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

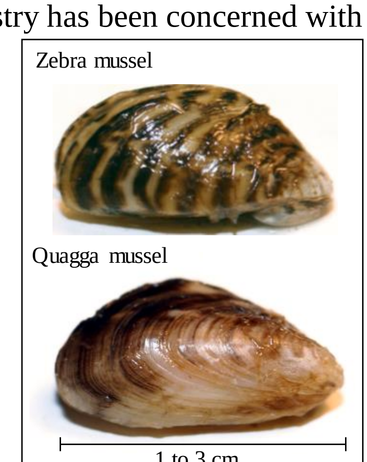
Summary

2018

Contents

1. 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®, 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^+) 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^3), 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.

2. Project 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^{-1} of 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.

3. Potash Preparation and Field Studies

Potash Preparation

Methods

For the purpose of the current research project, a concentration of 100 mg L^{-1} 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® Inc. (now Nutrien™), 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 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 mg L^{-1} K^+ (Figure 1).

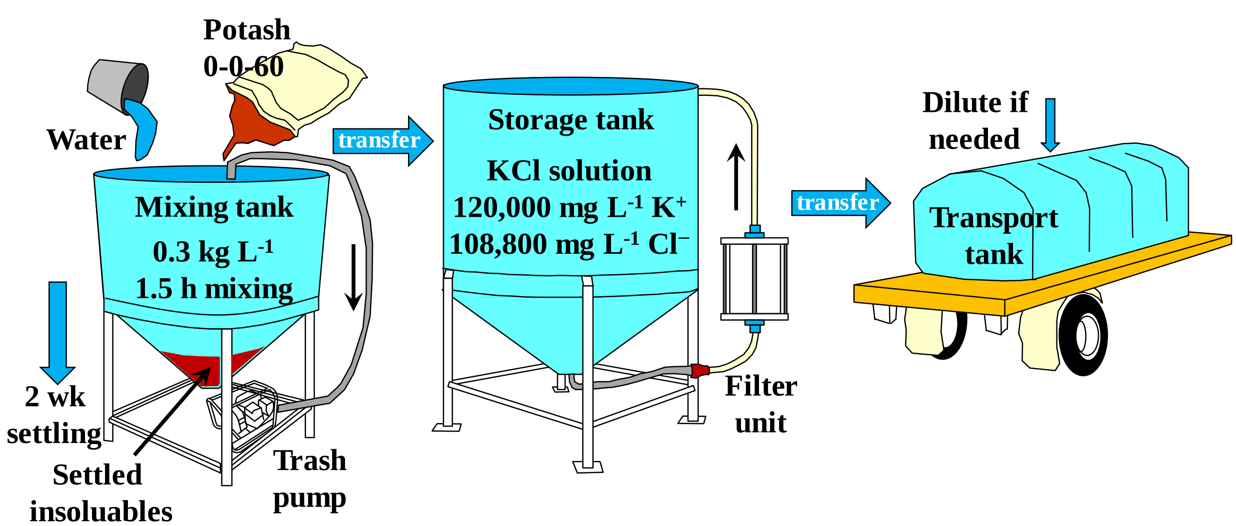


Figure 1 Preparation of potassium chloride (KCl) stock solution for injection into irrigation pipeline field trial.

Key Findings

- 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^{-1} K^+, 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

Methods

Five irrigation-district pipelines were selected for the study: three in the Eastern Irrigation District (Pipelines A, B, and C), one in the Taber Irrigation District (Pipeline D), and one in the St. Mary River Irrigation District (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[z]	District[y]	Total length[x] (km)	Total volume[x] (m^3)	Pipe diameter at inlet (m)	Number of irrigation systems on pipeline	Number of irrigation systems used[w]	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

[z] Actual names of the pipelines were not used for reporting purposes.
[y] EID = Eastern Irrigation District; TID = Taber Irrigation District; SMRID = St. Mary River Irrigation District.
[x] Includes district- and producer-owned pipelines.
[w] All were centre-pivot systems used in the trials.

Stock solution of KCl (54,400 to 112,000 mg L^{-1} K^+) 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 2). The target concentration in the pipelines was 100 mg L^{-1} K^+, which has been used as a lethal concentration in other jurisdictions. Irrigation water in Alberta typically contains on average 2.4 mg L^{-1} K^+. 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^+ 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^+ 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^+ 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.

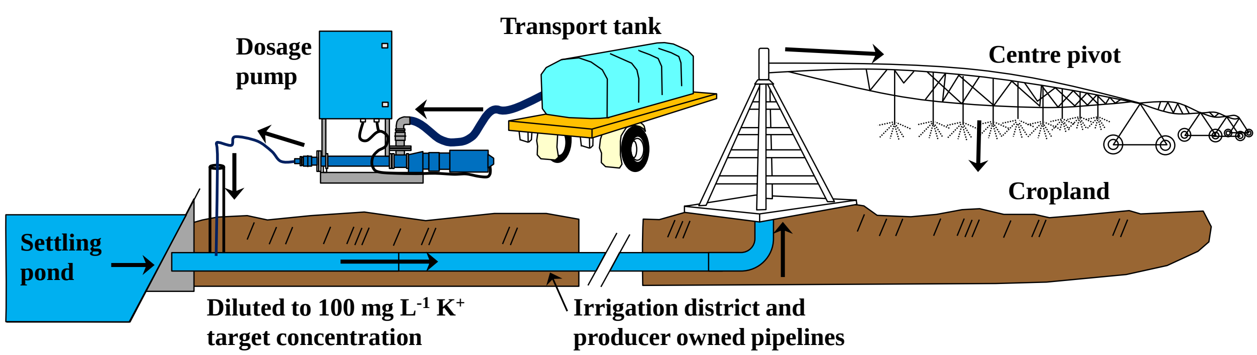


Figure 2 Schematic diagram showing the main components of the KCl-injection arrangement.

Key Findings

- 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^+ achieved was near the target value (i.e., 100 mg L^{-1} K^+) for three of the pipelines. The K^+ concentration was 106 mg L^{-1} for Pipeline A, 102 to 105 mg L^{-1} for pipeline B, and 89 mg L^{-1} for Pipeline C.
- The concentration was consistently high for Pipeline D (122 to 130 mg L^{-1} K^+) and consistently low for Pipeline E (77 to 86 mg L^{-1} K^+).
- It is believed that inaccurate estimates of water flow through Pipelines D and E caused the K^+ 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^+ and the amount of water applied, the application rate of K^+ on the fields ranged from 3 to 29 kg ha^{-1}, with a mean of 12 kg ha^{-1} among the fields.
- The amount of K^+ 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^{-1} depending on the crop type.

- The EC of KCl-treated water ranged from 0.52 to 0.84 dS m^{-1} among the pivots, with an overall mean of 0.66 dS m^{-1}. Water in Alberta with an EC value less than 1 dS m^{-1} and a sodium adsorption ratio less than 5 is considered safe for irrigation.
- Extractable K^+ 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^+ 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^-) 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^- 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^{-3} 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

Methods

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^{-1} 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 3). The treatments were three application rates of K^+ in irrigation water: 0, 100, 500 mg L^{-1} (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^+ and Cl^- 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^{-1} K^+) 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^{-1} (2016 and 2017) or 500 mg L^{-1} (2016) K^+ concentration in the centre pivot and delivered through the nozzles. The actual K^+ 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^{-1} with a mean of 105 mg L^{-1}. The application concentration of K^+ for 500T ranged from 439 to 568 mg L^{-1} with a mean of 485 mg L^{-1} 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^+, and extractable Cl^-. 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.

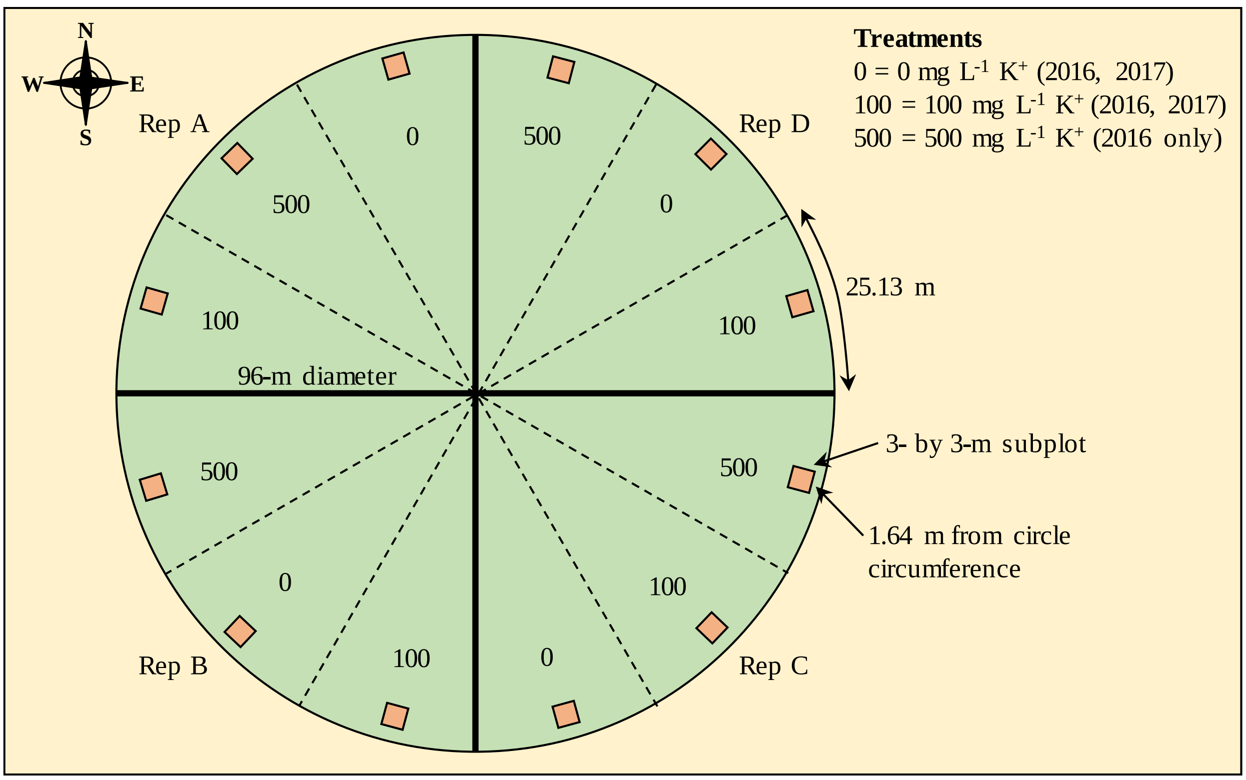


Figure 3 The experimental design of the small-plot study.

Key Findings

- Repeated applications of KCl-treated water caused an increase in soil K^+, Cl^-, and EC.
- Residual K^+ remained in the top soil layer (0 to 15 cm); whereas, Cl^- 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^{o} 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^+ 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, 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 needed to be assessed if the treatment of individual irrigation systems is determined to be a viable option.

4. Strategic Pest Management Plan and Cost Estimate Study

Study Methodology

This study was carried out to obtain a comprehensive strategic management plan for the control and management of invasive dreissenid mussels in Alberta's irrigation distribution systems. The study assessed relevant North American data for the control and management of dreissenid mussels, the Government of Alberta (GoA) dreissenid mussel prevention strategies being undertaken, existing water quality and water temperature data for irrigation water supply reservoirs and irrigation distribution systems, and current research data developed by Alberta Agriculture and Forestry for successful injection of KCl into irrigation water supply pipelines.

The study focussed on five key objectives:

1. Assess the potential for dreissenid mussels to develop and grow in Alberta's irrigation water supply reservoirs and irrigation distribution systems.
2. Assess additional prevention techniques to minimize the potential for dreissenid mussels to establish in Alberta's irrigation water supply reservoirs.
3. Prepare a strategic pest management plan for the irrigation districts for a coordinated invasive mussel control program.
4. Develop a range of dreissenid mussel management and treatment approaches for injecting KCl into irrigation district water supply pipelines, and irrigation producer-owned water supply pipelines and on-farm irrigation systems.
5. Prepare estimates of the annual operational costs associated with KCl treatment approaches in the 13 irrigation districts.

Conclusions

Alberta is fortunate that dreissenid mussels do not appear to be currently present in any of the province's water bodies. The extensive irrigation water supply network in southern Alberta will be especially vulnerable if invasive mussels are introduced to irrigation water supply reservoirs in the province. An enhanced program to prevent the introduction of dreissenid mussels into these reservoirs should be a high priority for the GoA and irrigation districts.

This work identifies the need for Alberta's irrigation districts and GoA to prevent the spread of dreissenid mussels into irrigation water supply reservoirs, and potential management and control options if a mussel infestation occurs. An enhanced prevention strategy includes controlling boat launch sites on reservoirs to certify that all incoming boats and other watercraft are free of mussels, combined with a comprehensive public education program. Targeted monitoring of irrigation water supply reservoirs will help irrigation districts better understand the growth and development potential of the dreissenid mussels, and this will support the development and assessment of more effective mussel management and control options.

Southern Alberta's relatively long and cold winters are considered a key element in the control of dreissenid mussels in water supply reservoirs, irrigation canals, and pipelines. Where winter desiccation and freezing are not practical for selected pipelines, injection of KCl solution (potash) into mussel-infected pipelines is considered to be the most effective, practical, and environmentally benign mussel control option available to the irrigation districts. While there are many other chemical and non-chemical treatment options that are being used to control dreissenid mussels, most are being used in relatively small, stand-alone operations.

The following provides a more detailed description of the key conclusions and supporting rationale.

Dreissenid mussels (zebra and quagga) entered the eastern United States from Europe in the 1980s, and have since spread to the Great Lakes and waterways, rivers, and lakes in many parts of North America.

- Dreissenid mussels can reproduce rapidly, and the accumulation of adult mussels results in challenges due to fouling of water structures and pipelines.
- Ongoing management and treatment costs to control dreissenid mussels can be very high for industries and municipalities.
- In 2013, the total annual cost of invasive mussel control for Alberta was calculated at about $75.5 million.
- This total cost does not include costs associated with irrigation district or rural water supply pipelines.

It is likely that dreissenid mussels will appear in irrigation water supply reservoirs under the current prevention program being implemented in Alberta.

- Recreational boats are the primary means by which dreissenid mussels move from one body of water to another. Adult mussels attach to the hull of boats, larval stages can be transported in water filled internal ballast tanks or live wells, and both life stages can survive overland transport to new water bodies.
- In 2013, zebra mussels were found in Lake Winnipeg (Manitoba). There was concern that mussels had been discovered in the Tiber Reservoir (Montana) in November 2016. However, further investigations carried out in 2017 found no evidence of mussels.

Oldman dam and reservoir

- In 2013, mussel-infested boats were discovered at inspection stations at several central Alberta lakes (Sylvan, Pigeon, Gull, and Wabamun lakes), and Chestermere Lake, which supplies water to the WID in southern Alberta.
- The discovery of dreissenid mussels in water bodies that are relatively close to southern Alberta's borders, combined with the high volume of boat and watercraft traffic into Alberta from mussel-infested areas in Canada and the United States, makes it likely that dreissenid mussels will be introduced into Alberta irrigation water supply reservoirs in the future

Alberta's irrigation water supply reservoirs and irrigation district water supply infrastructure will support the growth and development of dreissenid mussels.

- Key factors such as calcium, pH, dissolved oxygen, and temperature in irrigation water supply reservoirs and water supply infrastructure meet the requirements for dreissenid growth and development.
- Mussel development will likely be limited to the shallower portions in many of the irrigation water supply reservoirs, where summer water temperatures are warmer.
- Growth rates for the dreissenid mussels are expected to be 1 to 1.5 mm mo^{-1} for most of the reservoirs.
- The length of the reproductive season is likely to be relatively short, as reproductive temperature timelines are generally short for most irrigation water supply reservoirs in southern Alberta. Increasing temperatures related to climate change may increase the length of the reproductive season.

- From the time mussels first appear in an upstream reservoir to when there is an adequate number of veligers present to settle in downstream irrigation systems will likely take 3 to 5 yr.
- Only one irrigation water supply reservoir in Alberta may be naturally resistant to mussel establishment. High levels of naturally occurring K^+ in Cavan Lake Reservoir will likely prevent growth and development of dreissenid mussels in the Ross Creek Irrigation District.

A mussel infestation in an upstream reservoir will likely affect several downstream reservoirs, and the rivers that accept return water related to the infested reservoir(s).

- Active treatment of most water supply reservoirs to eradicate these mussels is not feasible.
- Since mussel development will mainly take place in the shallower zones of most irrigation water supply reservoirs, drawdown of these reservoirs for normal winter operations will kill any exposed mussels due to desiccation and freezing.
- Once a reservoir becomes infected, water supply canals and underground pipelines located downstream of the infested reservoirs will become infested.
- Control and eradication of the dreissenid mussels in the irrigation water supply infrastructure will likely become the focus of the irrigation districts.

Natural desiccation and freezing during the winter provides the most cost-effective means of controlling dreissenid mussels in Alberta's irrigation water supply canals and pipelines.

- Southern Alberta winters, which require that all irrigation water delivery and on-farm irrigation systems be drained, can effectively kill exposed mussels.
- Mussels in surface canals are particularly vulnerable during the winter months, and 100% mortality is expected each winter.
- All exposed mussels in underground pipelines will be killed through desiccation during the winter months, because of prolonged exposure and relatively low humidity.
- Mussels present in pools of water that remain in pipelines after drainage in the fall may survive the winter if the water does not freeze, and dissolved oxygen levels exceed 3 mg L^{-1}.
- Complete drainage of underground pipelines, and/or exposure of pipelines to cold winter air, is required to ensure complete mortality of mussels during the winter season.

Canal full of water in the Bow River Irrigation District

Currently, there are no registered control options for invasive mussels in open bodies of water or irrigation pipelines in Canada.

- To date, most successful treatment options to control or eradicate dreissenid mussels in North America have been carried out in relatively small, stand-alone facilities, such as power stations, industrial plants, and municipal water treatment facilities.
- Chlorine is used extensively for dreissenid mussel control in the Great Lakes Basin, through an exemption to registration by the Ontario Ministry of Environment. The use of chlorine as well as discharge is controlled by an individual facility's permit for use.

- Potassium chloride (potash) has been successfully used to control mussels in water bodies in Canada and the United States, and is currently considered to be the primary approach for controlling dreissenid mussels in Alberta's irrigation water delivery systems.
- Alberta Environment and Parks is currently working to register KCl with the PMRA for use in Alberta water systems.
- Research is being carried out to develop practical, cost-effective KCl injection methods for Alberta's irrigation water supply pipelines.

Irrigation districts have three options to consider for management and/or control of dreissenid mussels that are present in underground water delivery pipelines.

- Winter desiccation.
  - Nearly all mussels that accumulate in the underground pipelines during the summer will be exposed after the pipelines are drained in the fall. These exposed mussels are expected to die during the prolonged winter period through desiccation.
  - The small pools of water remaining in the pipeline after drainage, where mussels might survive, generally represent a small fraction of the total pipeline capacity.
  - Mussels present at these locations during the winter will be isolated, because the remainder of the drained pipeline will be too dry to sustain them.
  - These colonies of mussels living in these pools of water are likely to have a minimal impact on the flow and capacity of the affected pipelines.
  - This option would have minimal costs to the irrigation district, and should pose no impacts on the ability to delivery water to all users.
  - This option does not address the possible accumulation of mussels in producer-owned water supply pipelines that are not properly drained in the fall.
- Kill all mussels by injecting sufficient volume of KCl to fill the pipeline.
  - Potassium chloride solution is injected into the irrigation district pipeline until the desired K^+ concentration of 100 mg L^{-1} is reached in the pipeline, and producer-owned water supply pipelines, and irrigation pivot systems. The treated water is held in the irrigation district and producer-owned water supply pipelines for five to six days. After the treatment is completed, fresh water is injected into the pipeline, and the treated water is applied to the irrigated fields through the pivots.
  - This option is relatively costly, and requires a significant amount of time and manpower to complete.
  - This option aims to have all treated water applied to the land, and potash-treated water does not return to an irrigation canal or other surface water body.
  - An initial flush of water through the treated pipeline segments in the spring should remove all detached mussel shells from the pipeline.
  - This option may be logistically difficult to achieve during the spring and fall time periods, that are the most conducive to irrigation producers.
- Introduce a relatively small volume of KCl into the pipelines to kill mussels that may survive in remaining pools of water.
  - Since the surviving mussels are concentrated in the small pools of water on the pipeline floor, injecting a relatively small volume of KCl solution, enough to cover the remaining pools of water after drainage, should achieve 100% mortality of any remaining mussels. The volume of treated water would have to be sufficient to flow into all pipeline segments. The potash solution could be pumped into the pipeline inlet, without it needing to be completely sealed. The treated water could be discharged onto the land through

    producer-owned pivot systems, or left in the pipeline during the winter months, and discharged from the pipeline when the water is turned on in the spring.
  - This option will require much less volume of KCl solution than the above option, will be easier to introduce into the pipeline, and require less time and manpower to implement.
  - This option would not address the potential accumulation of mussels in producer-owned water supply pipelines.

Complete treatment of all irrigation district and producer-owned water supply pipelines with potassium chloride (potash) is estimated to cost about $1.1 million.

- This estimate is based on the costs associated with the use of potash to control mussels in Lake Winnipeg.
- The majority of the cost is associated with manpower and equipment. The actual cost of the potash represents about 11% of the total cost estimate.
- Actual costs to treat the 900+ pipeline segments within the 13 irrigation districts, if required, may be greater because of the number of mobile treatment systems that may be required. In addition, this equipment will have to be moved many times over relatively long distances.
- Treatment periods in the spring and fall of each year are likely the most agreeable to irrigation producers, given their need for irrigation to meet crop demands during the summer. Treatment in early May and late September/early October would provide about 30 d of active pipeline treatment activities.

It will be logistically difficult to treat all 900+ pipeline segments during the 30-d spring and fall periods.

- At least 9 d will be required to initiate, implement, and complete the K^+ treatment of each pipeline segment.
  - Cool water temperatures at these times will require the potassium-treated water to remain in the pipeline segment and pivots for 5 to 6 d to ensure 100% mortality of the dreissenid mussels.
  - Additional time will be required to set up and charge the pipelines to achieve the target K^+ concentration.
  - An additional 2 d are required, after the treatment is complete, to determine if all mussels in the treated water have been killed.
- It is estimated that at least 60 mobile treatment systems, operating simultaneously, would be required to treat all pipeline segments in the combined 30-d window during the spring and fall.
- The number of mobile treatment systems could be reduced to about 10 if continuous treatment of the 900+ pipeline segments took place from May 1 to October 30 each year.

Recommendations

The GoA and irrigation districts should consider implementing additional prevention measures to minimize the threat of mussel infestation at high-risk water storage reservoirs.

- Remaining mussel free should be a very high priority for the GoA and the irrigation districts to avoid the difficulties and high costs of control and treatment programs once dreissenid mussels become established.
- The current boat monitoring program at key entry points is beneficial, but may not be totally effective, as boats can continue to enter the province at many locations that may not be fully monitored.

- An enhanced GoA/irrigation district prevention strategy is recommended, which includes:
  - Restricting and controlling the number of boat launch sites on reservoirs, and staffing each boat launch site to ensure all incoming boats and other watercraft are free of mussels; and
  - A comprehensive public education program that precedes and complements actions such as limiting boat access to reservoirs. Public education regarding the effects associated with dreissenid mussel infestation should also be an ongoing activity for the irrigation districts. This will reinforce the understanding of current and future recreation users of the economic and environmental effects of a dreissenid mussel infestation, and increase understanding and acceptance for the irrigation districts' actions.
- Cost of prevention measures will be less than those related to management and control of a dreissenid mussel infestation, and will prevent potentially harmful environmental effects to reservoirs, rivers, and irrigation district water supply systems.

An ongoing monitoring program should be implemented to detect the presence of dreissenid mussels in irrigation water supply reservoirs.

- Existing data indicates it will take 3 to 5 yr for mussels introduced into a reservoir to become a significant problem in downstream irrigation water supply systems.
- At minimum, annual monitoring of veliger and adult mussels in GoA and irrigation district reservoirs should be continued. The following are recommendations for annual monitoring of veligers and adult mussels in GoA and irrigation district reservoirs.
  - Collection of a plankton sample in August/September provides a good opportunity to determine if veligers are present.
  - Visual inspection of exposed infrastructure in the fall of the year, after the reservoirs have been drawn down, would provide a good opportunity to determine if adult mussels are present.
  - These, combined with additional monitoring to obtain information related to mussel growth potential for a particular reservoir, will help determine the timing and expected severity of a mussel infestation in downstream water delivery canals and pipelines, and on-farm irrigation systems.

Sampling for mussel veligers

- It is important to know, as soon as possible, when dreissenid mussels are present in a reservoir.
- This, combined with available information related to mussel growth potential for a particular reservoir, will help determine the timing and expected severity of a mussel infestation in downstream water delivery canals and pipelines, and on-farm irrigation systems.

Monitoring water in the irrigation districts' water supply reservoirs should continue, to assess the growth and development potential of dreissenid mussels.

- There are many factors that determine the ability of dreissenid mussels to develop and grow in southern Alberta reservoirs, and the GoA and irrigation districts have collected a significant amount of information for many of these factors.

- The Alberta Agriculture and Forestry irrigation water quality monitoring program (2006 to 2007 and 2011 to 2016) provides good information on growth factors such as calcium, pH, and temperature. However, chlorophyll a data were somewhat limited.
- Additional information related to these key factors, while not critical, would be useful to more accurately assess mussel growth and development potential within each of the reservoirs.
- This information may allow the GoA and irrigation districts to more effectively target and develop prevention and control measures.
  - Water profile temperature data for reservoirs will help determine the depths where most mussel development will take place. These data may help determine the feasibility to kill, through desiccation and freezing, a significant percentage of the mussels through normal reservoir drawdown for winter operations.
  - The data may also show that periodically drawing the reservoir down slightly more than normal may kill a much higher percentage of the mussel population.
- The use of portable water quality meters (e.g., Hydrolab DS5X) may provide a more cost-effective alternative than laboratory analyses to carry out "spot-check" measurement of these parameters.

Irrigation districts should exploit Alberta's cold winter temperatures to control dreissenid mussels that settle in irrigation water delivery infrastructure.

It is recommended the irrigation districts and irrigation producers take the following actions to assess the desiccation and freezing potential of the underground pipeline systems, and implement appropriate actions to correct any deficiencies.

- Assess the dewatering potential of all underground pipelines.
  - Identify all depressions or other locations within the pipeline where water may remain after the pipeline is drained each fall.
  - Complete drainage of a pipeline will result in desiccation and death of any dreissenid mussels in the pipeline.
  - Mussels located in small pools of water may survive the winter if oxygen levels in the water are adequate (>3 mg L^{-1}), and the water does not freeze completely. During several years, this population may grow, not from the reproduction of the mussels present, but from upstream recruitment.
  - Depending on the intensity of upstream infestation, 3 yr of recruitment may result in partial obstruction of the pipe as well as a continuing source of shell debris as adult mussels die.
- Assess the natural freezing potential of all underground pipelines.
  - Install temperature sensors during the winter season to measure the temperature in representative pipelines sections, to determine if complete freezing of any ponded water will occur.
  - Assess the oxygen level of retained water in the pipelines.
  - These measurements should be carried out for a number of years, as oxygen levels and freezing potential may change.
- Implement a pumping program to remove excess water from pipelines.
  - Discussions with irrigation district representatives indicated that significant volumes of water may remain in some small sections of pipelines.
  - Pumping is already being carried out to remove excess water in some sections. This program should be expanded to include all sections where mussels are present.
- Assess and develop the potential to introduce freezing winter air into pipelines.

- For those pipelines located below the winter frost line, some type of suction fan installed at the downstream end of the pipeline should be tested to draw sufficient cold winter air into the pipeline to freeze any pools of water where mussels are present.
- Air vents strategically located along the pipelines may also increase the potential to draw the cold air into the entire pipeline.

- Assess and retrofit pipelines to allow for the disposal of dead mussel shells.
  - Removing mussels that have been killed through winter desiccation and freezing may require changes to the downstream end of irrigation district pipeline segments.
    - Discussions with irrigation district representatives indicate that some type of valve assembly is located at the end of the pipelines to allow drainage at the end of the irrigation season.
    - This valve opening may be relatively small, and mounted part way up the side of the pipeline.
    - This may not allow all water to be drained from the pipeline, and not permit flushing of mussel shells from the pipeline.
  - It is recommended that the downstream end of all pipelines be retrofitted to allow it to be opened completely during drainage, to allow flushing of all mussel carcasses from the system.
  - Provided that only 1 yr of mussel recruitment is present in the pipeline, the mussel volume should be manageable, given the size of the population and the size of the individual mussels.

Irrigation producers should work with the irrigation districts to assess the drainage and freezing potential of all underground pipelines that supply water to their on-farm sprinkler irrigation systems.

- Pump out any remaining water in underground water supply pipelines that do not freeze in winter, and where mussels may congregate.
- Ensure that pump intake screens for sprinkler irrigation systems are suitable to exclude dreissenid mussels that may plug sprinkler nozzles. Additional cleaning and maintenance of the screens may be required, depending on the extent of the mussel infestation.

New pipelines being installed within the irrigation districts should be designed and constructed to optimize winter control of dreissenid mussels.

- Ensure that pipelines are installed on-grade to minimize the number of depressions in the pipelines, that may create after-drainage pools of water where mussels can collect and survive during the winter.
- Use eccentric, rather than concentric reducers wherever possible to minimize the number of sites where mussels can survive after drainage of the pipeline.
- Consider installing air vents at strategic locations on pipelines located below the frost line to optimize the transfer of cold winter air into the entire length of the pipeline.

Installation of a district pipeline

- At the downstream end of pipeline segments, incorporate a system that:
  - Allows the pipeline to be completely drained, and effectively flushed to remove any mussel shells from the pipeline; and
  - Accommodates installation of a suction fan to draw cold winter air into the pipeline to ensure freezing of any ponded water.

Design and implement a comprehensive research study to assess the potential to manage and/or control dreissenid mussels in irrigation district and producer-owned irrigation water delivery pipelines through winter desiccation and freezing.

- Select representative pipelines in the 13 irrigation districts and identify the locations and volumes of water that remain after dewatering in the fall of the year.
- Assess if remaining water in the pipelines will freeze during the winter periods.
- Determine if dissolved oxygen in water that remains in the pipelines is sufficient for mussels to survive the winter period.
- Assess whether these mussels pose a threat to the pipeline integrity, flow characteristics, and capacity to effectively serve all water users.
- Design and test practical and economically feasible methods to transfer sufficient cold winter air into the pipelines to freeze all remaining water.
- Design and test systems that can effectively allow dead mussels shells to be removed from pipeline segments.
- Develop and test pipeline design and construction technologies that will minimize the amount of water that remains in the drained pipelines during the winter, to increase the proportion of mussels killed through desiccation.

Develop a potash injection strategy for those underground pipeline segments where winter desiccation and freezing may not be viable.

- Identify pipeline segments that may require potash injection to kill mussels that are present.
  - Maximize the number of pipeline segments where mussel control can be accomplished by winter desiccation and freezing; and
  - Minimize the number of pipeline segments that will require potash injection treatment.
- Determine if this work can be most effectively provided by private contractors or by irrigation district staff.
  - If the decision is to use irrigation district staff, determine what mobile equipment will be required to transport, mix, and inject the potash solution into mussel-infested pipeline segments.
  - Develop and implement a training program for irrigation district staff for the injection of potash into the pipelines.
- For pipelines where potash may be required, there may be a need to install:
  - Potash injection valves near pipeline inlets; and
  - Some type of gate structure at the pipeline inlet to isolate and retain the potash solution in the pipeline segment.
- Develop a coordinated pipeline treatment program with irrigation producers served by the pipeline segment, to ensure potash injection activities are effectively coordinated.

5. Information Sources

The above information was obtained from Olson et al. (2018) (Sections 1 to 3) and Paterson Earth & Water Consulting (2018) (Section 4).

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.

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.

These publications are available at:
https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/irr15127

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