Systems 1987).

The 2017 plant samples were analyzed for the content of total K, N, P, S, Ca, Mg, Zn, B, Cu, Fe, and Mn as described in Section 3.2.6.

#### 4.2.5 Weather Data

Total precipitation and average daily temperature data for the growing seasons were obtained from the Alberta Climate Information Service (AAF 2018). Data were obtained for the

Lethbridge Demo Farm Irrigation Management Climate Information Network station, which was about 660 m southwest from the plot site.

#### **4.2.6 Statistical Analysis**

Soil chemistry, crop yield, and crop tissue means were compared ( $p < 0.05$ ) using the SAS software Version 9.4 for Windows (SAS Institute Inc., Cary, North Carolina, United States).

The data were first checked for assumptions of normality of residuals, homogeneity of variances, and non-additivity of main effects. The normality of residuals was checked using PROC UNIVARIATE in SAS software using the Shapiro-Wilk test. Homogeneity of variances was checked using Levene's test in PROC GLM. The Tukey's one degree of freedom test with PROC GLM was used to test for non-additivity.

Blocking (i.e., replicates) in the experimental design was considered a fixed effect. For data that met the above assumptions, PROC GLM (General Linearized Model) was used for the analysis of variance, and the Tukey's studentized range test in the PROC MEANS statement was used as the ad hoc test. For data that did not meet one or more of the assumptions, the non-parametric Friedman's test for two-way analysis of variance was used and the calculated ranked values assessed using PROC GLM and Tukey's test.

### **4.3 Results and Discussion**

#### **4.3.1 Weather**

Total precipitation during the growing season (April to September) in 2016 was 285 mm, which was only slightly less than the long-term mean (Table 4.2). However in 2016, June was much drier and July was much wetter compared to the long-term means. Mean daily temperature per month in 2016 was generally similar to the long-term means, except for April, which was above the long-term mean. In 2017, precipitation was less than the long-term means, particularly from July to September. The total precipitation during the 6-mo growing season was 47% less than the long-term mean. The mean daily temperature from April to September in 2017 was consistently higher compared to the long-term values.

#### **4.3.2 Pre-treatment Soil Characteristics**

The mean soil chemistry values of plots assigned with the same treatment were reasonably consistent among the three intended treatments for each soil layer (Table 4.3). This suggests that the soil chemical properties were reasonably uniform at the site prior to the start of the study.

In terms of soil chemistry at the site, pH and EC were similar with depth (Table 4.3). The EC values indicate the soil was non-saline. The concentration of  $\text{Cl}^-$  was considered typical, with an overall average concentration of  $8 \text{ mg kg}^{-1}$  for the 0- to 60-cm layer. Mengel et al. (2009) reported that values  $>6 \text{ mg kg}^{-1}$  were considered high in Kansas soils. In Canada, most soils have 6 to  $15 \text{ mg kg}^{-1} \text{ Cl}^-$ , with 8 to  $10 \text{ mg kg}^{-1}$  being typical (A & L Laboratories 2008). It is interesting that the concentration of  $\text{Cl}^-$  in the 0- to 2.5-cm layer was much lower than in the 0-

to 15-cm layer. This likely reflects the high mobility of  $\text{Cl}^-$ , which can leach readily from the shallow soil layer. Extractable  $\text{NO}_3\text{-N}$  concentration was high in the soil. Averaging the  $\text{NO}_3\text{-N}$  concentration for the three soil layers in Table 4.2 and assuming a soil bulk density of  $1.2 \text{ g cm}^{-3}$ , the amount of extractable  $\text{NO}_3\text{-N}$  in the 0- to 60-cm soil layer was about  $248 \text{ kg ha}^{-1}$ . Based on McKenzie et al. (2000), nitrogen fertilizer was not needed for irrigated barley silage. Similarly, plant available  $\text{PO}_4\text{-P}$  and  $\text{K}^+$  were estimated at 57 and  $494 \text{ kg ha}^{-1}$ , respectively, in the 0- to 15-cm soil layer. These levels suggest that 17 to  $22 \text{ kg ha}^{-1}$  of P fertilizer and no  $\text{K}^+$  fertilizer were required for irrigated grain or oilseed production (McKenzie et al. 2013).

**Table 4.2 Growing season precipitation and temperature data for the potash small-plot study in 2016 and 2017.**

Month	2016 growing season <sup>z</sup>		2017 growing season <sup>z</sup>		Long-term means <sup>z,y</sup>	
	Precipitation (mm)	Mean daily temperature (°C)	Precipitation (mm)	Mean daily temperature (°C)	Precipitation (mm)	Mean daily temperature (°C)
Apr	17.3	9.3	27.7	6.3	34.9	5.5
May	68.4	11.6	45.1	13.6	52.3	10.9
June	23.0	16.9	68.3	16.5	81.1	15.2
July	105.5	17.6	4.7	20.5	42.4	18.1
Aug	46.1	17.1	7.9	18.4	39.9	17.6
Sep	24.3	12.6	1.8	13.4	40.3	12.6
Total	284.6		155.5		290.9	

<sup>z</sup> Lethbridge Demo Farm Irrigation Management Climate Information Network Station at  $49.6867^\circ \text{N}$  latitude,  $112.7449^\circ \text{W}$  longitude, 906.87 m elevation (AAF 2018).

<sup>y</sup> Long-term means includes the period from 1961 to 2015, based on the Alberta Climate Database (AAF 2018).

### 4.3.3 Application of KCl

Small amounts of  $\text{K}^+$  and  $\text{Cl}^-$  were applied through the control treatment because of the background concentration in the source irrigation water. All water samples from the control plots were less than the detection limit for both ions (Appendix 7.10), and it was estimated that less than  $2 \text{ kg ha}^{-1}$  of  $\text{K}^+$  and less than  $5 \text{ kg ha}^{-1}$   $\text{Cl}^-$  were applied from the six applications. These amounts represented only a small proportion (1 to 5%) of the cumulative loads applied to the 100T and 500T plots. The mean cumulative loads of  $\text{K}^+$  and  $\text{Cl}^-$  applied to the plots was 92 and  $88 \text{ kg ha}^{-1}$ , respectively, for 100T (Table 4.4). For 500T, the mean cumulative loads were  $210 \text{ kg ha}^{-1}$   $\text{K}^+$  and  $198 \text{ kg ha}^{-1}$   $\text{Cl}^-$ . There was some variation among the replicates per treatment because of the variation in the water applied and the actual concentrations of  $\text{K}^+$  and  $\text{Cl}^-$  in the water (Appendix 7.10).

In comparison, a typical grain yield of barley ( $4.3 \text{ Mg ha}^{-1}$ ) may remove about  $26 \text{ kg ha}^{-1}$   $\text{K}^+$  (Canadian Fertilizer Institute 2001), which is less than the total amounts applied in the two  $\text{K}^+$  treatments. However, a typical silage yield of barley ( $10 \text{ Mg ha}^{-1}$  dry weight) may remove about  $123 \text{ kg ha}^{-1}$   $\text{K}^+$  (Canadian Fertilizer Institute 2001), which is 34% more than the amount of  $\text{K}^+$  applied in the 100T treatment, but still less by 38% than the total amount applied in the 500T treatment.

**Table 4.3 Pre-treatment mean values (n = 3) of soil chemical properties according to the intended treatment.**

Intended treatment <sup>z</sup>	pH	EC (dS m <sup>-1</sup> )	Cl <sup>-</sup>	NO <sub>3</sub> -N	NH <sub>4</sub> -N	PO <sub>4</sub> -P	K <sup>+</sup>
			----- (mg kg <sup>-1</sup> ) -----				
<i>0–2.5 cm soil layer</i>							
0T	7.5	0.6	2.6	10.7	4.5	43.3	366
100T	7.4	0.7	3.2	15.0	5.1	37.5	372
500T	7.5	0.7	2.6	15.4	4.6	43.2	367
<i>0–15 cm soil layer</i>							
0T	7.4	1.3	9.8	45.8	4.0	39.8	316
100T	7.3	1.1	11.7	40.7	4.5	32.1	313
500T	7.4	1.3	13.6	46.8	4.8	35.3	295
<i>15–30 cm soil layer</i>							
0T	7.4	1.4	12.4	57.3	3.3	19.3	167
100T	7.3	1.4	17.5	53.4	3.5	11.8	172
500T	7.4	1.3	14.9	54.7	3.7	17.3	187
<i>30–60 cm soil layer</i>							
0T	7.6	1.5	4.0	18.2	3.0	9.7	156
100T	7.6	1.3	6.7	20.7	2.7	6.6	157
500T	7.6	1.2	3.6	18.2	3.1	9.0	161

<sup>z</sup> 0T = 0 mg L<sup>-1</sup> K<sup>+</sup>, 100T = 100 mg L<sup>-1</sup> K<sup>+</sup>, 500T = 500 mg L<sup>-1</sup> K<sup>+</sup>.

Potash is most commonly used as a crop fertilizer. In a soil with a moderate deficient level of K<sup>+</sup> (168–280 kg ha<sup>-1</sup> K<sup>+</sup> in 0–15 cm of soil), a typical fertilizer application may range from 14 to 88 kg ha<sup>-1</sup> K<sup>+</sup>, depending on the soil and annual crop type (McKenzie and Pauly 2013). Another source of K<sup>+</sup> often applied to cropland is in the form of livestock manure. For example, a single application of 65 Mg ha<sup>-1</sup> of wet (about 50% water) beef manure may apply 700 kg ha<sup>-1</sup> K<sup>+</sup> (Subsection 1.6.2), which is considerably more than what was applied during this study (i.e., <210 mg ha<sup>-1</sup>; Table 4.4).

Similarly, the average total amount of Cl<sup>-</sup> applied to the plots after six applications was 88 kg ha<sup>-1</sup> for the 100T treatment and 198 kg ha<sup>-1</sup> for the 500T treatment (Table 4.4). Even though Cl<sup>-</sup> is considered a micronutrient, crops can take up substantial amounts of Cl<sup>-</sup>. However, the amount of Cl<sup>-</sup> removed, i.e., through harvest, is usually relatively small. For example, a Cl<sup>-</sup> concentration of 0.43 g kg<sup>-1</sup> in wheat grain reported by Fixen (1993)<sup>1</sup> and a crop yield of 2500 kg ha<sup>-1</sup> would remove about 1.1 kg ha<sup>-1</sup> Cl<sup>-</sup>. However, based on Cl<sup>-</sup> content of 0.9 to 2.7 mg g<sup>-1</sup> (dry

<sup>1</sup> The original reference reported 0.026 pounds of chloride per bushel for wheat grain. It was assumed a bushel of wheat weighed 60 pounds to make the conversion to grams of chloride per kilogram.

matter) (Xu et al. 2000), alfalfa with a dry-matter yield of 11 Mg ha<sup>-1</sup> may remove 10 to 30 kg ha<sup>-1</sup> Cl<sup>-</sup>. And barley silage (10 Mg ha<sup>-1</sup> dry weight) may remove about 40 kg ha<sup>-1</sup> Cl<sup>-</sup>, assuming a tissue concentration of 4 mg g<sup>-1</sup> (dry matter) (Xu et al. 2000). In comparison to other additions of Cl<sup>-</sup> to soil, the range of 14 to 88 kg ha<sup>-1</sup> K<sup>+</sup> fertilizer as potash, reported above, would also include the application of 13 to 80 kg ha<sup>-1</sup> Cl<sup>-</sup>.

**Table 4.4 Mean (n = 4) potassium and chloride cumulative loads applied at the small-plot study in 2016 and 2017.**

Application date	Potassium load applied			Chloride load applied		
	0T <sup>z</sup>	100T	500T	0T	100T	500T
	----- (kg ha <sup>-1</sup> ) -----			----- (kg ha <sup>-1</sup> ) -----		
Aug 5, 2016	0.3	12.4	66.4	0.7	12.1	61.3
Aug 16, 2016	0.3	18.0	73.3	0.7	17.0	69.7
Sep 16, 2016	0.3	14.6	69.5	0.7	13.7	65.1
July 11, 2017	0.3	16.8	0.3	0.7	16.4	0.7
July 17, 2017	0.3	14.9	0.3	0.7	14.4	0.7
July 20, 2017	0.3	15.4	0.3	0.8	14.8	0.8
Total <sup>y</sup>	1.7	92.0	210.0	4.3	88.3	198.3

<sup>z</sup> Treatments: 0T = 0 mg L<sup>-1</sup> K<sup>+</sup>, 100T = 100 mg L<sup>-1</sup> K<sup>+</sup>, 500T = 500 mg L<sup>-1</sup> K<sup>+</sup>.

<sup>y</sup> Some totals may not add exactly due to rounding.

#### 4.3.4 Effects of KCl Application on Soil Chemistry

The application of KCl-treated water in 2016 had minimal effect on the concentration of extractable K<sup>+</sup> in soil. In the 0- to 2.5-cm layer, K<sup>+</sup> concentration increased with K<sup>+</sup> concentration in the irrigation water; however, the differences among the treatment means were not statistically significant (Table 4.5). In contrast, Cl<sup>-</sup> concentration was significantly increased in the top 2.5-cm layer with the 500T plots containing seven times more Cl<sup>-</sup> compared to the 0T plots. Significant increases in Cl<sup>-</sup> concentration also occurred in the 0- to 15-cm and 15- to 30-cm layers, suggesting leaching of Cl<sup>-</sup>. The application of KCl-treated water to the 500T plots also caused a significant increase in EC in the 0- to 2.5-cm and 0- to 15-cm soil layers in 2016.

As pointed out for the pipeline study, the amount of K<sup>+</sup> applied to soil was relatively small compared to the existing K<sup>+</sup> content in the soil. Whereas, the amount of Cl<sup>-</sup> added was relatively large compared to the existing Cl<sup>-</sup> content in soil, and this resulted in the ability to detect significant increases of Cl<sup>-</sup>.

In 2017, the concentration of K<sup>+</sup> was still highest in the 0- to 2.5-cm soil layer for 500T, followed by 100T, and then 0T; however, the means were not significantly different (Table 4.6). The higher level in 500T is not surprising, as the 2-yr of 100T applications (45 kg ha<sup>-1</sup> in 2016 and 47 kg ha<sup>-1</sup> in 2017) was less than the amount applied to the 500T plots (about 208 kg ha<sup>-1</sup>) in 2016 (Table 4.4). The 100T values in 2017 were similar to the 2016 values. Even though K<sup>+</sup> was applied in 2017 to 100T, crop removal during 2017 may have resulted in the similar concentrations between the two years.

**Table 4.5 Mean (n = 4) extractable potassium (K<sup>+</sup>), extractable chloride (Cl<sup>-</sup>), and electrical conductivity (EC) in soil at the small-plot site in September 2016.**

Parameter	Soil layer	Treatment <sup>z</sup>		
	(cm)	0T	100T	500T
K <sup>+</sup> (mg kg <sup>-1</sup> )	0–2.5	487 <sup>y</sup>	633	799
	0–15	292	282	310
	15–30	168	181	160
	30–60	142	127	130
	0–60	186	179	183
Cl <sup>-</sup> (mg kg <sup>-1</sup> )	0–2.5	18.8a	56.8b	135b
	0–15	16.3a	29.5a	70.3b
	15–30	6.9a	15.3a	32.2b
	30–60	3.0	4.6	6.0
	0–60	7.3a	13.5a	28.6b
EC (dS m <sup>-1</sup> )	0–2.5	0.70a	1.02a	1.68b
	0–15	0.81a	0.84a	1.10b
	15–30	0.86	0.79	0.97
	30–60	1.49	1.52	1.82
	0–60	1.16	1.17	1.43

<sup>z</sup> Treatments: 0T = 0 mg L<sup>-1</sup> K<sup>+</sup>, 100T = 100 mg L<sup>-1</sup> K<sup>+</sup>, 500T = 500 mg L<sup>-1</sup> K<sup>+</sup>.

<sup>y</sup> Means within the same row with the same letter or no letters are not significantly different ( $p < 0.05$ ).

The K<sup>+</sup> concentration was nearly identical in the 0- to 15-cm layer between the 0T and 100T treatments in 2017 (Table 4.6). In comparison, the concentration was about 39% higher in this soil layer for the 500T plots, reflecting residual carryover from the 2016 applications. Below the 15-cm depth, the concentration of K<sup>+</sup> was similar among the treatments, suggesting that the applied K<sup>+</sup> remained in the 0- to 15-cm layer and did not leach into the soil profile. In fact, much of the added K<sup>+</sup> likely remained in the top few centimetres of soil.

The concentration of Cl<sup>-</sup> in the 0- to 2.5-cm layer was significantly higher for 500T compared to the other two treatments in 2017 (Table 4.6). The mean concentration of Cl<sup>-</sup> for 500T was more than nine times higher than 0T and more than three times higher than 100T in this surface soil layer. Significant differences were also observed in the 0- to 15-cm soil layer, with 500T eight times and 1.6 times higher than 0T and 100T, respectively. The Cl<sup>-</sup> in 500T represents residual carryover from the applications in 2016. However, the Cl<sup>-</sup> concentration in the 0- to 2.5-cm layer decreased from 135 mg kg<sup>-1</sup> in 2016 (Table 5) to 37 mg kg<sup>-1</sup> in 2017. Therefore, the application of regular irrigation water to 500T in 2017 likely caused leaching of the Cl<sup>-</sup>. Crop removal would have also contributed to the decrease. The concentration in the 0- to 15-cm and 15- to 30-cm layers were higher than in the 0- to 2.5-cm layer, also suggesting leaching of Cl<sup>-</sup> deeper into the soil. Though not significantly different from the other two treatments, the 500T plots also had the highest Cl<sup>-</sup> concentration in the 30- to 60-cm soil layer. Below the 60-cm depth, the concentration of Cl<sup>-</sup> was low and similar among the three treatments, signifying that very little, if any Cl<sup>-</sup> leached deeper than 60 cm under the conditions of this study.

**Table 4.6 Mean<sup>z</sup> extractable potassium (K<sup>+</sup>), extractable chloride (Cl<sup>-</sup>), and electrical conductivity (EC) in soil at the small-plot site in September 2017.**

Parameter	Soil layer (cm)	Treatment <sup>y</sup>		
		0T	100T	500T
K <sup>+</sup> (mg kg <sup>-1</sup> )	0–2.5 <sup>x</sup>	505	617	728
	0–15	275	278	383
	15–30	159	138	148
	30–60	149	138	152
	60–90 <sup>w</sup>	166	157	135
	90–120 <sup>w</sup>	179	144	110
	120–150 <sup>w</sup>	189	127	123
	0–150 <sup>w,v</sup>	178	167	156
Cl <sup>-</sup> (mg kg <sup>-1</sup> )	0–2.5	4.1a	12.2b	37.4c
	0–15	8.7a	44.9ab	71.4b
	15–30	14.4a	40.4b	51.9b
	30–60	3.7a	6.9b	13.4b
	60–90 <sup>w</sup>	2.4	3.3	2.5
	90–120 <sup>w</sup>	3.9	4.5	3.2
	120–150 <sup>w</sup>	2.5	5.4	4.3
	0–150 <sup>w,v</sup>	4.1	13.0	14.9
EC (dS m <sup>-1</sup> )	0–2.5	0.78a	0.94ab	1.17b
	0–15	0.65a	0.87ab	1.10b
	15–30	1.21	0.89	0.92
	30–60	1.99	2.15	1.80
	60–90 <sup>w</sup>	3.81	4.51	3.33
	90–120 <sup>w</sup>	2.72	4.75	2.95
	120–150 <sup>w</sup>	2.28	4.19	2.83
	0–150 <sup>w,v</sup>	2.46	2.77	2.64

<sup>z</sup> n = 4, except n = 3 for the control treatment for the 60–90, 90–120, and 120–150 cm soil layers.

<sup>y</sup> Treatments: 0T = 0 mg L<sup>-1</sup> K<sup>+</sup>, 100T = 100 mg L<sup>-1</sup> K<sup>+</sup>, 500T = 500 mg L<sup>-1</sup> K<sup>+</sup>.

<sup>x</sup> Means within the same row with the same letter or no letters are not significantly different ( $p < 0.05$ ).

<sup>w</sup> The three bottom soil layers (60–90, 90–120, and 120–150 cm) were not sampled for the control treatment in Replicate C, and therefore, did not contribute to the total soil depth (0–150 cm) mean values.

<sup>v</sup> Replicate C results were not used for the statistical test for treatment effect.

As in 2016, EC in the 0- to 2.5-cm and 0- to 15-cm soil layers was significantly higher for the 500T plots compared to the 0T plots (Table 4.6). The 500T treatment was also higher than the 100T treatment in 2017; however, the differences were not significant. Electrical conductivity mean values for the 0T and 100T plots were similar between the two years in the 0- to 2.5-cm layer. In contrast, EC decreased from 1.68 dS cm<sup>-1</sup> in 2016 to 1.17 dS m<sup>-1</sup> in 2017, and this may have been caused by leaching with the application of irrigation water in 2017. However, there was no evidence of leaching below the 15-cm depth based on the EC results.

#### 4.3.5 Effects of KCl Application on Crop Yield and Nutrient Content

Even though the dry-matter yield in 2017 was higher (about 18%) for 100T and 500T compared to 0T, the three treatments were not significantly different (Table 4.7).

Nutrient content of plant issue was not significantly different among the treatments for nearly all parameters, except for Cu, which was significantly less for 100T and 500T compared to 0T (Table 4.7). Of particular interest is that the application of  $K^+$  did not cause an increase in the uptake of  $K^+$ , as the tissue concentration was very similar among the treatments.

The reason why Cu concentration in barley tissue significantly decreased as the amount of applied KCl increased, and none of the other plant nutrients were affected, is unknown. It has been shown that the application of macronutrients (e.g.,  $K^+$ ) can affect the availability of micronutrients (e.g., Cu) in soil and the concentration in plants (Fageria 2001; Li et al. 2007). Interactions among nutrients in terms of availability in soil and uptake by plants is complex and depends on a number of factors (Fageria 2001). Li et al. (2007) found that deficiencies in phosphorus or  $K^+$  significantly increased the uptake of Cu by wheat and corn. In a field study, Smith (1975) found that topdressing  $K^+$  decreased Cu concentration in alfalfa. He also reported decreases in N, P, S, Ca, Mg, Na, Zn, and B, all of which were not observed in our study (Table 4.7). In contrast, Li et al. (2007) reported other work that showed the application of N, P, and K fertilizer increased the concentration of Cu and other nutrients in wheat. There are two main categories of nutrient interactions at the root interface or within plants: (1) chemical bonding between ions, and (2) competition for sites of adsorption, absorption, transport, and function on plant root surfaces or within plant tissues among ions with similar characteristics (Fageria 2001).

The mean dry-matter yield among all treatments was  $13.2 \text{ Mg ha}^{-1}$ , and the mean  $K^+$  concentration was  $12.4 \text{ g kg}^{-1}$ . Based on these two values, the crop removal of  $K^+$  was  $166 \text{ kg ha}^{-1}$ . This amount removed by the crop in 2017 was nearly double the total amount of  $K^+$  added to 100T in 2016 and 2017, and 80% of the amount added to 500T in 2016. These results show that repeated applications of KCl-treated irrigation water will likely not cause an accumulation of  $K^+$  in soil, particularly if crops with high  $K^+$  requirements are grown, such as forages. In addition, as the pipeline trials demonstrated, only a small portion of an irrigated field will receive KCl-treated water from a single application. Distributing successive applications throughout a field combined with crop removal is expected to prevent  $K^+$  accumulation in soil.

The K:(Mg+Ca) ratio in the barley tissue was 2.0 for 100T and 500T. In comparison, 0T had a ratio value of 1.8. To prevent the onset of grass tetany in cattle, it is recommended that diets have a K:(Mg+Ca) ratio of less than 2.2 (Marx 2004). Therefore, the application of KCl-treated water did not negatively affect the quality of barley as livestock feed.

**Table 4.7 Mean (n = 4) barley dry-matter yield and plant tissue nutrient content in 2017.**

Parameter	Unit	Treatment <sup>z</sup>		
		0T	100T	500T
Dry-matter yield <sup>y</sup>	Mg ha <sup>-1</sup>	11.8 <sup>x</sup>	14.1	13.8
Total nitrogen	g kg <sup>-1</sup>	19.8	19.7	21.8
Total phosphorus	g kg <sup>-1</sup>	2.0	1.9	2.2
Total potassium	g kg <sup>-1</sup>	11.9	12.8	12.4
Total sulphur	g kg <sup>-1</sup>	2.4	1.9	1.9
Total calcium	g kg <sup>-1</sup>	4.33	4.24	3.92
Total magnesium	g kg <sup>-1</sup>	2.18	2.11	2.12
Total zinc	mg kg <sup>-1</sup>	10.71	10.52	11.05
Total boron	mg kg <sup>-1</sup>	5.4	5.1	5.4
Total copper	mg kg <sup>-1</sup>	3.28a	3.01b	2.75c
Total iron	mg kg <sup>-1</sup>	54.82	48.57	44.51
Total manganese	mg kg <sup>-1</sup>	22.52	19.50	20.71

<sup>z</sup> Treatments: 0T = 0 mg L<sup>-1</sup> K<sup>+</sup>, 100T = 100 mg L<sup>-1</sup> K<sup>+</sup>, 500T = 500 mg L<sup>-1</sup> K<sup>+</sup>.

<sup>y</sup> Whole, above-ground barley plants were harvested at the silage/green-feed stage.

<sup>x</sup> Means within the same row with the same letter or no letters are not significantly different ( $p < 0.05$ ).

## 5 Conclusions

### 5.1 Potash Preparation for Injection (Objective 1)

The lab-bench trials were successfully scaled up to prepare larger batches of dissolved KCl using commercial granulated potash. Mixing 0.3 kg potash per 1 L of water generated a concentrated stock solution of about 120,000 mg L<sup>-1</sup> K<sup>+</sup>, and most impurities were removed or filtered from solution. It is expected that KCl solution will not damage or degrade irrigation equipment. Additional improvements on large-scale preparation and improved efficiencies would likely be needed for commercial production for wide-spread use, if required. Other considerations would include proper disposal of residual waste material, proper storage of KCl solution, safe transportation of product, and spill prevention and containment. Prepared KCl solution should not be stored at less than 0° C. Some of the residual material will contain amines, which are used as an anti-caking additive, and are considered toxic to marine life.

### 5.2 Pipeline Study (Objectives 2 and 3)

The pipeline trials demonstrated that it is technically feasible to treat irrigation district pipelines with KCl-treated water to control invasive mussels if they become established in the irrigation infrastructure. However, with more than 900 pipelines within the 13 irrigation districts in Alberta, treatment on a large scale may be logistically challenging.

The application of the K<sup>+</sup> stock solution to three of the five irrigation district pipelines was successful in that the target concentration of 100 mg L<sup>-1</sup> K<sup>+</sup> in the pipelines was achieved or nearly achieved. For the other two pipelines, the final concentration was 13 to 24% less than the target in one pipeline and 22 to 30% greater than target in the other pipeline. The discrepancies for these two pipelines was likely due to inaccurate estimates of flow in the pipelines. Therefore, having accurate flow values is critical when treating pipelines, particularly for larger pipelines serving several irrigation systems, which will cause the flow to change as systems are turned on and off.

To treat pipelines with potash will require extensive coordination among the applicators, irrigation districts, and water users. The efforts required for pipeline treatment were much greater for the larger pipelines with multiple irrigation systems in terms of coordination of irrigators and the irrigation districts. Timing of pipeline treatment will need to consider cropping systems and irrigation demand. Also, other uses of water provided by pipelines, such as domestic use and livestock watering, need to be considered.

The variable-rate dosing pump used in the trials was suitable for the application of injecting KCl solution into district pipelines. Considerations for pumps include matching pump size to pipeline size, power supply, and thoroughly cleaning of pumps of KCl solution after use. Additional work is required to assess how best to meter flow and to automate flow measurements with pump control systems.

A single application of potash-treated water from a district pipeline onto cropland will not adversely affect soil or crop quality. A single application resulted in a significant increase in soil

$K^+$  and  $Cl^-$  in only a few fields, and no effect on soil EC. The treated water was only applied to a small portion of each field (<4 to 11 ha) and the application rate ranged from 3 to 29 kg ha<sup>-1</sup>  $K^+$ , with an average of 12 kg ha<sup>-1</sup>, which is less than what most crops grown in Alberta will remove. Careful management of distribution within a field and crop uptake are expected to prevent  $K^+$  accumulation in soil from repeated applications of KCl-treated water. Also, operating pivots at 100% speed would minimize the application rate (i.e., kg ha<sup>-1</sup>) of KCl.

A single application of potash-treated water from one district pipeline had no effect on tissue quality of an alfalfa crop.

The exposure time of KCl-treated water within the pivot systems was relatively short (<4 h), which would be insufficient to kill attached mussels. Continuous flow of treated water for several days may be an option, however, this is likely too costly and impractical. Frequent drainage of pivot systems and exposure to high temperatures in summer and sub-zero temperatures in winter may be sufficient to prevent the buildup of attached mussels within pivot systems. Options should be investigated on how to manage shell fragments in water to prevent nozzles from plugging.

### **5.3 Small-plot Study (Objective 3)**

Repeated applications of KCl-treated water caused an increase in soil  $K^+$ ,  $Cl^-$ , and EC. Residual  $K^+$  remained in the 0- to 15-cm soil layer; whereas,  $Cl^-$  leached deeper into the 30- to 60-cm soil layer. By managing the distribution of repeated potash-treated water applications on a field and through crop removal,  $K^+$  accumulation should not be a concern.

Repeated applications of potash-treated water had no effect on the yield and tissue quality of barley harvested at the silage stage.

The control system of the fertigation unit used in the small-plot study was inconsistent in delivery of injection volumes, and re-calibration was required each time the volume control was changed. Performance of pumps will need to be assessed if the treatment of individual irrigation systems is determined to be a viable option.

## 6 References

- A & L Canada Laboratories. 2008. Chlorine vs. chloride. Fact Sheet No. 800. London, Ontario, Canada. 3 pp.
- Agrium. 2015. Muriate of potash 0-0-60. Product data sheet. Product code: 2003-25777. Agrium, Calgary, Alberta, Canada.
- Alberta Agriculture and Forestry (AAF). 2018. Alberta climate information service (ACIS). [Online] Available: <https://agriculture.alberta.ca/acis/> (July 19, 2018).
- Alberta Agriculture and Rural Development (AARD). 2013. Alberta irrigation management manual. Irrigation Management Branch, Irrigation and Farm Water Division. 49 pp.
- Alberta Irrigation Projects Association (AIPA). (no year). Water fun and campgrounds in and around Alberta's irrigation districts. Alberta Irrigation Projects Association, Lethbridge, Alberta, Canada. 30 pp.
- Alberta Soil Information Centre. 2018. AGRASID: Agricultural region of Alberta soil inventory database (AGRASID). Version 4.1. Alberta Agriculture and Rural Development. [Online] Available: [https://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/sag10372](https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag10372) (May 2018).
- American Public Health Association (APHA). 1995a. Conductivity 2510 B laboratory method. In A.D. Eaton, L.S. Clesceri, and A.E. Greenberg, eds. Standard methods for the examination of water and wastewater, 19th edn. APHA, Washington DC, United States.
- American Public Health Association (APHA). 1995b. 3111 D atomic absorption spectrometric method. In A.D. Eaton, L.S. Clesceri, and A.E. Greenberg, eds. Standard methods for the examination of water and wastewater, 19th edn. APHA, Washington DC, United States.
- American Public Health Association (APHA). 1995c. 3111 B atomic absorption spectrometric method. In A.D. Eaton, L.S. Clesceri, and A.E. Greenberg, eds. Standard methods for the examination of water and wastewater, 19th edn. APHA, Washington DC, United States.
- American Public Health Association (APHA). 1995d. 3500-K D flame emission photometric method. In A.D. Eaton, L.S. Clesceri, and A.E. Greenberg, eds. Standard methods for the examination of water and wastewater, 19th edn. APHA, Washington DC, United States.
- American Public Health Association (APHA). 1995e. 3500-Na D flame emission photometric method. In A.D. Eaton, L.S. Clesceri, and A.E. Greenberg, eds. Standard methods for the examination of water and wastewater, 19th edn. APHA, Washington DC, United States.
- American Public Health Association (APHA). 1995f. 4500-Cl D potentiometric method. In A.D. Eaton, L.S. Clesceri, and A.E. Greenberg, eds. Standard methods for the examination of water and wastewater, 19th edn. APHA, Washington DC, United States.
- Armstrong, D.L. (ed.). 1998. Potassium for agriculture. *Better Crops* **82(3)**: 4–5, 20–23.
- Association of Official Analytical Chemists (AOAC). 1990. Protein (crude) determination in animal feed: Copper catalyst Kjeldahl method 984.13. 15th edn. Official Methods of Analysis of AOAC International, Gaithersburg, Maryland, United States.
- Ballantyne, A.K. 1974. The movement of salts and the effects on cereal yields resulting from the application of potassium refinery dust to the soil surface. *Can. J. Soil Sci.* **54**: 45–51.
- Benson, A.J., Raikow, D., Larson, J., Fusaro, A., and Bogdanoff, A.K. 2018a. *Dreissena polymorpha* (Pallas 1771). United States Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, Florida, United States. [Online] Available: <http://nas.er.usgs.gov/queries/factsheet.aspx?speciesid=5> (August 2018).

- Benson, A.J., Richerson, M.M., Maynard, E., Larson, J., Fusaro, A., Bogdanoff, A.K., and Neilson, M.E. 2018b. *Dreissena rostriformis bugensis* (Andrusov 1897). United States Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, Florida, United States. [Online] Available: <http://nas.er.usgs.gov/queries/factsheet.aspx?speciesid=95> (August 2018).
- Benton Jones, Jr., J. 2001. Laboratory guide for conducting soil tests and plant analysis. 1st edn. Boca Raton, Florida, United States. 384 pp.
- Brady, N.C. and Weil, R.R. 2008. The nature and properties of soils. Pearson Prentice Hall, Upper Saddle River, New Jersey, United States. 975 pp.
- Canadian Fertilizer Institute. 2001. Nutrient uptake and removal by field crops: Western Canada. Canadian Fertilizer Institute. 2 pp.
- Clarke R. 2011. Preventing the blemish of downer cows. *Cattleman* **74(6)**: 26.
- Department of Fisheries and Oceans Canada (DFOC). 2013. Science advice from the risk assessment of three dreissenid mussels (*Dreissena polymorpha*, *Dreissena rostriformis bugensis*, and *Mytilopsis leucophaeata*) in Canadian freshwater ecosystems. Science Advisory Report 2012/082. Canadian Science Advisory Secretariat, Ottawa, Ontario, Canada. 22 pp.
- Department of Fisheries and Oceans Canada (DFOC). 2014. Lake Winnipeg zebra mussel treatment. Science Advisory Report 2014/031. Canadian Science Advisory Secretariat, Ottawa, Ontario, Canada. 12 pp.
- Dyck, M.F., Kachanoski, R.G., and de Jong, E. 2003. Long-term movement of a chloride tracer under transient, semi-arid conditions. *Soil Sci. Soc. Am. J.* **67**: 471–477.
- Elliott, M. 2008. Grass tetany in cattle — predicting its likelihood. Primefacts 785. Department of Primary Industries, New South Wales Government, Australia. 6 pp.
- Elliott, M. 2009. Grass tetany in cattle. Primefacts 240. Department of Primary Industries, New South Wales Government, Australia. 4 pp.
- Encanto Potash Corp. (no year). About potash. [Online] Available: <http://www.encantopotash.com/english/aboutpotash/default.aspx> (December 2016).
- Engvild, K.C. 1986. Chlorine-containing natural compounds in higher plants. *Phytochem.* **25**: 781–791.
- Fageria, V.D. 2001. Nutrient interactions in crop plants. *J. Plant Nutr.* **24**: 1269–1290.
- Fernald, R.T. and Watson, B.T. 2014. Eradication of zebra mussels (*Dreissena polymorpha*) from Millbrook Quarry, Virginia: Rapid response in the real world. Pages 195–213 in T.F. Nalepa and D.W. Schloesser, ed. 2nd edn. Quagga and zebra mussels: Biology, impacts, and control. CRC Press, Boca Raton, Florida, United States.
- Fisher S.W., Stromberg, P., Bruner, K.A., and Boulet, L.D. 1991. Molluscicidal activity of potassium to the zebra mussel, *Dreissena polymorpha*: Toxicity and mode of action. *Aquat. Toxicol.* **20**: 219–234.
- Fixen, P.E. 1993. Crop removal of chloride. *Better Crops* **77(4)**: 15.
- Glomski, L. 2015. Zebra mussel chemical control guide. Version 2. ERDC/EL TR-15-9. Environmental Laboratory, United States Army Engineer Research and Development Center, Vicksburg, Mississippi, United States. 91 pp.
- Government of Alberta (GoA). 2018a. Alberta irrigation information 2017. Irrigation and Farm Water Branch, Alberta Agriculture and Forestry, Lethbridge, Alberta, Canada. 32 pp.
- Government of Alberta (GoA). 2018b. Aquatic invasive species pocket guide. Alberta Environment and Parks, Edmonton, Alberta, Canada. 142 pp.

- Government of Alberta (GoA). 2018c. 2017 annual report: Alberta aquatic invasive species program. Alberta Environment and Parks, Edmonton, Alberta, Canada. 37 pp.
- Government of Alberta (GoA). 2018d. Environmental quality guidelines for Alberta surface waters. Water Policy Branch, Alberta Environment and Parks. Edmonton, Alberta, Canada. 53 pp.
- Government of Canada (GoC). 2018. Waterton Lake National Park: Invasive Mussel information. Parks Canada. [Online] Available: <https://www.pc.gc.ca/en/pn-np/ab/waterton/info/index/reglements-regulations/envahissantes-invasive/information> (October 26, 2018).
- Government of Manitoba (GoM). 2014. Province advises zebra mussel larvae found in Lake Winnipeg's south basin. News release — Manitoba. August 11, 2014. [Online] Available: <https://news.gov.mb.ca/news/index.html?item=32168> (September 12, 2018).
- Government of Manitoba (GoM). 2015a. Aquatic invasive species update bulletin #18. News release — Manitoba. October 22, 2015. [Online] Available: <https://news.gov.mb.ca/news/index.html?item=36496&posted=2015-10-22> (September 12, 2018).
- Government of Manitoba (GoM). 2015b. Manitoba doubles its investment to fight zebra mussels, strengthen enforcement, research. News release — Manitoba. October 26, 2015. [Online] Available: <https://news.gov.mb.ca/news/index.html?archive=&item=36515> (September 12, 2018).
- Government of Manitoba (GoM). 2016. Invaded waters. [Online] Available: [http://www.gov.mb.ca/waterstewardship/stopais/zebra\\_mussel/invaded.html](http://www.gov.mb.ca/waterstewardship/stopais/zebra_mussel/invaded.html) (September 12, 2018).
- Grunes, D.L., Stout, P.R., and Brownell, J.R. 1970. Grass tetany of ruminants. *Adv. Agron.* **22**: 331–374.
- Grunes, D.L. and Welch, R.M. 1989. Plant contents of magnesium, calcium, and potassium in relation to ruminant nutrition. *J. Anim. Sci.* **67**: 3485–3494.
- Hall, D.L., Sterner, S.M., and Bodnar, R.J. 1988. Freezing point depression of NaCl-KCl-H<sub>2</sub>O solutions. *Econ. Geol.* **83**: 197–202.
- Hao, X. and Chang, C. 2002. Effect of 25 annual cattle manure applications on soluble and exchangeable cations in soil. *Soil Sci.* **167**: 126–134.
- Hao, X. and Chang, C. 2003. Does long-term heavy cattle manure application increase salinity of a clay loam soil in semi-arid southern Alberta? *Agric. Ecosyst. Environ.* **94**: 89–103.
- Hebert, P.D.N., Muncaster, B.W., and Mackie, G.L. 1989. Ecological and genetic studies on *Dreissena polymorpha* (Pallas): A new mollusc in the Great Lakes. *Can. J. Fish. Aquat. Sci.* **46**: 1587–1591.
- Hossain, M.Z., Rabbi, S.M.F., Khanom, M.S., Amin, M.S., Islam, M.S., and Rahman, A. 2010. Effect of salinity and potassium fertilizer application on yield contributing characteristics of rice. *Khulna University Studies* **10(1–2)**: 145–152.
- Hussein, M. and Donaldson, A. 2017. Monitoring of anti-caking solution preparation and loading during loadout treatment of potash using FT-NIR. *J. Chem. Eng. Process Technol.* **8(3)**: DOI: 10.4172/2157-7048.1000342.
- IPEX. 2009. EPDM and FKM chemical resistance guide. 1<sup>st</sup> edn. IPEX, Mississauga, Ontario, Canada. 32 pp. [Online] Available: <http://www.ipexna.com/media/1231/epdm-fkm-chemical-resistance-guide.pdf> (October 31, 2018).

- IPEX. 2013. PVC chemical resistance guide. 1<sup>st</sup> edn. IPEX, Mississauga, Ontario, Canada. 8 pp. [Online] Available: <http://www.ipexna.com/media/1588/pvc-chemical-resistance-guide.pdf> (October 31, 2018).
- Janzen H.H. 1993. Soluble salts. Pages 161–166 in M.R. Carter, ed. Soil sampling and method of analysis. Canadian Society of Soil Science. Lewis Publishers, Boca Raton, Florida, United States.
- Kafkafi, U., Xu, G., Imas, P., Magen, H., and Tarchitzky, J. 2001. Potassium and chloride in crops and soils: The role of potassium chloride fertilizer in crop nutrition. IPI Research Topic No. 22. International Potash Institute, Basel, Switzerland. 220 pp.
- Karatayev A.Y., Burlakova, L.E., and Padilla, D.K. 2015. Zebra versus quagga mussels: A review of their spread, population dynamics, and ecosystem impacts. *Hydrobiologia* **746**: 97–112.
- Kemp, A. 1960. Hypomagnesemia in milking cows: The response of serum magnesium to alterations in herbage composition resulting from potash and nitrogen dressings on pasture. *Neth. J. Agr. Sci.* **8**: 281–304.
- King, C. 2017. A closer look at fertigation. [Online] Available: <https://www.topcropmanager.com/irrigation/a-closer-look-at-fertigation-19963> (December 20, 2018).
- Lemus, R. and Rivera, D. 2009. Spring grazing and grass tetany in beef cattle production. In *Forage News*, February 2009. Mississippi University Extension Service.
- Li, B.Y., Zhou, D.M., Cang, L., Zhang, H.L., Fan, X.H., and Qin, S.W. 2007. Soil micronutrient availability to crops as affected by long-term inorganic and organic fertilizer applications. *Soil Tillage Res.* **96**: 166–173.
- Liebhardt, W.C. and Shortall, J.G. 1974. Potassium is responsible for salinity in soils amended with poultry manure. *Commun. Soil Sci. Plant Anal.* **5**: 385–398.
- Machado, R.M.A. and Serralheiro, R.P. 2017. Soil salinity: Effect on vegetable crop growth. Management practices to prevent and mitigate soil salinization. *Horticulturae* **3(2)**: 1–13.
- Mackie, G.L. and Claudi, R. 2010. Monitoring and control of macrofouling mollusks in fresh water systems. 2nd edn. CRC Press, Boca Raton, Florida, United States. 508 pp.
- Manwell, B.R. and Ryan, M.C. 2006. Chloride as an indicator of non-point source contaminant migration in a shallow alluvial aquifer. *Water Qual. Res. J. Can.* **41**: 383–397.
- Marx T. 2004. Tetany problems in beef cows. Alberta Agriculture, Food and Rural Development, Edmonton, Alberta, Canada. 2 pp.
- Maynard, D.G. and Kalra, Y.P. 1993. Nitrate and extractable ammonium nitrogen. Pages 25–38 in M. Carter, ed. Soil sampling and methods of analysis. Canadian Society of Soil Science. Lewis Publishers, CRC Press, Boca Raton, Florida, United States.
- McKenzie, R.H. 1992. Micronutrient requirements of crops. Agri-Facts, Agdex 531-1. Alberta Agriculture, Food and Rural Development, Lethbridge, Alberta, Canada. 7 pp.
- McKenzie, R.H., DeMulder, J., and Solberg, E. 2000. Optimizing barley silage production in Alberta. Agri-Facts, Agdex 114/540-1. Alberta Agriculture, Food and Rural Development. 4 pp.
- McKenzie, R.H., Kryzanowski, L., and Pauly, D. 2013. Fertilizer requirements of irrigated grain and oilseed crops. Agri-Facts, Agdex 100/541-1. Government of Alberta. 23 pp.
- McKenzie, R.H. and Pauly, D. 2013. Potassium fertilizer application in crop production. Agri-Facts, Agdex 542-9. Alberta Agriculture and Rural Development, Lethbridge, Alberta, Canada. 7 pp.

- Mengel, D., Lamond, R., Martin, V., Duncan, S., Whitney, D., and Gordon, B. 2009. Chloride fertilization and soil testing — update for major crops of Kansas. *Better Crops* **93**(4): 20–22.
- Miller, J.J., Beasley, B.W., Larney, F.J., and Olson, B.M. 2005. Soil salinity and sodicity after application of fresh and composted manure with straw or wood-chips. *Can. J. Soil Sci.* **85**: 427–438.
- Mills E.L., Rosenberg, G., Spidle, A.P., Ludyanskiy, M., Pligin, Y., and May, B. 1996. A review of the biology and ecology of the quagga mussel (*Dreissena bugensis*), a second species of freshwater dreissenid introduced to North America. *Amer. Zool.* **36**: 271–286.
- Moffitt, C.M., Stockton-Fiti, K.A., and Claudi, R. 2016. Toxicity of potassium chloride to veliger and byssal stage dreissenid mussels related to water quality. *Manag. Biol. Invasions* **7**: 257–268.
- Montana Government. 2018a. AIS news: FWP takes another look at Tiber access options. [Online] Available: <http://cleandraindry.mt.gov/News/fwp-takes-another-look-at-tiber-access-options> (October 26, 2018).
- Montana Government. 2018b. AIS news: Keeping vigilant on protecting Montana’s waterways. Montana Fish, Wildlife and Park. [Online] Available: <http://cleandraindry.mt.gov/News/keeping-vigilant-on-protecting-montanas-waterways> (October 26, 2018).
- Munns, R. 1993. Physiological processes limiting plant growth in saline soils: Some dogmas and hypotheses. *Plant Cell Environ.* **16**: 15–24.
- Neupane, A. 2013. An estimate of annual economic cost of invasive dreissenid mussels to Alberta. Alberta Environment and Sustainable Resource Development, Socioeconomics and Health Section, Policy Integration Branch. Edmonton, Alberta, Canada.
- Nutrien 2017. Muriate of Potash 0-0-60 Red Premium: Product data sheet. [Online] Available <https://agproducts.nutrien.com/products/?d-4028674-p=1&primaryCategory=7> (October 30, 2018).
- Nutrien. 2018a. Fact book 2018. Saskatoon, Saskatchewan, Canada. [Online] Available: [https://www.nutrien.com/sites/default/files/uploads/2018-01/Nutrien%20Fact%20Book%202018\\_1.pdf](https://www.nutrien.com/sites/default/files/uploads/2018-01/Nutrien%20Fact%20Book%202018_1.pdf) (September 12, 2018).
- Nutrien. 2018b. Safety data sheet: Muriate of potash 0-0-60 special standard. Version 2.6. [Online] Available at <https://agproducts.nutrien.com/products/?d-4028674-p=2&primaryCategory=7> (October 18, 2018).
- Olson, B.M., McKenzie, R.H., Bennett, D.R., Ormann, T., and Atkins, R.P. 2003. Manure application effects on soil and groundwater quality under irrigation in southern Alberta. Alberta Agriculture, Food and Rural Development, Lethbridge, Alberta, Canada. 377 pp.
- Parida, A.K. and Das, A.B. 2005. Salt tolerance and salinity effects on plants: A review. *Ecotoxicol. Environ. Saf.* **60**: 324–349.
- Paterson Earth & Water Consulting. 2015. Economic value of irrigation in Alberta. Prepared for the Alberta Irrigation Projects Association, Lethbridge, Alberta, Canada. 137 pp.
- Paterson Earth & Water Consulting. 2018. Dreissenid mussels and Alberta’s irrigation infrastructure: Strategic pest management plan and cost estimate. Prepared for the Eastern Irrigation District, Brooks, Alberta, Canada. 130 pp.
- Pratt, P.F. 1984. Salinity, sodium, and potassium in an irrigated soil treated with bovine manure. *Soil Sci. Soc. Am. J.* **48**: 823–828.

- Province of Alberta. 2017. Agricultural Operation Practices Act — standards and administration regulation. Alberta Queen's Printer, Edmonton, Alberta, Canada.
- Qian, P., Schoenau, J.J., and Karamanos, R.E. 1994. Simultaneous extraction of available phosphorus and potassium with a new soil test: A modification of Kelowna extraction. *Comm. Soil Sci. Plant Anal.* **25**: 627–635.
- Quinn A., Gallardo, B., and Aldridge, D.C. 2014. Quantifying the ecological niche overlap between two interacting invasive species: The zebra mussel (*Dreissena polymorpha*) and the quagga mussel (*Dreissena rostriformis bugensis*). *Aquatic Conserv.* **24**: 324–337.
- Rayburn, E. and Matlick, D. 2012. Reducing the risk of grass tetany. West Virginia University Extension Service, Morgantown, West Virginia, United States. 2 pp.
- Rengasamy, P. 1983. Clay dispersion in relation to changes in the electrolyte composition of dialysed red-brown earths. *J. Soil Sci.* **34**: 723–732.
- Robbins, C.W. and Mayland, H.F. 1993. Calcium, magnesium, and potassium uptake by crested wheatgrass grown on calcareous soils. *Commun. Soil Sci. Plant Anal.* **24**: 915–926.
- Römheld, V. and Kirkby, E.A. 2010. Research on potassium in agriculture: Needs and prospects. *Plant Soil* **335**: 155–180.
- Sheldon, A., Menzies, N.W., Bing So, H., and Dalal, R. 2004. The effect of salinity on plant available water. In *SuperSoil 2004: 3rd Australian New Zealand Soils Conference*. University of Sydney, Australia. December 5–9, 2004.
- Smith, D. 1975. Effects of potassium topdressing a low fertility silt loam soil on alfalfa herbage yields and composition and on soil K values. *Agronomy J.* **67**: 60–64.
- Spidle, A.P., Mills, E.L., and May, B. 1995. Limits to tolerance of temperature and salinity in the quagga mussel (*Dreissena bugensis*) and the zebra mussel (*Dreissena polymorpha*). *Can. J. Fish. Aquat. Sci.* **52**: 2108–2119.
- Sykes, C.L. and Wilson, W.D. 2015. Challenges of developing a molluscicide for use on *Dreissena rostriformis bugensis* veligers in fish transport tanks. Pages 487–506 in W.H. Wong and S.L. Gerstenberger, eds. *Biology and management of invasive quagga and zebra mussels in the western United States*. CRC Press, Boca Raton, Florida, United States.
- Technicon Industrial Systems. 1986. Chloride. Bran + Luebbe, Inc. Industrial Method no. 783-86T. Tarrytown, New York, New York, United States.
- Technicon Industrial Systems. 1987. Ortho phosphorus. TRAACS 800 methods, Bran + Luebbe Industrial Method no. 781-86T. Tarrytown, New York, New York, United States.
- Therriault, T.W., Weise, A.M., Higgins, S.N., Guo, Y., and Duhaime, J. 2013. Risk assessment for three dreissenid mussels (*Dreissena polymorpha*, *Dreissena rostriformis bugensis*, and *Mytilopsis leucophaeata*) in Canadian freshwater ecosystems. Research Document 2012/174. Canadian Science Advisory Secretariat, Fisheries and Oceans Canada, Ottawa, Ontario, Canada. 88 pp.
- Tisdale, S.L., Nelson, W.L., Beaton, J.D., and Havlin, J.L. 1993. *Soil fertility and fertilizers*. 5th edn. MacMillan Publishing Company, New York, New York, United States. 634 pp.
- United States National Library of Medicine. 2015. Toxnet — potassium chloride. [Online] Available: <https://toxnet.nlm.nih.gov/cgi-bin/sis/search2/f?./temp/~2v2o2p:3> (September 12, 2018).
- Vinten, A.J.A, Vivian, B., and Redman, M.H. 1991. An analysis of the leaching of chloride tracer applied to pipe-drained plots using a coupled unsaturated-saturated zone model of solute transport. *Soil Use Manage.* **7(2)**: 103–109.

- Walker, A., Schmidt, T., Doig, B., Campbell, J., and McKinnon, J. 2006. A case study of factors influencing tetany-like symptoms in beef cows. In Proceedings of 27th western nutrition conference. Winnipeg, Manitoba, Canada, September 19–20, 2006.
- Waller, D.L., Rach, J.J., Cope, W.G., Marking, L.L., Fisher, S.W., and Dabrowska, H. 1993. Toxicity of candidate molluscicides to zebra mussels (*Dreissena polymorpha*) and selected nontarget organisms. *J. Great Lakes Res.* **19**: 695–702.
- White P.J. and Broadley, M.R. 2001. Chloride in soils and its uptake and movement within the plant: A review. *Ann. Bot.* **88**: 967–988.
- Xu, G., Magen, H., Tarchitzky, J., and Kafkafi, U. 2000. Advances in chloride nutrition of plants. *Adv. Agron.* **68**: 97–150.
- Zhu, J.-K. 2007. Plant salt stress. Pages 1–3 in A. O'Daly, ed. *Encyclopedia of life sciences*. John Wiley and Sons, Ltd., Chichester, United Kingdom.

## 7 Appendices

- Appendix 7.1 Muriate of Potash
- Appendix 7.2 Pest Management Regulatory Agency (PMRA) annotated experimental label
- Appendix 7.3 Signage used at the pipeline trial sites
- Appendix 7.4 Irrigation pipelines used in the pipeline study
- Appendix 7.5 Pipeline fields
- Appendix 7.6 Soil description at the five irrigation district pipeline trials
- Appendix 7.7 Calculation of stock solution volumes used during the pipeline trials
- Appendix 7.8 Chronological order of main events during each pipeline trial
- Appendix 7.9 Centre-pivot systems used in the pipeline trials
- Appendix 7.10 Amount of water and actual concentrations of potassium ( $K^+$ ), chloride ( $Cl^-$ ), and electrical conductivity (EC) applied at the small-plot site in 2016 and 2017

## Appendix 7.1 Muriate of Potash

Product Code: 2003-25777

# Agrium

Product Data Sheet  
Effective: March 9, 2015  
Location: Vanscoy

Muriate of Potash  
**0-0-60**

Special Standard Grade — Low Sodium Chloride

### CHEMICAL ANALYSIS

Component/equivalent	Units	Minimum	Typical
Total potash	wt. % K <sub>2</sub> O	60.0	60.8
Chloride	wt. % Cl	47.0	47.7
Potassium	wt. % K	-	50.4
Sodium	wt. % Na	1.38	1.35
Sodium chloride	wt. % NaCl	-	3.43
Calcium	wt. % Ca	-	0.03
Magnesium	wt. % Mg	-	0.03
Bromine	wt. % Br	-	0.01
Sulphate	wt. % SO <sub>4</sub>	-	0.05
Total organics	wt. %	-	0.05
Water insolubles	wt. %	-	0.45
Moisture	wt. % H <sub>2</sub> O	-	0.02
pH of 10% wt./wt. aqueous solution		-	9.0
Product conditioner	ppm amine	-	40

### PHYSICAL ANALYSIS

Parameter	Unit	Range	Typical
Colour	-	-	Clear to brick red
Angle of repose	degrees	-	31
Bulk density	lb ft <sup>-3</sup>	-	75
	kg m <sup>-3</sup>	-	1200
Size guide number (SGN)		90-100	100
Uniformity index		-	20

### PARTICALE SIZE DISTRIBUTION

	Tyler Mesh	US mesh	mm mesh	Range wt. %	Typical wt. %
Retained on ...	10	12	1.700	0-8	4
	65	70	0.212	97-99	98

Please obtain a Material Safety Data Sheet for more information.

To the best of Agrium's knowledge and belief the information contained herein is accurate and reliable as of the date compiled. However, Agrium makes no representation, warranty or guarantee as to the information's accuracy, reliability, completeness or timeliness. It is the user's responsibility to determine the suitability and completeness of such information for the user's own particular use or purposes. Agrium does not accept any liability for any loss or damage that may occur from any use of this information.

Agrium, 13131 Lake Fraser Drive SE, Calgary, Alberta T2J 7E8; Phone: (403) 225-7000.  
Agrium U.S. Inc., 4582 S. Ulster Street, Suite 1700, Denver, Colorado 80237; Phone: (303) 804-4400.

**Appendix 7.2 Pest Management Regulatory Agency (PMRA) annotated experimental label**

**PMRA annotated (SC)  
27 Feb 2017  
2016-6193**

**SOLID MURIATE of POTASH (Potassium Chloride)**

**EXPERIMENTAL USE ONLY**

RESEARCH AUTHORIZATION NO. 0005-RA-17  
PEST CONTROL PRODUCTS ACT / P.C.P. ACT

**SALE PROHIBITED. NOT FOR DISTRIBUTION TO ANY PERSON  
OTHER THAN A RESEARCHER OR COOPERATOR**

MANUFACTURING GUARANTEE:  
Active ingredient: 96.2 % KCl (60.8% K<sub>2</sub>O)

KEEP OUT OF REACH OF CHILDREN

READ THE LABEL BEFORE USING

CAUTION – EYE IRRITANT

Net Contents:  
1 tonne dry  
1700 kg in solution

Manufactured by:

AGRIUM  
North American Wholesale  
13131 Lake Fraser Drive S.E.  
Calgary, Alberta Canada  
T2J 7E8

## PRECAUTIONS:

May irritate eyes  
Avoid Contact with eyes

Avoid inhaling/breathing any dust generated while handling Potassium Chloride in its solid form.

Use only in well ventilated areas.

During mixing, loading, clean-up or repair of equipment, personnel should wear goggles or a face shield, long-sleeved shirt, long pants, shoes, and socks. Personnel should also wear a dust mask when handling Muriate of Potash in its solid form.

For good hygiene practice, if clothing has been contaminated, remove it and launder it with detergent and hot water as soon as possible separately from other clothing. Clean personal protective equipment upon removal with soapy water.

For good hygiene practices wash hands and face before eating, drinking, chewing gum, using tobacco, as well as using the toilet. Take a shower immediately after work.

Irrigate with treated water only when the potential for drift to areas of human habitation or areas of human activity such as houses, cottages, schools, and recreational areas is minimal. Take into consideration wind speed, wind direction, temperature inversions, application equipment, and sprayer settings.

**FIRST AID:**

- |                        |  |
|------------------------|--|
| If swallowed           | Call a poison control centre or doctor immediately for treatment advice. Have person sip a glass of water if able to swallow. Do not induce vomiting unless told to do so by a poison control centre or doctor. Do not give anything by mouth to an unconscious person |
| If on skin or clothing | Take off contaminated clothing. Rinse skin immediately with plenty of water for 15–20 minutes. Call a poison control centre or doctor for treatment advice.  |
| If inhaled             | Move person to fresh air. If person is not breathing, call 911 or an ambulance, then give artificial respiration, preferably by mouth-to-mouth, if possible. Call a poison control centre or doctor for further treatment advice.                                      |
| If in eyes             | Hold eye open and rinse slowly and gently with water for 15–20 minutes. Remove contact lenses, if present, after the first 5 minutes, then continue rinsing eye. Call a poison control centre or doctor for treatment advice.  |

Take the container, label, or product name and Pest Control Product Research Authorization Number or Notification Number with you when seeking medical attention.

**TOXICOLOGICAL INFORMATION:**

**Treat symptomatically**

**ENVIRONMENTAL HAZARDS:**

**This product is to be used only in the manner authorized; consult provincial pesticide regulatory authorities about use permits that may be required.**

**DO NOT discharge effluent containing this product into sewer systems, lakes, streams, ponds, estuaries, oceans or other waters unless the effluent has been detoxified by suitable means.**

**DIRECTIONS FOR USE:**

Purpose: For the development and testing of potash preparation methods and pipeline injection equipment, and ensuring a steady concentration of 100 mg L<sup>-1</sup> of potassium (K<sup>+</sup>), for a 'lethal dose' to dreissenid mussels for the protection of irrigation pipeline in the event of a dreissenid mussel detection in an irrigation reservoir.

Crop/ Site: Alberta irrigation district pipelines.

Pest: Dreissenid mussels (zebra, quagga)

Dilution and application rates:

Dependent on pipeline diameter and flow. Injection rates will range from 3-80 L min<sup>-1</sup> to achieve a 100 mg L<sup>-1</sup> K<sup>+</sup> concentration in pipelines.

Method of application:

Granular KCl will be mixed with water in tanks off site. The solution will be delivered to the injection site. A pump near the pipeline inlet will inject the KCl solution into the moving irrigation water.

Timing of application:

The duration of the proposed use is for 31 months (March 2017 to October 2019). Tests may be performed on a monthly basis during the irrigation season, outside of peak irrigation months. Ideal times to perform the tests are May, June, and September.

**NOTICE TO USER:**

This pest control product is to be used only in accordance with the directions on the label. It is an offence under the *Pest Control Products Act* to use this product in a way that is inconsistent with the directions on the label. The user assumes the risk to persons or property that arises from any such use of this product.

**DISPOSAL:**

**Any unused product must be returned to the manufacturer.**

The generation of waste should be avoided or minimized wherever possible. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Dispose of surplus and non-recyclable products via a licensed waste disposal contractor. Waste should not be disposed of untreated to the sewer unless fully compliant with the requirements of all authorities with jurisdiction. Waste packaging should be recycled. Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers.

Recover and place material in a suitable container for intended use or disposal. Ensure disposal complies with government requirements and local regulations.

Appendix 7.3 Signage used at the pipeline trial sites

**PEST CONTROL  
EXPERIMENTAL SITE**  
**SITE D'EXPÉRIMENTATION DE  
LUTTE ANTIPARASITAIRE**

**DO NOT ENTER  
WITHOUT AUTHORIZATION**  
**ACCÈS INTERDIT SANS  
AUTORISATION**

**FOR INFORMATION CONTACT  
POUR PLUS D'INFORMATION S'ADRESSER À  
DR. BARRY OLSON 403-381-5884**

---

**Research Authorization Number  
Numéro d'Autorisation de Recherche  
0028-RA-16**

---

**ACTIVE INGREDIENT: 96.2% KCl (potassium chloride)  
INGRÉDIENT ACTIF: 96, 2% KCl (chlorure de potassium)**

## Appendix 7.4 Irrigation pipelines used in the pipeline study

Pipeline length and inside-diameter values for the district-owned pipelines (i.e., pipeline segments with CONVWGID numbers) were obtained from Alberta Agriculture and Forestry's database maintained by the Basin Water Management Section in Lethbridge, Alberta. Corrected inside-diameter values were calculated by adding 22 mm to the nominal diameter values in the database.

Values for the producer-owned pipelines were obtained from the producers (diameter), or from Google Earth Pro (length), or assumed (diameter).

<b>Pipeline A in the Eastern Irrigation District.</b>			
Pipeline segment	Length (m)	Corrected inside diameter (m)	Volume (m <sup>3</sup> )
13012648 <sup>z</sup>	2386	0.3071	176.7
13012649 (north spur)	116	0.3071	8.6
13012650 (north spur)	6	0.2589	0.3
Producer-owned pipeline: Site 4	410	0.2589	21.6
<b>Total</b>	<b>2918</b>	<b>–</b>	<b>207.2</b>
13012651 (south spur)	6	0.3071	0.4
13012652 (south spur)	122	0.1596	2.4

<sup>z</sup> Conveyance works global identification number (CONVWGID).

<b>Pipeline B in the Eastern Irrigation District.</b>			
Pipeline segment	Length (m)	Corrected inside diameter (m)	Volume (m <sup>3</sup> )
13001507 <sup>z</sup>	1,421	0.623	433.2
13001505	337	0.522	72.1
13001905	1,328	0.420	184.0
13001504	732	0.420	101.4
13001503	459	0.370	49.4
Producer-owned pipeline: Site 2	575	0.254	29.1
Producer-owned pipeline: Site 3	428	0.254	21.7
Producer-owned pipeline: Site 4	450	0.409	59.1
<b>Total</b>	<b>5730</b>	<b>–</b>	<b>950.0</b>

<sup>z</sup> Conveyance works global identification number (CONVWGID).

---

**Pipeline C in the Eastern Irrigation District.**

---

Pipeline segment	Length (m)	Corrected inside diameter (m)	Volume (m <sup>3</sup> )
13001914 <sup>z</sup>	1166	0.623	355.4
13001502	616	0.623	187.8
13001501	513	0.5218	109.7
13001500	769	0.32	61.8
Producer-owned pipeline: Site 2	735	0.254	37.2
Producer-owned pipeline: Site 3	535	0.254	27.1
<b>Total</b>	<b>4334</b>	<b>–</b>	<b>779.1</b>

<sup>z</sup> Conveyance works global identification number (CONVWGID).

---

**Pipeline D in the Taber Irrigation District.**

---

Pipeline segment	Length (m)	Corrected inside diameter (m)	Volume (m <sup>3</sup> )
8002089 <sup>z</sup>	942	1072	850.2
8000336	343	397	42.5
8002096	898	472	157.1
8002100	702	1072	633.6
8002097	348	472	60.9
8002144	180	1072	162.5
8002091	407	922	271.7
8002090	1,198	772	560.8
8002092	405	622	123.1
8002093	1,234	522	264.1
8002094	320	372	34.8
8002095	135	322	11.0
Producer-owned pipeline: Site 2	585	272	34.0
Producer-owned pipeline: Site 3	371	342	34.1
Producer-owned pipeline: Site 4	326	342	29.9
Producer-owned pipeline: Site 6	375	342	34.4
Producer-owned pipeline: Site 8	555	342	51.0
Producer-owned pipeline: Site 9	590	342	54.2
Producer-owned pipeline: Site 10	411	342	37.8
Producer-owned pipeline: Site 11	422	342	38.8
Producer-owned pipeline: Site 12	31	342	2.8
<b>Total</b>	<b>10,778</b>	<b>–</b>	<b>3489.2</b>

<sup>z</sup> Conveyance works global identification number (CONVWGID).

---

**Pipeline E in the St. Mary River Irrigation District.**

---

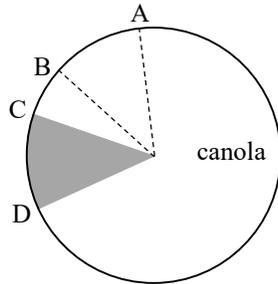
Pipeline segment	Length (m)	Corrected inside diameter (m)	Volume (m <sup>3</sup> )
9004630 <sup>z</sup>	665	0.772	311.3
9004590	635	0.622	192.9
9004551	798	0.372	86.7
9004552	22	0.322	1.8
9004549	830	0.522	177.6
9004507	50	0.472	8.7
9004502	245	0.472	42.9
9004505	545	0.422	76.2
9004504	45	0.372	4.9
9004506	30	0.322	2.4
9004501	105	0.422	14.7
9004489	191	0.322	15.6
9004481	234	0.272	13.6
Producer-owned pipeline: Sites 2 and 3	58	0.320	4.7
Producer-owned pipeline: Site 2	547	0.320	44.0
Producer-owned pipeline: Site 3	774	0.320	62.2
Producer-owned pipeline: Site 4	28	0.230	1.2
Producer-owned pipeline: Site 5	427	0.320	34.3
Producer-owned pipeline: Site 6	647	0.320	52.0
Producer-owned pipeline: Site 7	403	0.320	32.4
<b>Total</b>	<b>7279</b>	<b>–</b>	<b>1180.2</b>

---

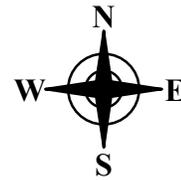
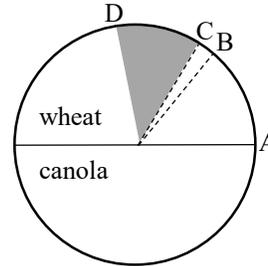
<sup>z</sup> Conveyance works global identification number (CONVWGID).

## Appendix 7.5 Pipeline fields

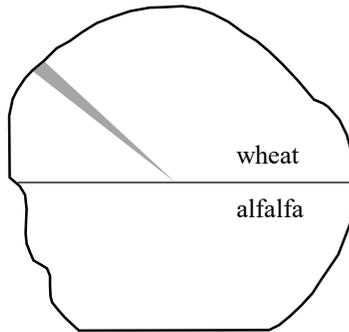
**Pipeline A, Site 4**



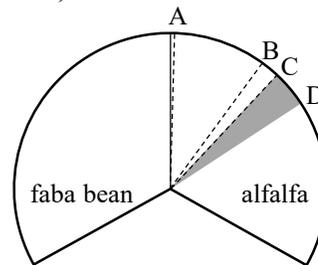
**Pipeline C, Site 2**



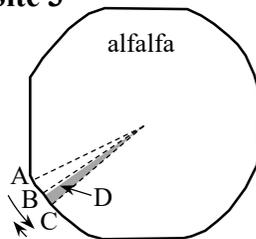
**Pipeline B, Site 2 (See next page)**



**Pipeline C, Site 3**



**Pipeline B, Site 3**



### **Injection phase:**

A = pivot start position

B = KCl-peak concentration reached

C = pivot stopped position

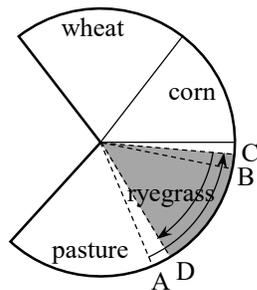
### **Purging phase:**

C = pivot start position

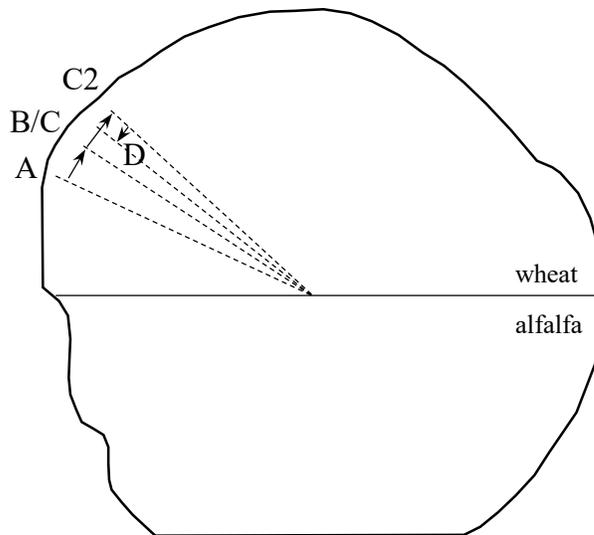
D = background concentration reached

 KCl-treated water applied (approximately)

**Pipeline B, Site 4**



## Pipeline B Site 2



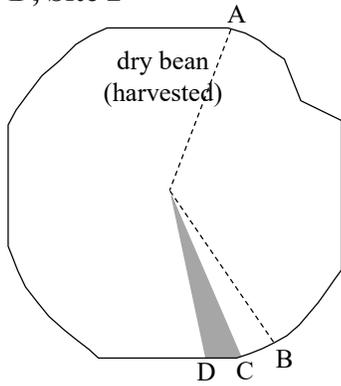
A = initial position for injection phase.

B/C = position after K<sup>+</sup> concentration peaked and the pivot stopped because of power failure.

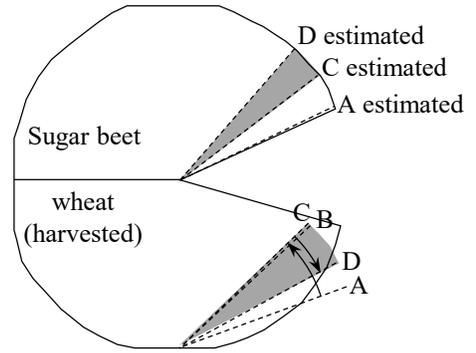
C2 = Position pivot was moved for mechanical repairs and where the pivot started for the purging phase in reverse direction.

D = Background conditions were reached near the B/C position, but did not reach the soil sampling points near the B/C position. A second set of soil sampling points were located close to C2 position where KCl-treated water was applied.

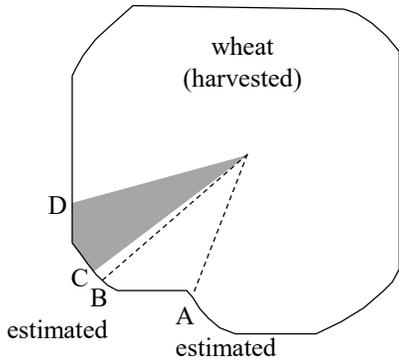
**Pipeline D, Site 2**



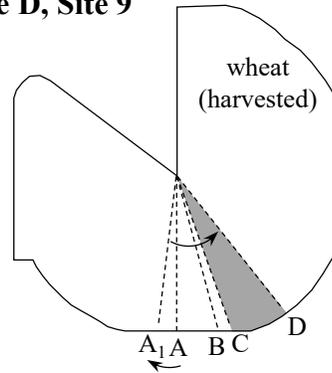
**Pipeline D, Sites 6 (bottom) and 8**



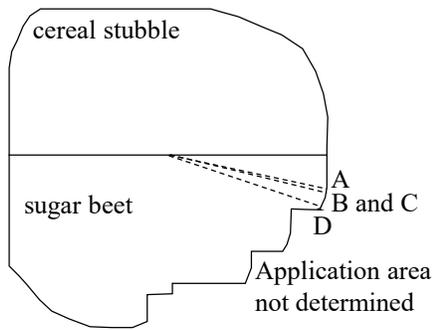
**Pipeline D, Site 3**



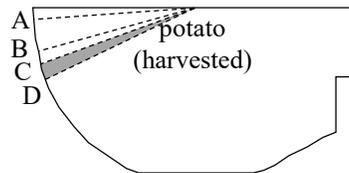
**Pipeline D, Site 9**



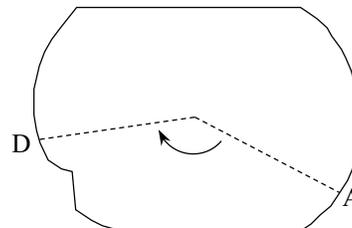
**Pipeline D, Site 4**



**Pipeline D, Site 10**

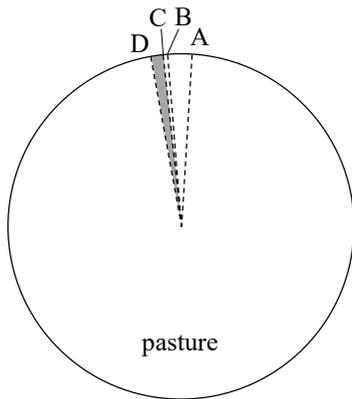


**Pipeline D, Site 11**

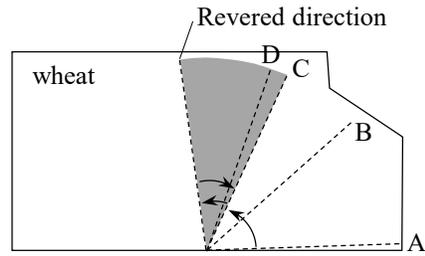


 KCl-treated water applied (approximately)

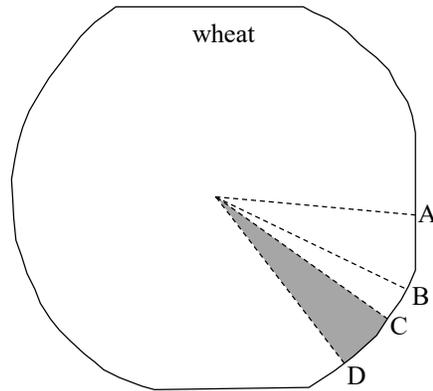
**Pipeline E, Site 2**



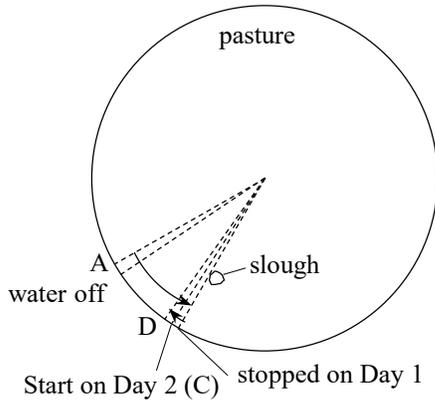
**Pipeline E, Site 5**



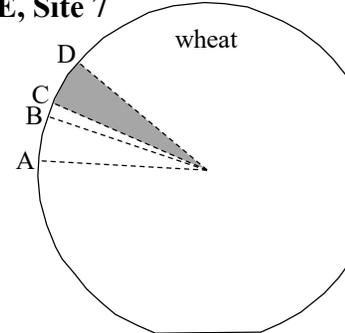
**Pipeline E, Site 6**



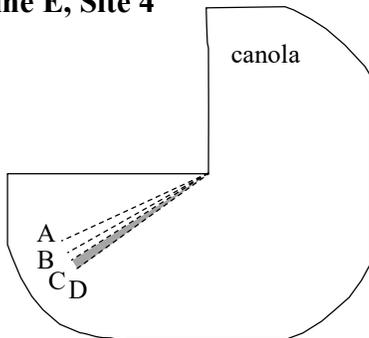
**Pipeline E, Site 3**



**Pipeline E, Site 7**



**Pipeline E, Site 4**



 KCl-treated water applied (approximately)

## Appendix 7.6 Soil description at the five irrigation district pipeline trials

The following soil information was obtained from the Agricultural Region of Alberta Soil Inventory Database (Alberta Soil Information Centre 2018).

### Pipeline A (Eastern Irrigation District)

In the Dry Mixedgrass Natural Subregion

Map unit	Landform	Limiting slope (%)	Soil series	Drainage	Subgroup	Surface texture
HUK16/Uhe	Undulating high relief	4	Hemaruka 60%	Well	Brown Solodized Solontez	Loam
			Misc. Eroded 20%	Well	Rego Brown Chernozem	Clay loam
			Halliday 20%	Well	Brown Solod	Silty loam

### Pipelines B and C (Eastern Irrigation District)

In the Mixedgrass to Dry Mixedgrass Natural Subregions

Map unit	Landform	Limiting slope (%)	Soil series	Drainage	Subgroup	Surface texture
ROL7/H11	Hummocky low relief	6	Ronalaine 60%	Well	Brown Solodized Solontez	Clay loam
			Maleb 20%	Well	Orthic Brown Chernozem	Clay loam
			Halliday 20%	Well	Brown Solod	Silty loam
MCT7/U11	Undulating low relief	2	Milliant 60%	Well	Solonetz Brown Chernozem	Clay loam
			Seven Persons 20%	Well	Orthic Brown Chernozem	Silty clay
			Rosemary 20%	Well	Brown Solod	Clay loam
PTA1/U11e	Undulating low relief	2	Patricia 60%	Well	Brown Solodized Solontez	Clay loam
			Rosemary 20%	Well	Brown Solod	Clay loam
			Stirling 20%	Mod. well	Brown Solonetz	Silty clay

## Pipeline D (Taber Irrigation District)

In the Dry Mixedgrass Natural Subregion

Map unit	Landform	Limiting slope (%)	Soil series	Drainage	Subgroup	Surface texture
BVL1/U11	Undulating Low relief	2	Bingville 80%	Well	Orthic Brown Chernozem	Sandy loam
			Antonio 20%	Well	Orthic Brown Chernozem	Sandy loam
CFCH1/U11	Undulating Low relief	2	Crandford 80%	Well	Orthic Brown Chernozem	Loam
			Chin 20%	Well	Orthic Brown Chernozem	Loam
BVL4/U11	Undulating Low relief	2	Bingville 80%	Well	Orthic Brown Chernozem	Sandy loam
			Misc. Eroded 20%	Well	Rego Brown Chernozem	Clay loam

## Pipeline E (St. Mary River Irrigation District)

In the Mixedgrass Natural Subregion

Map unit	Landform	Limiting slope (%)	Soil series Extent (%)	Drainage	Subgroup	Surface texture
LEWN1/U11	Undulating Low relief	2	Lethbridge 50%	Well	Orthic Dark Brown Chernozem	Loam
			Whitney 50%	Well	Orthic Dark Brown Chernozem	Loam
RDWN11/H11	Hummocky Low relief	6	Readymade 35%	Well	Orthic Dark Brown Chernozem	Silty loam
			Whitney 35%	Well	Orthic Dark Brown Chernozem	Loam
			Kessler 10%	Well	Orthic Dark Brown Chernozem	Sandy loam
			Misc. Eroded 10%	Well	Rego Dark Brown Chernozem	Clay loam
			Lethbridge 10%	Well	Orthic Dark Brown Chernozem	Loam
KSLE8/U1h	Undulating High relief	4	Kessler 30%	Well	Orthic Dark Brown Chernozem	Sandy loam
			Lethbridge 30%	Well	Orthic Dark Brown Chernozem	Loam
			Misc. Eroded 10%	Well	Rego Dark Brown Chernozem	Clay loam
			Oasis 10%	Well	Orthic Dark Brown Chernozem	Loam
			Readymade 10%	Well	Orthic Dark Brown Chernozem	Silty loam
			Misc. Gleysol 10%	Poorly	Orthic Humic Gleysol	Loam
LEWN1/U1h	Undulating High relief	4	Whitney 40%	Well	Orthic Dark Brown Chernozem	Loam
			Lethbridge 40%	Well	Orthic Dark Brown Chernozem	Loam
			Readymade 20%	Well	Orthic Dark Brown Chernozem	Silty loam

## Appendix 7.7 Calculation of stock solution volumes used during the pipeline trials

Pipeline	Duration of injection (min)	Flow at pipeline inlet (L s <sup>-1</sup> )	Stock solution concentration (mg L <sup>-1</sup> K <sup>+</sup> )	Stock solution injection rate (L min <sup>-1</sup> ) <sup>z</sup>	Stock solution injected (L)	KCl load injected (kg) <sup>y</sup>
A	111	58	112,000	3.11	345	73.7
B	38	205	74,261	16.56	629	89.1
	3	90	74,261	7.27	22	3.1
	3	85	74,261	6.87	21	2.9
	16	90	74,261	7.27	116	16.5
	78	95	74,261	7.68	599	84.8
	2	55	74,261	4.44	9	1.3
	21	50	74,261	4.04	85	12.0
C	2	118.9	78,850	9.05	18	2.7
	34	108	78,850	8.22	279	42.0
	30	115	78,850	8.75	263	39.5
	10	109	78,850	8.29	83	12.5
	16	114	78,850	8.67	139	20.9
	17	111	78,850	8.45	144	21.6
	7	112	78,850	8.52	60	9.0
	7	104	78,850	7.91	55	8.3
	2	56	78,850	4.26	9	1.3
	14	52	78,850	3.96	55	8.3
D	183	243	107,900	13.51	2473	508.8
	34	175	107,900	9.73	331	68.1
	24	110	107,900	6.12	147	30.2
	5	175	107,900	9.73	49	10.0
	20	120	107,900	6.67	133	27.5
	7	63	107,900	3.50	25	5.0
	12	123	107,900	6.84	82	16.9
	15	183	107,900	10.18	153	31.4
	3	120	107,900	6.67	20	4.1
	11	56	107,900	3.11	34	7.0
	13	116	107,900	6.45	84	17.3
36	170	107,900	9.45	340	70.0	
E	57	285	54,400	31.43	1792	185.9
	30	228	54,400	25.15	754	78.3
	8	171	54,400	18.86	151	15.7
	1	114	54,400	12.57	13	1.3
	51	57	54,400	6.29	321	33.3
A	111	–	–	–	345	73.7
B	161	–	–	–	1481	209.7
C	139	–	–	–	1105	166.1
D	363	–	–	–	3871	796.3
E	147	–	–	–	3031	314.5
Total	–	–	–	–	9833	1560.3

<sup>z</sup> Calculated based on the flow at the pipeline inlet and the concentration of potassium (K<sup>+</sup>) in the stock solution.

<sup>y</sup> The mass of K<sup>+</sup> in the volume of stock solution was converted to KCl.

Estimates of stock solution used based of the initial and final volumes in the transport tank:

Pipeline A: 425 L      Pipeline B: 1500 L      Pipeline C: 1050 L  
 Pipeline D: 3600 L      Pipeline E: 2800 L

## Appendix 7.8 Chronological order of main events during each pipeline trial

---

### Pipeline A in 2016

---

#### July 4 Pre-trial events

Collected one water sample from the settling pond  
Collected soil moisture samples from four sites in the field  
The position of the pivot was recorded with a GPS unit (Position A)

#### July 5 Injection phase

Pivot started at 10:16 (Position A)  
Three background samples collected at Sites 1 and 4 at 5, 10, and 15 min after the pivot started  
KCl injection pump started at 10:34  
Site 1 (settling pond) sampled 11 times in 10-min intervals (10:44–12:24)  
Site 2 (turn out) sampled 11 times in 10-min intervals (10:44–12:24)  
Site 3 (turn out) sampled nine times in 10-min intervals (10:54–12:14)  
Site 4 (pivot) sampled five times in 10-min intervals (11:14–11:45)  
Site 4 pivot reached Position B (11:44)  
Site 4 sampled three times to confirm steady concentration of K<sup>+</sup> (11:59, 12:02, 12:06)  
Site 4 sampled three times for lab analysis (12:11, 12:16, 12:21)  
Site 4 pivot was stopped and turned off at 12:25 (Position C)  
KCl injection pump turned off at 12:25  
Pipeline inlet closed (12:27)  
Settling pond inlet gate closed (12:27)  
Canal outlet gate closed (12:34)  
The position of the pivot was recorded with a GPS unit  
Soil chemistry samples were collected from 10 locations in front of the pivot

#### July 6 24-h water samples

Three water samples were collected at Sites 1, 2, 3, and 4 (12:15–12:52)

#### July 7 Purging phase

Three water samples were collected from Sites 1, 2, 3, and 4 (9:20–9:49)  
Five rain gauges were installed in front of the pivot  
Pipeline inlet opened (9:51)  
Canal gate and settling pond inlet gate were opened  
Pivot valve at Site 3 opened (9:52)  
Pivot started at 9:56 (Position C)  
Site 1 was no longer sampled<sup>z</sup>  
Site 2 sampled nine times in 10-min intervals (10:04–11:26)  
Site 3 sampled eight times in 10-min intervals (10:16–11:26)  
Site 4 sampled nine times in 10-min intervals (10:36–11:26) — background concentration reached  
Site 4 sampled three times for lab analysis (11:31–11:41)  
Position of pivot was recorded after background concentration was confirmed at 11:26 (Position D)  
Pivot turned off at 11:45  
Rain gauges recorded and removed  
The four soil moisture sites were resampled  
The 10 soil chemistry sampling points were resampled

---

<sup>z</sup> The three samples collected at Site 1 on July 7 prior to turning on the pivot were tested in the field. The results showed the K<sup>+</sup> in the settling pond was at background concentration, and as a result, the pond was no longer sampled.

---

**Pipeline B in 2017**

---

**June 7 Injection phase**

Pivots at Sites 2 (14:49), 3 (14:45), and 4 (15:05) turned on (Position A)  
KCl injection started (15:20)  
Site 1 (settling pond) sampled 17 times (15:30–18:10)  
Site 2 pivot sampled 19 times (15:25–16:00)<sup>z</sup>  
Site 3 pivot sampled 18 times (16:00–17:56)  
Site 4 pivot sampled 14 times (16:30–17:36)  
Site 2 pivot at Position B (15:55)  
Site 2 pivot stopped (16:00) Position C  
Site 4 pivot at Position B (17:25)  
Site 4 pivot stopped (17:38) Position C  
Site 3 pivot at Position B (17:50)  
Site 3 pivot stopped (after 17:56) Position C  
KCl injection stopped (18:01)  
Inlet gate closed (18:04)  
Soil chemistry samples were collected from Sites 2, 3, and 4: transect of 10 sampling points per site

**June 8 24-h water samples**

Three water samples were collected at Sites 1 and 4 (11:35–12:40)

**June 9 Purging phase**

Three water samples were collected from Site 1 (14:40–14:44)  
Site 1 was no longer sampled<sup>y</sup>  
Five rain gauges were installed in front of the pivots at the soil sampling points<sup>x</sup>  
Site 2 pivot turned on (16:52) and three lab samples collected (16:53–16:54)  
Site 2 pivot sampled eight times (16:53–17:28)  
Site 2 pivot at Position D (17:22)  
Site 3 pivot turned on (17:01 estimated) and three lab samples collected (17:01–17:09)<sup>w</sup>  
Site 3 pivot sampled 19 times (17:01–19:34)  
Site 3 pivot at Position D (19:20)  
Site 4 pivot turned on (16:55) and three lab samples collected (16:55–16:59)<sup>w</sup>  
Site 4 pivot sampled 17 times (16:55–19:09)  
Site 4 pivot at Position D (19:00)  
Rain gauges recorded and removed  
The 10 soil chemistry sampling points were resampled for each pivot site

---

<sup>z</sup> Shortly after the K<sup>+</sup> concentration peaked, the pivot shutdown due to power supply malfunction. The three laboratory samples were collected immediately after the shutdown.

<sup>y</sup> The three samples collected at Site 1 on July 7 prior to turning on the pivot were tested in the field. The results showed the K<sup>+</sup> in the settling pond was at background concentration, and as a result, the pond was no longer sampled.

<sup>x</sup> Rain gauges were not installed at Site 2. The pivot was set to deliver about 6.4 mm.

<sup>w</sup> Sites 3 and 4 pivots were operated counter clockwise on June 7 and clockwise on June 9.

---

**Pipeline C in 2017**

---

**June 20 Injection phase**

Pivots at Sites 2 (09:27) and 3 (time not recorded) turned on (Position A)  
KCl injection started (09:44)  
Site 1 (settling pond) sampled 19 times (09:15–12:39)  
Site 2 pivot sampled 16 times (10:44–11:38)  
Site 3 pivot sampled seven times (11:33–11:57)  
Site 2 pivot at Position B (11:25)  
Site 2 pivot stopped (11:45) Position C  
Site 3 pivot at Position B (11:48)  
Site 3 pivot stopped (time not recorded) Position C  
KCl injection stopped at 12:03  
Inlet gate closed (12:04)  
Soil chemistry samples were collected from Sites 2 and 3: transect of 10 sampling points per site

**June 21 Purging phase**

Three water samples were collected from Site 1 (13:58–14:08)  
Site 1 was no longer sampled<sup>y</sup>  
Five rain gauges were installed in front of the pivots at the soil sampling points  
Site 2 pivot turned on (14:50) and three lab samples collected (14:52–15:00)  
Site 2 pivot sampled 23 times (16:53–17:28)  
Site 2 pivot at Position D (16:28)  
Site 3 pivot turned on (15:00 estimated) and three lab samples collected (15:00)  
Site 3 pivot sampled 11 times (15:00–16:57)  
Site 3 pivot at Position D (16:53)  
Rain gauges recorded and removed (three gauges were blown over by wind)  
The 10 soil chemistry sampling points were resampled for each pivot site

---

<sup>z</sup> Shortly after the K<sup>+</sup> concentration peaked, the pivot shutdown due to a GPS system failure. The three laboratory samples were collected immediately after the shutdown.

<sup>y</sup> The three samples collected at Site 1 on July 7 prior to turning on the pivot were tested in the field. The results showed the K<sup>+</sup> in the settling pond was at background concentration, and as a result, the pond was no longer sampled.

---

**Pipeline D in 2017**

---

**Sep. 12 Injection phase**

Pivots at Sites 2<sup>z</sup> (09:05), 3<sup>y</sup> (09:20), 6 (09:23), and 8<sup>x</sup> (time not recorded) turned on (Position A)  
KCl injection started (09:33)  
Site 1 (settling pond) sampled 19 times (09:43–15:43) Sampled every 30 min after the tenth sample  
Site 2 pivot sampled 42 times (10:44–11:38)  
Site 2 pivot at Position B (12:38)  
Site 2 pivot stopped (13:07) Position C  
Site 3 pivot sampled nine times (12:00–12:32)  
Site 3 pivot at Position B (12:15)  
Site 3 pivot stopped (time not recorded) Position C  
Site 6 pivot sampled 20 times (10:00 –13:34)  
Site 6 pivot at Position B (13:24)  
Site 6 pivot stopped (13:30) Position C  
Site 8 pivot sampled 12 times (13:25–14:28)  
Site 8 pivot at Position B (14:24)  
Site 8 pivot stopped (time not recorded) Position C  
Site 4 pivot started (13:30) Position A  
Site 4 pivot sampled seven times (13:35–13:52)  
Site 4 pivot at Position B (13:40)  
Site 4 pivot stopped (approximately 13:42) Position C  
Site 9 pivot started (14:05) Position A  
Site 9 pivot sampled 15 times (14:14–15:48)  
Site 9 pivot at Position B (15:34)  
Site 9 pivot stopped (15:48) Position C  
Site 10 pivot started (14:29) Position A  
Site 10 pivot sampled 10 times (14:14–15:48)  
Site 10 pivot at Position B (15:20)  
Site 10 pivot stopped (15:37) Position C  
Site 11 pivot started (time not recorded) Position A  
Site 11 pivot sampled six times (15:37–16:10) Ran out of potash stock solution before KCl reached this site  
Site 11 pivot stopped (time not recorded, after 16:10)  
KCl injection stopped at 15:36  
Inlet gate closed (time not recorded)  
Soil chemistry samples collected from Sites 2, 3, 4, 6, 8, 9, and 10: 10 sampling points per site

**Set. 13 Purging phase**

Three water samples were collected from Site 1 (08:48–09:00)  
Site 1 was no longer sampled<sup>w</sup>  
Three rain gauges were installed in front of the pivots at the soil sampling points<sup>v</sup>  
Site 2 pivot turned on (09:37) and three lab samples collected (09:40–09:44)<sup>z</sup>  
Site 2 pivot sampled 22 times (09:40–12:08)  
Site 2 pivot at Position D (11:56)  
Site 3 pivot turned on (09:37) and three lab samples collected (09:08–09:18)  
Site 3 pivot sampled 21 times (09:08–11:55)  
Site 3 pivot at Position D (11:35)  
Site 6 pivot turned on (09:16) and three lab samples collected (09:19–09:29)<sup>u</sup>  
Site 6 pivot sampled 29 times (09:16–12:32)  
Site 6 pivot at Position D (12:20)  
Site 8 pivot turned on (09:11) and three lab samples collected (09:20–09:24)  
Site 8 pivot sampled 26 times (09:16–12:32)  
Site 8 pivot at Position D (13:00)

---

---

**Pipeline D in 2017 (continued)**

---

Site 4 pivot turned on (12:48) and three lab samples collected (12:50–12:59)  
Site 4 pivot sampled six times (12:50–13:10)  
Site 4 pivot at Position D (12:55)  
Site 9 pivot turned on (14:00) and three lab samples collected (14:05–14:09)  
Site 9 pivot sampled 10 times (14:05–15:12)  
Site 9 pivot at Position D (15:00)  
Site 10 pivot turned on (14:00) and three lab samples collected (14:00–14:04)  
Site 10 pivot sampled 12 times (14:00–14:39)  
Site 10 pivot at Position D (14:31)  
Site 11 pivot was operating when crew arrived at 14:10. Three lab samples collected (14:15–14:25)  
Site 11 pivot sampled 15 times (15:00–16:57)  
Site 11 pivot at Position D (15:55)  
Rain gauges recorded and removed  
The 10 soil chemistry samples points were resampled at Sites 2, 3, 4, 6, 8, 9, and 10.  
Site 12 side-roll system was turned on to complete the purging of the pipeline.

---

<sup>z</sup> Site 2 pivot was operated at 100% during injection and at 20% during purging.

<sup>y</sup> During injection, the pivot drop tube used for sampling became disconnected at 11:40. The pivot was stopped for a few seconds and the tube was reattached.

<sup>x</sup> Site 8 pivot was operated clockwise during injection and counter clockwise during purging.

<sup>w</sup> The three samples collected at Site 1 on September 13 prior to turning on the pivots were tested in the field. The results showed the K<sup>+</sup> in the settling pond was at background concentration, and as a result, the pond was no longer sampled.

<sup>v</sup> Rain gauges were not installed at Sites 8 and 11.

<sup>u</sup> Site 6 pivot shut down at 10:30 and was restarted at 10:36.

---

**Pipeline E in 2017**

---

**Sep. 19****Injection phase**

Pivots at Sites 2 (09:50), 4 (10:10), 5 (10:00), 6 (10:10), and 7 (10:10) turned on (Position A)

KCl injection started (10:20)

Site 1 (settling pond) sampled 16 times (10:30–13:00)

Site 2 pivot sampled 10 times (10:05–11:08)

Site 2 pivot at Position B (10:50)

Site 2 pivot stopped (about 11:15) Position C

Site 3 pivot started at 11:25 (counter clockwise)

Site 3 pivot sampled seven times (11:33–11:55)

Site 3 pivot at Position B (after 11:25 and before 11:33)

Site 3 pivot water flow stopped at 12:00, but continued to move until 15:00 stopping near slough

Site 4 pivot sampled 11 times (10:15–11:12)

Site 4 pivot at Position B (11:00)

Site 4 pivot stopped (about 11:20) Position C

Site 4 pivot sampled 11 times (10:15–11:12)

Site 4 pivot at Position B (11:00)

Site 4 pivot stopped (about 11:20) Position C

Site 5 pivot sampled 10 times (10:22–11:27)

Site 5 pivot at Position B (11:07)

Site 5 pivot stopped (11:45) Position C

Site 6 pivot sampled 11 times (10:35–11:38)

Site 6 pivot at Position B (11:18)

Site 6 pivot stopped (about 11:50) Position C

Site 7 pivot sampled 18 times (10:20–12:14)

Site 7 pivot at Position B (11:25)

Site 7 pivot stopped (about 12:50) Position C

KCl injection stopped at 12:47

Inlet gate closed (12:54)

Canal gate closed (12:54)

Soil chemistry samples were collected at Sites 2, 4, 5, 6 and 7: transect of 10 sampling points per site<sup>z</sup>

**Sep. 20****Purging phase**

Three water samples were collected from Site 1 (08:55)

Site 1 was no longer sampled<sup>y</sup>

Three rain gauges were installed in front of the pivots at the soil sampling points

Site 2 pivot turned on (09:45) and three lab samples collected (09:45–09:50)

Site 2 pivot sampled nine times (09:45–10:25)

Site 2 pivot at Position D (10:10)

Site 3 pivot moved (clockwise) about 30 m away from slough to Position C

Site 3 pivot turned on (10:40) and three lab samples collected (10:40), moving clockwise

Site 3 pivot sampled 10 times (10:40–11:12)

Site 3 pivot at Position D (10:45)

Site 4 pivot turned on (09:40) and three lab samples collected (09:40–09:44)

Site 4 pivot sampled 13 times (09:40–10:27)

Site 4 pivot at Position D (10:17)

Site 5 pivot turned on (09:45) and three lab samples collected (09:46–09:48)

Site 5 pivot reversed direction (clockwise)

Site 5 pivot at Position D (10:31) — did not reach soil sampling points

Site 6 pivot turned on (09:50) and three lab samples collected (09:52–09:55)

Site 6 pivot at Position D (10:33)

Site 7 pivot turned on (09:58) and three lab samples collected (10:00–10:04)

Site 7 pivot at Position D (10:45)

Rain gauges recorded and removed

The 10 soil chemistry sampling points were resampled for each pivot site

---

<sup>z</sup> The pre-KCl soil samples were collected at Site 3 on September 20 prior to re-starting the pivot.

<sup>y</sup> The three samples collected at Site 1 on September 20 prior to turning on the pivot were tested in the field. The results showed the K<sup>+</sup> in the settling pond was at background concentration, and as a result, the pond was no longer sampled.

## Appendix 7.9 Centre-pivot systems used in the pipeline trials

Pipeline	Site	Pivot discharge <sup>z</sup> (L s <sup>-1</sup> )	Number of towers	Length of pivot (m)
A	4	58	6	330
	2	110.4	12	600
B	3	53.80	8	400
	4	56.63	8	450
C	2	56.63	8	400
	3	na <sup>y</sup>	10	520
D	2	69.40	7	390
	3	59.94	7	345
	4	66.24	7	400
	6	50.47	8	385
	8	63.09	7	385
	9	59.94	7	385
	10	59.94	6	380
	11	59.94	6	355
E	12 <sup>x</sup>	9.46		
	2	56.92	7	390
	3	56.92	7	400
	4	56.92	10	400
	5	56.92	7	400
	6	56.92	8	470
	7	56.92	8	390

<sup>z</sup> Many of these values are estimates and not actually in-field measured values. These values can vary depending when end arms or end guns or both are turned on.

<sup>y</sup> na = not available.

<sup>x</sup> Side-roll irrigation system.

**Appendix 7.10 Amount of water and actual concentrations of potassium (K<sup>+</sup>), chloride (Cl<sup>-</sup>), and electrical conductivity (EC) applied at the small-plot site in 2016 and 2017**

Application date	Treatment (mg L <sup>-1</sup> K <sup>+</sup> )	Replicate	Plot number	Water applied (mm) <sup>z</sup>	Concentration applied		
					K <sup>+</sup> (mg L <sup>-1</sup> )	Cl <sup>-</sup> (mg L <sup>-1</sup> )	EC (dS m <sup>-1</sup> )
August 5, 2016	0	A	1	15.0	1.95 <sup>y</sup>	4.96 <sup>y</sup>	0.21
	0	B	5	15.0	1.95	4.96	0.21
	0	C	7	13.0	1.95	4.96	0.22
	0	D	11	na	1.95	4.96	0.21
	100	A	3	15.0	91.5	88.6	0.56
	100	B	6	15.0	87.2	85.1	0.55
	100	C	8	14.0	76.2	74.5	0.50
	100	D	10	na	83.3	81.5	0.53
	500	A	2	15.0	450.8	421.9	1.88
	500	B	4	15.0	463.7	418.3	1.88
	500	C	9	14.0	439.5	407.7	1.85
	500	D	12	15.0	446.9	414.8	1.88
August 16, 2016	0	A	1	14.25	1.95	4.96	0.22
	0	B	5	14.5	1.95	4.96	0.22
	0	C	7	13.0	1.95	4.96	0.22
	0	D	11	14.0	1.95	4.96	0.22
	100	A	3	13.0	106.0	99.3	0.62
	100	B	6	14.5	181.8	173.7	0.91
	100	C	8	14.0	106.7	99.3	0.62
	100	D	10	16.0	105.2	99.3	0.62
	500	A	2	na	504.0	482.2	2.12
	500	B	4	14.5	520.0	492.8	2.17
	500	C	9	14.5	505.2	478.6	2.10
	500	D	12	14.25	499.3	475.1	2.11
September 16, 2016	0	A	1	14.0	1.95	4.96	0.23
	0	B	5	14.0	1.95	4.96	0.23
	0	C	7	14.0	1.95	4.96	0.22
	0	D	11	16.0	1.95	4.96	0.23
	100	A	3	13.5	129.0	124.1	0.71
	100	B	6	14.0	70.4	67.4	0.48
	100	C	8	14.0	101.7	95.7	0.61
	100	D	10	16.0	106.0	95.7	0.61
	500	A	2	14.0	468.0	443.2	1.96
	500	B	4	13.0	501.6	478.6	2.09
	500	C	9	14.0	567.7	521.2	2.27
	500	D	12	15.0	451.6	421.9	1.89

<sup>z</sup> From manual rain gauges placed in the subplots.

<sup>y</sup> Results were less the detection limit for K<sup>+</sup> (3.9 mg L<sup>-1</sup>) and Cl<sup>-</sup> (9.927 mg L<sup>-1</sup>). Values were set to half the detection limits.

<sup>x</sup> na = not available. For calculation purposes, the overall mean of 14.5 mm was used for these values.

Application date	Treatment (mg L <sup>-1</sup> K <sup>+</sup> )	Replicate	Plot number	Water applied (mm) <sup>z</sup>	Concentration applied		
					K <sup>+</sup> (mg L <sup>-1</sup> )	Cl <sup>-</sup> (mg L <sup>-1</sup> )	EC (dS m <sup>-1</sup> )
July 11, 2017	0	A	1	13.0	1.95	4.96	0.23
	0	B	5	15.0	1.95	4.96	0.23
	0	C	7	17.0	1.95	4.96	0.23
	0	D	11	14.0	1.95	4.96	0.24
	100	A	3	14.0	104.9	99.3	0.63
	100	B	6	16.0	97.4	95.7	0.60
	100	C	8	14.0	155.5	152.4	0.82
	100	D	10	15.0	101.7	99.3	0.62
	500	A	2	12.0	1.95	4.96	0.23
	500	B	4	14.0	1.95	4.96	0.23
	500	C	9	15.0	1.95	4.96	0.23
	500	D	12	14.0	1.95	4.96	0.24
July 17, 2017	0	A	1	14.0	1.95	4.96	0.23
	0	B	5	14.0	1.95	4.96	0.23
	0	C	7	14.0	1.95	4.96	0.23
	0	D	11	14.0	1.95	4.96	0.23
	100	A	3	14.0	101.7	99.3	0.62
	100	B	6	14.0	101.7	99.3	0.62
	100	C	8	15.0	106.7	102.8	0.64
	100	D	10	na	102.8	99.3	0.62
	500	A	2	14.0	1.95	4.96	0.23
	500	B	4	13.0	1.95	4.96	0.23
	500	C	9	15.0	1.95	4.96	0.23
	500	D	12	13.0	1.95	4.96	0.23
July 20, 2017	0	A	1	14.0	1.95	4.96	0.22
	0	B	5	15.0	1.95	4.96	0.22
	0	C	7	16.0	1.95	4.96	0.22
	0	D	11	16.0	1.95	4.96	0.23
	100	A	3	14.0	106.3	102.8	0.62
	100	B	6	16.0	106.0	99.3	0.61
	100	C	8	18.0	91.1	88.6	0.57
	100	D	10	13.0	102.4	99.3	0.62
	500	A	2	15.0	1.95	4.96	0.22
	500	B	4	14.0	1.95	4.96	0.22
	500	C	9	20.0	1.95	4.96	0.22
	500	D	12	16.0	1.95	4.96	0.22

<sup>z</sup> From manual rain gauges placed in the subplots.

<sup>y</sup> Results were less the detection limit for K<sup>+</sup> (3.9 mg L<sup>-1</sup>) and Cl<sup>-</sup> (9.927 mg L<sup>-1</sup>). Values were set to half the detection limits.

<sup>x</sup> na = not available. For calculation purposes, the overall mean of 14.5 mm was used for these values.