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Hydrological and Economic Assessment of the Upper Qu'Appelle Water Supply Project

Report for Western Economic Diversification

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For the analysis, data was sparse and uncertain, until more data is available to better characterize the boundary conditions of the project frame, these results should be viewed as preliminary and used for review only.

1. Introduction

This report describes some water resource management modeling, water quality modeling, and economic implications of the Upper Qu'Appelle Water Supply Project.

2. Water resource model results

The Upper Qu'Appelle Water Supply Conveyance is a proposed project with a maximum diversion capacity of 65 m^3/sec, to move water from Lake Diefenbaker to the Buffalo Pound Lake near Moose Jaw. The existing Upper Qu'Appelle water supply diversion has a design capacity of 14 m^3/sec, and due to the channel meandering and siltation, the capacity is reduced by 57% (6 m^3/sec) which limits economic and social activities. The proposed new diversion will support growing water demand and is expected to create opportunities for agricultural and industrial expansion. Clifton Associates (2012) perform an economic impact and sensitivity study of this project in the intended project area. However, investigating the sensitivity of the downstream water resources system to the proposed diversion is vital, particularly in a complex transboundary river system like the Saskatchewan River Basin (SaskRB). We provide an executive summary of the sensitivity of the entire Saskatchewan water resources system (SaskRB-SK) downstream of the proposed diversion structure.

The present study utilizes the newly developed Integrated Water Management Model for the SaskRB (IWMSask) (Shah, 2019) for the sensitivity analysis of the SaskRB-SK system. The water demand data considered in this study is obtained from Kulshreshtha et al. (2012). The water diversion rate for existing infrastructure is obtained from the Environment and Climate Change Canada's HYDAT and climate database. The proposed diversion rate for the new structure is collected from Clifton Associates (2012). According to Clifton Associates (2012), the proposed diversion will reach its maximum capacity (65 m^3/sec) after 20 years of construction. Considering this constraint, we perturbed a total of 10 water diversion scenarios in the sensitivity analysis. The IWMSask, when representing the existing SaskRB-SK system, is defined as the Base condition (S0). Scenario S1 considered a new structure with the proposed diversion rate. Other scenarios (S2 to S11) are generated by increasing the proposed diversion rate from 10% to 100% within the maximum capacity of the channel (Table 1).

Table 1. Scenario consideration for Upper Qu'Appelle water supply project

Scenario	**Upper Qu'Appelle Water Supply**
S0	Current Water Diversion Rate (CDR)
S1	CDR + Proposed Water Diversion Rate (PDR)
S2 to S11	CDR + (PDR*WF ≤65)
Weighting Factor (WF)	1.1 (S2), 1.2 (S3), 1.3 (S4), 1.4 (S5), 1.5 (S6), 1.6 (S7), 1.7 (S8), 1.8 (S9), 1.9 (S10), 2.0 (S11)
Average Diversion (m^3/sec)	2.6 (S0), 13.0 (S1), 14.0 (S2), 15.1 (S3), 16.1 (S4), 17.1 (S5), 18.2 (S6), 19.2 (S7), 20.3 (S8), 21.3 (S9), 22.3 (S10), 23.4 (S11)

2.1 Results

The analysis of impacts is performed under four categories; changes in (1) water allocation to non-irrigation and irrigation users; (2) downstream flow at important locations, i.e., Saskatchewan River (SaskR) flow below Tobin Lake (before the Saskatchewan River Delta); (3) Lake Diefenbaker elevation at different periods; and (4) hydropower generation. The average annual change in each of these categories in each water diversion scenario (Table 1) is presented in Figure 1. Figure 1 shows that the proposed Upper Qu'Appelle water supply project in S1 to S11, would reduce: the mean annual water supply to non-irrigation and irrigation users by 0.1-0.2 and 3.9-8.7 MCM, respectively ((a) and (b)); SaskR flow below Tobin Lake by 10.6-21.0 m^3/sec (c); hydropower in Coteau Creek (d), Nipawin (e) and E.B. Campbell plants (f) by 3.8-8.0, 2.1-4.6, and 2.5-5.1 MW, respectively; and Lake Diefenbaker elevation by 0.7-1.3 meter (m) in November to January (g), 0.7-1.2 m in February to May (h), and 0.6-1.2 m in June to October (i).

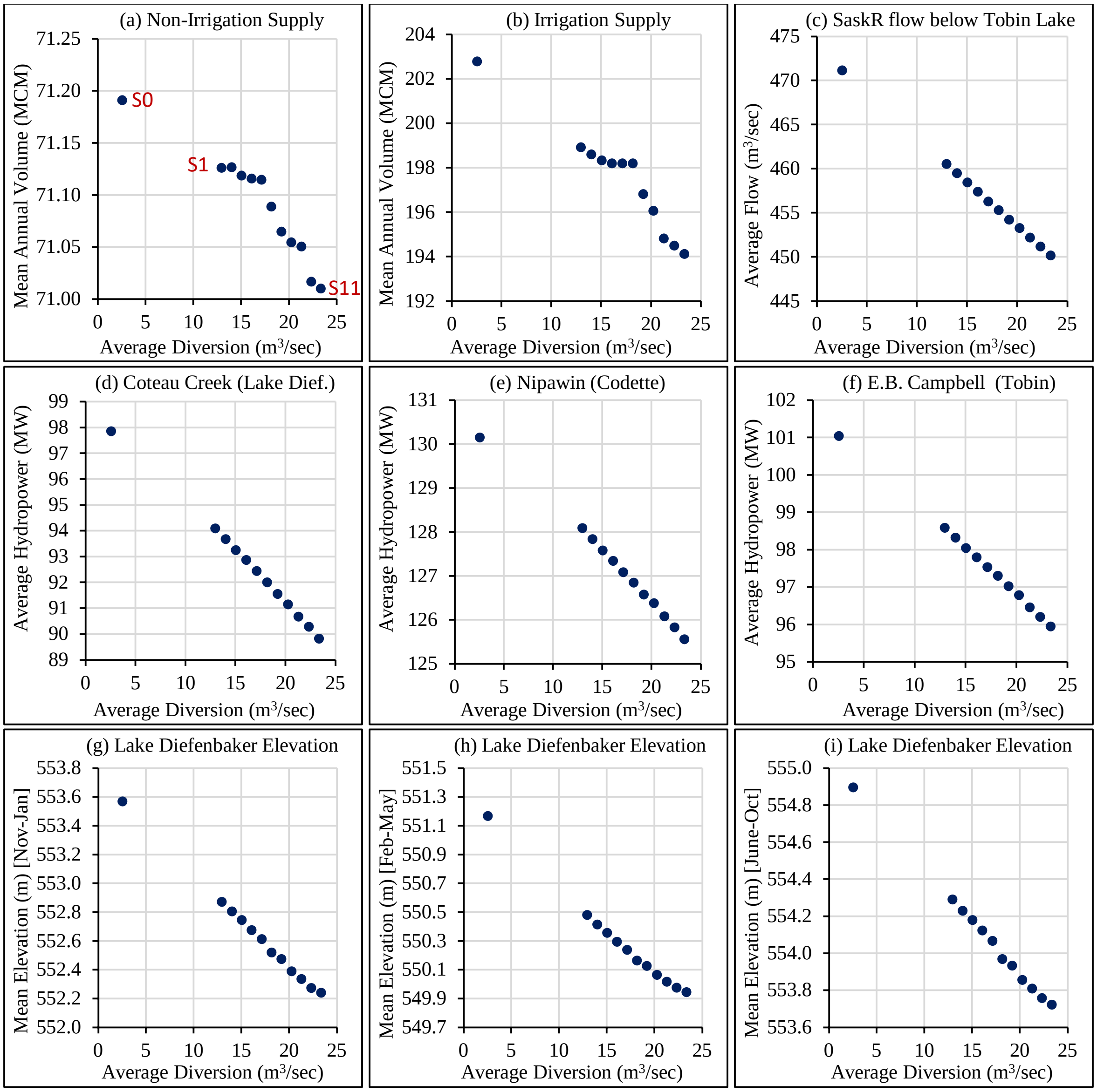

Figure 1. Changes in mean annual water allocation (million cubic meters) to non-irrigation (a) and irrigation (b), SaskR flow below Tobin Lake (c), hydropower generation in Coteau Creek (d), Nipawin (e) and E.B. Campbell plants (f), Lake Diefenbaker elevation in November to January (g), February to May (h), and June to October (i), due to different diversion rates for Upper Qu'Appelle Water Supply Conveyance.

We note that the trade-offs presented above are long-term averages, and it is expected that the trade-offs will be more significant under extreme conditions, particularly in drought years. We further note that the analyses above do not include climate change scenarios and assumes that the future flows will be similar to the flows in the past. Therefore, further analyses are warranted to investigate finer time-scale trade-offs and the impact of climate change. Additionally, further detailed investigation is required to assess the vulnerability of the SaskRB-SK system to a variety of uncertain, changing conditions such as climate change impacts to flows and new infrastructure developments (e.g., West Side Irrigation district development or private and district infill and expansion in Alberta and Saskatchewan). This would include a focus on additional requirements such as Lake Diefenbaker target elevations for irrigation intake, launching boats, recreational use, and Piping Plover nesting.

3. Water quality impacts

The following has been drawn from Terry (submitted; used with permission). This work presents a practical application of the CE-QUAL-W2 (W2) hydrological-ecological model focussing on Buffalo Pound Lake. The research looks towards testing an alternative approach to the standard model framework to allow increased complexity with limited data. It explores the capability of a complex water quality model to capture under ice and open water eutrophication processes in a continuous multiyear simulation.

Terry and Lindenschmidt (submitted) evaluate the most influential boundary conditions driving select eutrophication variables in Buffalo Pound Lake. Catchment conditions are found to have more influence than in-lake processes with inflow discharge having the greatest sensitivity for the eutrophication variables considered. The high sensitivity of inflows in Buffalo Pound Lake is concerning. Uncertainty becomes an issue with highly sensitive parameters. As the relative importance in the model increases for an input variable or fixed parameter, the greater the risk of model error propagating from inaccuracies in input data and calibrated coefficients. Terry et al. (2018) discuss a number of uncertainties with the available data for the Buffalo Pound Lake system. Inflows and outflows are particularly problematic with ungauged tributaries and wetlands, an unknown transition from riverine to lacustrine flow rates, and the confluence of Moose Jaw River all confounding gauging station data. Other boundary data are also inadequate to properly calibrate the water balance and lake hydrodynamics.

Terry and Lindenschmidt (submitted) conclude that flow management strategy may be the most important aspect of water quality management in Buffalo Pound Lake. The work acknowledges Water Security Agency (WSA) concerns about meeting increasing water demand with the current level of inflows, and their exploration into increasing the volume of water delivered from the upstream supply reservoir Lake Diefenbaker to Buffalo Pound Lake. From the results of Terry and Lindenschmidt (submitted) it is apparent that any proposed change in flow regime may have considerable impact on Buffalo Pound Lake's water quality. The calibrated water quality model of Buffalo Pound Lake can be applied to assist the WSA with their decision making. A scenario-based investigation is presented next.

Three scenarios are considered for discussion. The first is to simulate doubling the amount of water being released from Lake Diefenbaker through the existing Upper Qu'Appelle River channel and into Buffalo Pound Lake. For this scenario, the boundary inflow data were increased by a factor of two. No changes are made to the model hydraulic set-up, and it is assumed all other inflow and outflows, such as ungauged inflows or piped withdrawals for the Buffalo Pound Water Treatment Plant (BPWTP), remain as per the base model. Note that evaporation, ice cover and ice thickness are calculated by the W2 model. Inflow temperature and constituent files are as per the base model and described in Terry et al (2018). The base model constituent values are measured data recorded at Highway 2 at the downstream end of the river channel (and forming the upstream boundary of the Buffalo Pound Lake model). The three algal groups in the Terry et al. (2018) calibrated model are combined into one algal group for the purposes of the scenarios.

The second scenario again doubles the amount of water released from Lake Diefenbaker into Buffalo Pound Lake, yet assumes the flows travelling through the Upper Qu'Appelle River channel remain the same as the base model. The additional volume of water is conveyed to Buffalo Pound Lake along a projected upland canal. The upland canal is added to the model as an inflowing tributary entering the most upstream segment of the lake model grid. It is assumed that flows running through the conveyance canal will remain consistent through the length of the channel with no irrigation or return flow, for example. Inflow temperatures are assumed the same as the existing river channel. Inflow constituent concentrations for the upland canal are averages of historical Lake Diefenbaker concentrations (so as would be released into the upstream end of the canal) and are a constant value.

The third scenario assumes that volume releases are made from Lake Diefenbaker so as to reach the maximum capacity of the projected upland canal at peak flow rates. The assumed trend in the upland canal flow rates is based on a hydrograph of historical monthly average flow data for a Water Survey of Canada gauge below the Qu'Appelle River Dam – this dam releases water from Lake Diefenbaker into the Upper Qu'Appelle River channel. Historical monthly averages are multiplied (by a factor of 4.5) to produce a maximum flow rate of 65 cms, which is the proposed capacity of the new upland canal (Lindenschmidt and Carstensen, 2015). Winter flows are expected to reach 6 cms (Lindenschmidt and Carstensen, 2015), and, here, ice cover is assumed between October and March. Inflow temperatures are assumed the same as the existing river channel. Inflow constituent concentrations are as scenario two. Flows travelling through the Upper Qu’Appelle River channel are kept the same as per the base model.

Results of the first scenario compared against the base model are presented in Figure 2. Output is for the downstream segment encompassing the sampling point location of the BPWTP, as per Terry et al. (2018). Results indicate that doubling the volume of water released into Buffalo Pound Lake from Lake Diefenbaker does not improve water quality when pushed along the existing Upper Qu’Appelle River channel. Chlorophyll-a (Chl-a) amounts increase from baseline over each winter as well as spring/summer (from here on just summer) periods 1986, 1987 and 1992. Chl-a concentrations are calculated by W2 and represent algae biomass in the Buffalo Pound Lake model using an algae/Chl-a ratio. Nutrient loading of phosphate (PO4), ammonium (NH4), and nitrate (NO3) increase. Buffalo Pound Lake has a greater amount of total nitrogen (TN) in the scenario run in all but the winter of 1988. Dissolved oxygen (DO), DOC and total dissolved solids (TDS) concentrations show some fluctuation although are not impacted greatly. Algal growth appears to be phosphorus limited in the scenario model. A maximum capacity for nitrogen uptake leads to excess concentrations of NH4 and NO3 including periods where algae previously suffered nitrogen limited growth (1987, 1988 and 1992).

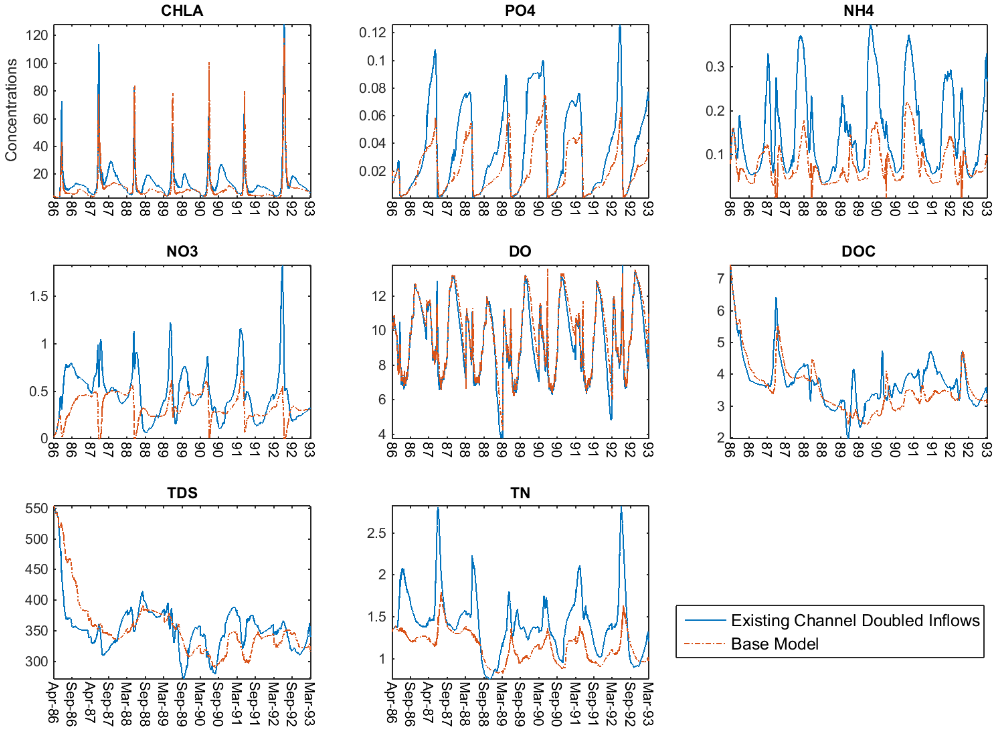

Figure 2. Scenario results where flows in the existing Upper Qu'Appelle River channel are doubled. Concentrations are mg/l.

Results of the second scenario are plotted in Figure 3. Chl-a summer concentrations are slightly greater than the base model in 1986 and 1987, although the latter five-years demonstrate a significant reduction in peak values in the scenario model. Winter concentrations of Chl-a still reach higher values than concentrations in the base model although show improvement over scenario one results. Chl-a concentrations are depleted lower than the base model by the end of most winters. This may explain why the summer peaks do not reach the same scale as the base model. Nutrient loading is clearly reduced from scenario one by the diversion of the additional discharge volume through the projected upper canal. DOC levels, however, increase over the latter half of the simulation period from both the base model and from scenario one.

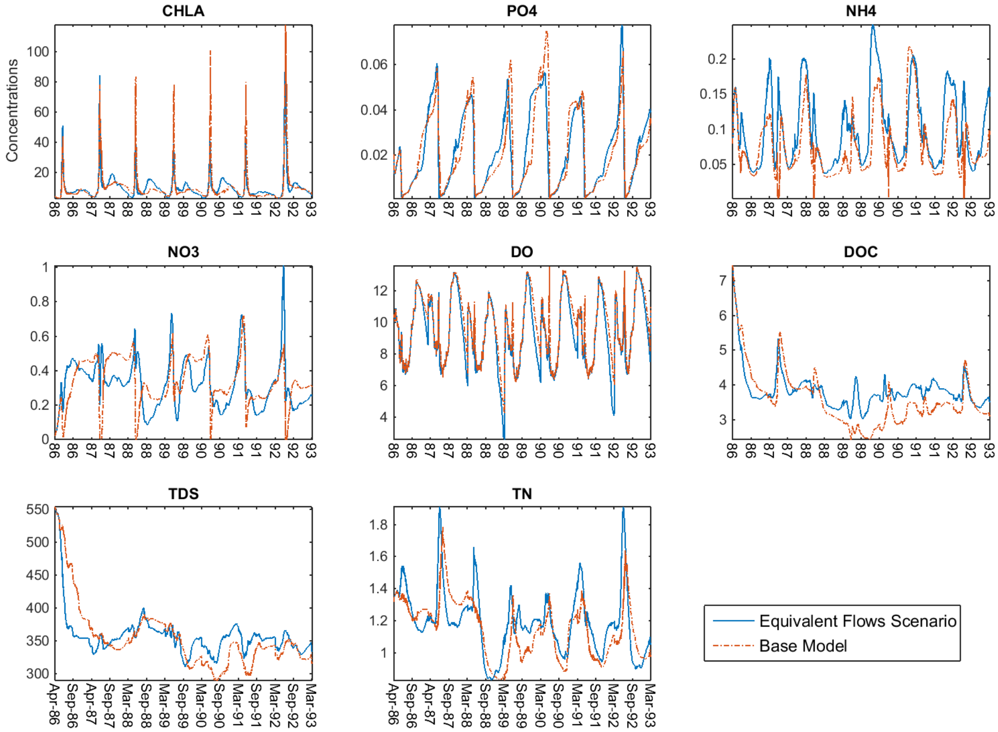

Figure 3. Scenario results where flows in the existing Upper Qu'Appelle River channel are doubled with the extra water then transported to Buffalo Pound Lake through the projected upland canal (flows in the existing river channel remain the same). Concentrations are mg/l.

The third scenario results are plotted in Figure 4. Most notable is the reduction in overall Chl-a concentrations as a result of the influx of cleaner water from Lake Diefenbaker conveyed along the projected upper canal. The low algae biomass in the scenario leads to reduced DO concentrations in both summer and winter – reaching critically low levels in the winter of 1990. Algal growth once again appears to be phosphorus limited. Nutrient loading is again substantially reduced from the base model. DOC and TDS concentrations level out within the first year as a result of the majority of flows now carrying a constant loading concentration.

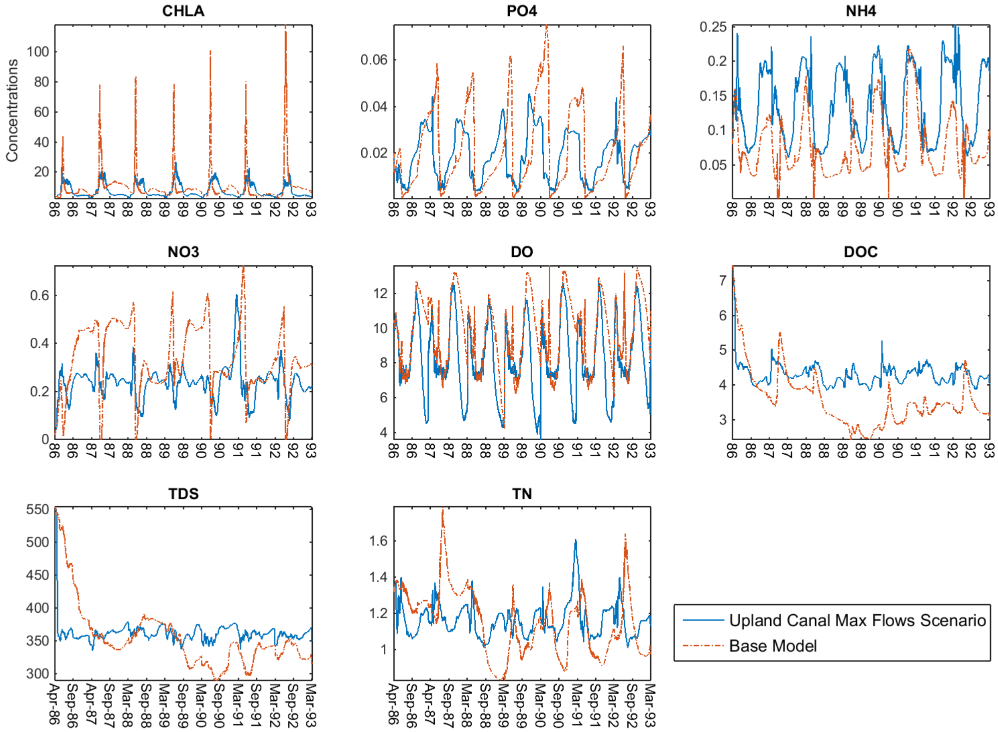

Figure 4. Scenario results where maximum flow rates are assumed along the projected upland canal. Flows in existing Upper Qu'Appelle River channel remain the same. Concentrations are mg/l.

These flow scenarios underscore several important factors regarding increasing the volume of water moving from Lake Diefenbaker to Buffalo Pound Lake to meet rising water demands. A core finding is that Buffalo Pound Lake's water quality is highly influenced by lake inflows as discussed in Terry and Lindenschmidt (submitted). The scenarios presented here identify that both the volume of water, and the method of transfer are contributing factors to the lake's water quality status.

The first scenario demonstrates that increasing the volume of water released from Lake Diefenbaker though the existing river channel does not improve nutrient concentrations. Almost all variables plotted in Figure 2 are in fact made worse with the additional discharge volume. The exception to this are DO concentrations that display little change. This DO result agrees with Hosseini et al. (2018) in a similar scenario increasing flow between Lake Diefenbaker to Buffalo Pound Lake using the WASP7 model. It is worth mentioning that while a 10% increase in inflows show most sensitivity to DO (Terry and Lindenschmidt, submitted, Fig. 3) the maximum change from baseline is less than 0.8 mg/l. TDS is another exception as concentrations decrease slightly in the initial years of the simulation period. Although not plotted here, further simulations of triple and quadruple flows released from Lake Diefenbaker into the existing river channel confirm that as discharge volumes increase so do Chl-a and nutrient concentrations in Buffalo Pound Lake. Water quality challenges are amplified in line with the additional loading amounts entering the lake through the river channel due to the higher flows. The WASP7 simulations in Hosseini et al. (2018) also find Chl-a and NO3 concentrations increase in Buffalo Pound Lake when more water is released from Lake Diefenbaker along the original channel. NH4 and PO4, however, are shown by WASP7 to decrease with the greater flow volume. The authors state the main source of NH4 and PO4 in Buffalo Pound Lake are sediment fluxes, which they specify in the WASP7 model as a fixed daily flux (loading) rate. The authors suggest the increased inflow volume thus dilutes these flux concentrations. In the W2 scenarios presented here the NH4 and PO4 fluxes are calculated internally by the model as discussed in Terry et al. (2018) and Terry and Lindenschmidt (submitted), and flux rates differ between both models. The time periods of the two model simulations are almost two decades apart and WQ data are not directly comparable.

Nutrient loading in these W2 scenarios follows basic assumptions. Loading concentrations in the original river channel remain the same in both the base model and in scenario one – the doubling of inflows therefore doubles the inflow constituent loading. In reality, doubling the discharge volume may lead to a dilution of inflow nutrient concentrations as the cleaner Lake Diefenbaker waters ‘wash out’ the channel. Conversely, the additional discharge volume travelling the channel on any given day may lead to additional sloughing of river banks and movement of the sediment bed if shear stresses are sufficient. In turn this will likely increase inflow nutrient concentrations entering Buffalo Pound Lake from the original channel. W2 has the ability to link a number of waterbodies together in one model structure, and the Buffalo Pound Lake water quality model could be extended to include the Upper Qu’Appelle River channel as a means to investigate this. Both the W2 model and the WASP7 river-lake model agree that Buffalo Pound Lake remains eutrophic after augmenting inflows from Lake Diefenbaker to Buffalo Pound Lake along the existing channel.

In the second and third scenarios, inflow constituent concentrations for the projected upland canal are constant values throughout the simulation period - being estimated from average

Lake Diefenbaker concentrations. The concentrations are based on long-term historical data, and should be reasonably representative of expected loadings. Interannual and seasonal changes in concentrations will occur in Lake Diefenbaker that are not factored into the inflow constituent file - Chl-a in particular will fluctuate seasonally. For these scenarios, potential substances input to the canal through runoff are not considered. It is also assumed that there will be no transformation of Lake Diefenbaker constituents being transported through the canal. These assumptions are made as it is not possible to predict how the constituents will transform as they travel through the channel or canal - nor the amount of water and substances abstracted or emitted into the waterbodies from the catchment areas.

The inflow temperature file is the same for both the existing river channel and the projected upland canal in all scenarios. In real life inflow temperatures along the existing river channel will be influenced by a number of inflowing tributaries along the river stretch. Inflow temperatures in the upland canal will remain more consistent being a function of flow volume and local climate. Results of a further scenario simulation where inflow temperatures are increased by 2°C indicate inflow temperatures have little impact on the overall outcome of the simulations – the in-lake temperature being the driving factor of water quality processes in this case. Output variables such as Chl-a are therefore not impacted by the inflow temperature assumptions made for this scenario study. The flow scenarios have no discernible relationship with the simulated dates of ice cover, although scenario two appears to cause both earlier ice formation and melt events.

For the scenarios it is assumed lake water levels will remain close to full supply level of 509.47 masl and the dynamic pump option in the W2 model is used to calculate the appropriate outflow files. The ability of the Buffalo Pound Dam structure to cope with the increased volume of inflows and outflows in Buffalo Pound Lake is not considered in these analyses. Existing reports establish that the movement of water across the dam structure during flood events is extremely complex with tailwater creating a significant drop in capacity of the spillway to deal with outflows. Several instances of water backflowing into Buffalo Pound Lake from the downstream Moose Jaw Creek have occurred during high water events after waters overtop the dam (MPE Engineering, 2013). Moose Jaw Creek backflows are discussed in Terry et al. (2018).

The results appear to support the construction of the projected upland canal as a means to transport additional discharge volume from Lake Diefenbaker to Buffalo Pound Lake. Dependent on the quantity of water transferred the increased volume of water can improve water quality in

Buffalo Pound Lake as well as provide additional lake water to meet growing demand. The greater the amount of water that can be transported from Lake Diefenbaker along the projected upland canal the greater the improvement in Buffalo Pound Lake in-lake Chl-a concentrations. The alternative option of pushing additional discharge volume through the existing Upper Qu'Appelle River channel is not recommended and will likely lead to deterioration of current water quality in the lake.

4. Economic implications

A project the size of the Qu'Appelle Water Supply development will have substantial economic implications for agricultural producers, firms, and people living in the region. There will be impacts to the economy as well as economic benefits and costs to society. This section reviews the types of economic analyses used to evaluate public projects, outlines a framework for understanding the economic net benefits of the project, and describes some water pricing and financing considerations. The main findings of this section are:

- There remains a lot of uncertainty over the scope and scale of economic implications
- Economic impacts are not economic benefits
- There is potential for irrigation net benefits, but this requires economic modelling and landowner buy-in
- Non-irrigation net benefits of the project have been identified in previous assessments, but rarely quantified or valued
- There is a need for a comprehensive benefit cost analysis of the project

4.1. Types of economic analysis

There have been several economic analyses conducted for the Qu'Appelle Water Supply project and similar water diversion and irrigation expansion projects in the Canadian prairies, but there remains some confusion between different types of economic analysis and resulting conclusions. There are numerous good backgrounds on Economic Impact Analysis (EIA) and Benefit Cost Analysis (BCA) including guidelines produced by the Canadian and United States government (Treasury Board of Canada Secretariat 2007; United States Environmental Protection Agency 2016). The purpose of this section is to detail some of the more pertinent differences and the reader is advised to consult these sources for additional information on the specific steps to conduct an economic analysis.

Economists use two main analyses to evaluate public projects – economic impact analysis and benefit-cost analysis. An economic impact analysis (EIA) is a quantitative assessment of how a shock will impact economic indicators such as jobs and income. EIA use specialized methods to trace supply linkages in the economy to determine both the direct and indirect economic impacts of a project. A benefit-cost analysis (BCA) is a calculation to determine if a project's net effects on society's welfare is positive or negative. BCA is grounded in welfare economics and benefits and costs are measured using consumer surplus and producer surplus measures to quantify the effects of projects. If the overall benefits of a project exceed its costs (i.e. net present value is positive), then the project is said to be economically efficient, or increases the welfare of society. Even if a project has a negative net present value, the project might be justified on equity grounds, economic development arguments, or other valid reasons. EIA and BCA are best viewed as providing complementary pieces of information on a project's economic implication. Neither one is 'correct' or 'better', just different. They both also have implementation challenges and other limitations.

The main differences between EIA and BCA are:

- **Address different policy questions:** An EIA answers the following question, how will the formal economy change as the result of the project? A BCA answers the question, is society better off with the project than without the project? As discussed below, 'better off' is defined using economic welfare measures.

- **Use different counterfactuals (gross vs net effects):** In an EIA, the effects are typically assessed as *gross* impacts and investment is treated as a shock to the economy. There is not accounting for alternative uses for the investment dollars. A BCA calculates *net* effects that are assessed relative to a counterfactual scenario (i.e. with and without the project) taking into account alternative uses of funds.

- **Use different methods:** The main methods economists use in EIAs, ranked from least to most complex, are economic multipliers, input-output models, and computational general equilibrium models. These methods differ in their complexity and representativeness of the economy and their ability to incorporate feedback effects. BCA use market and non-market valuation methods to measure the costs and benefits of the project on firms and people. For example, the irrigation net benefits of the project can be measured using changes in producer surplus between dryland farming and irrigation farming. Economic values are not necessarily the same as market prices but instead measure the net surplus to consumers and producers.

- **Measure different things:** EIA quantify economic impacts which are the effects the project has on the economy in terms of gross domestic product, jobs, income, tax revenue, and other economic indicators. A BCA calculates the net effects of the project on society's well-being (i.e. welfare) measured through consumer and producer surplus. In general, only a BCA can include impacts that occur outside of the formal economy such as environmental externalities resulting from a project. While economic impacts are often presented as 'economic benefits' by politicians and the media, for economists, economic benefit is a particular measure of social welfare.

There are also challenges implementing these different methods and using the results to guide public policy investments. For EIA, one challenge is that the quantified economic impacts are practically always larger than the project related investment capital and operating costs. The economic impacts scale almost proportionally with the costs of the project and more expensive projects are associated with larger economic impacts. For example, if the costs of the water supply project doubled, the economic impacts would also approximately double. The benefits would double if using economic multipliers or an input-output model because impacts are calculated linearly. But that is not necessarily a good thing for society as now it costs twice as much to build the project. Even if project costs are the same, the second challenge with EIAs is that all investments generate economic impacts and it's not clear that a project with a higher economic impact is more desirable from society's standpoint. This can be seen using jobs as the metric and the 2004 Economic Impact Multipliers for Saskatchewan published by Statistics Canada. A $1 million investment in the Water, Sewage and Other Systems would generate 9.2 full-time jobs in Saskatchewan compared to an equivalent investment in Pipeline Transportation sector which would generate 3.4 jobs. However, the highest number of jobs would be generated if the $1 million was invested in the Cut and Sew Clothing Contracting sector which would generate 56.5 jobs. These economic multipliers would indicate that the government invest in the tailoring sector to maximize jobs, but this says nothing about the value derived from this sector. A final challenge is the inherent uncertainty in the quantified impacts, especially at a more localized or regional scale.

BCA also has its challenges to implement. The main challenge is actually quantifying and valuing the various effects of the project. This will typically require a combination of market and non-market valuation methods which can be time and resource intensive and require specific expertise. Partial valuation of effects can still be useful if it is unlikely that the remaining unvalued effects would change the net present value sign. If substantial effects are left unvalued and the net present value is close to zero, there are concerns that this omission might result in faulty recommendations.

In sum, EIAs and BCAs are two complementary approaches to understanding the economic implications of public projects but the results of the analysis should generally be kept separate. There have been several EIA of irrigation expansion projects in Saskatchewan (Brown 2017). The most recent economic assessment of the Upper Qu’Appelle Water Supply project is best characterized as an economic impact assessment (Clifton Associates 2012). The engineering costs of the project were calculated and an input-output table was used to compute the direct, indirect, and induced impacts of the project. To the best of our knowledge, there has not been a BCA conducted of the project, although we understand there is an ongoing economic assessment by an engineering firm. In light of this, in the next section we discuss some broad considerations that could go into a conducting a BCA for the Upper Qu’appelle Water Supply project.

4.2. Understanding the economic net benefits of the project

Besides the economic impacts, the project will have economic benefits and costs to various groups of people in the region. These economic net benefits (benefits minus costs) are important to understand for two reasons. First, the economic net benefit measures provide the basis for a credible BCA. Second, economic net benefit information can be helpful for guiding the potential ability and fairness of beneficiaries to contribute to the financing of the project.

The primary purpose of the Qu’appelle Water Supply project is to provide a reliable water supply for irrigation, but there are likely other non-irrigation economic benefits and costs.
There are three main categories of economic net benefits for the project:

1. Net benefits of irrigation;
2. Net benefits of effects in the Saskatchewan River Basin; and
3. Net benefits of effects in Buffalo Pound Lake and the Qu’Appelle system.

Overall, there has been more research in understanding the potential net benefits of irrigation than the other two effects. In general there has been efforts to identify the potential non-irrigation net benefits, but little research to quantify and value these net benefits (Clifton Associates 2012).

Economic net benefits of irrigation

The Upper Qu’Appelle Water Supply project is expected to expand irrigation by about 110,000 acres. There have been numerous estimates of the economic impacts of irrigation, with the most recent conducted using an input-out model based on 2011 data (Brown 2017). As described earlier, while these types of analyses can tell us about the impacts of irrigation on formal economic metrics such as jobs, tax revenue, and GDP, they do not answer the question of whether society is better off with the project relative to without the project.

The net benefits of irrigation per acre can be calculated as the relative net returns from an acre with irrigation and the net returns without access to irrigation (i.e. dryland farming). For example, if the dryland net returns for Spring Wheat is $30 per acre and the irrigated net returns for Spring Wheat is $70, then the net benefits of irrigation for Spring Wheat is $40. The Ministry of Agriculture provides crop production budgets that can form the basis for these calculations and studies have used this data and found that the net returns from irrigated land are higher than dryland farming. Samarawickrema and Kulshreshtha (2008) uses data from the 1990s and early 2000s to estimate the net returns for different crops in the Lake Diefenbaker Development Area.

While the relative returns is a relatively simple calculation conceptually, there are four main reasons these calculations are more difficult in practice when assessing the relative merits of irrigation. At the centre of these four challenges is the difficulty in predicting what will happen with irrigation opportunities and they raise cautions with simplistic dryland versus irrigation net return calculations.

1. The first challenge to calculating the net benefits to irrigation is changing crop mixes. Landowners may change their crop mix when they adopt irrigation systems potentially planting higher value crops such as potatoes to help recover the added farming costs.
2. The second challenge is that landowners may not actually adopt irrigation systems in practice (Bjornlund, Nicol, and Klein 2009; Wang et al. 2016). If these analyses do not account for the realistic adoption rates, they may overestimate the net benefits of irrigation. This challenge is especially pertinent in Saskatchewan where the uptake of irrigation by landowners have often lagged projections.
3. The third challenge is that the net returns for crops such as potatoes are highly dependent on nearby processing facilities as transportation costs are high. Thus the decision to adopt irrigation systems and plant higher valued crops is not independent on nearby food processing infrastructure.
4. The fourth challenge is that existing cost structures and climate conditions may not be a good predictor of future scenarios. For example, there are several reasons that the relative returns to irrigation might increase in the future due to increased variability of precipitation, longer growing seasons, and improved irrigation technology lowering costs.

Instead of focusing on crop returns, another method to estimating the economic net benefits of irrigation is to compare the value of irrigated parcels to non-irrigated parcels, holding all other land characteristics and other drivers of land values constant. There are no recent studies conducted in Saskatchewan that could inform current water management but there is evidence in other jurisdictions that irrigated parcels are valued more. For example, Sampson et al. (2019) estimate that the irrigation premium is 53% in Kansas. Furthermore, they find that this premium has been increasing by about 1% per year since 1988.

Net benefits in the Saskatchewan River Basin

The quantified hydrological changes measured through the water resource management model can form the basis for the economic measured of relevant impacts. Given that less water is flowing downstream, these economic net benefits are likely negative. The change in river flow resulting from the project will have impacts on the three hydroelectric stations that are downstream of Lake Diefenbaker. The lost hydropower calculated through the water resource management model will have an associated lost net revenue to SaskPower. The lost net revenue will depend on how SaskPower alters reservoir management in response to these changes. If the change in water volume is small, power prices may be a useful proxy for net returns. Reduced river flows through the rest of the system and into the Saskatchewan River Delta has the potential to have negative economic consequences for affected local communities and ecosystems. There has not been any studies undertaken to understand the scope and scale of these economic consequences, nor ways to mitigate these impacts.

Net benefits in Buffalo Pound Lake and the Qu'Appelle system

There is the potential for non-irrigation economic net benefits in the Buffalo Pound Lake and the Qu'Appelle system due to increased water availability and changes to water quality. Many of these benefits have been identified in previous economic assessments, but the quantification and valuation of these non-irrigation effects has been limited. These net benefits include:

Recreation and amenity benefits

Changes to water levels and water quality might impact recreation behaviour and benefit people living alongside the affected water bodies. There has been no study that has quantified the impact of water quality changes on recreation behaviour and values. Understanding how many people use Buffalo Pound Lake for recreation would be a first step towards building a recreation demand model that could value recreation benefits (Parsons 2017).

To assess amenity benefits to local property owners of water stabilization and water quality changes in Buffalo Pound Lake a hedonic price method could be used (Taylor 2003). For example, in Chestermere Lake near Calgary, waterfront homeowners witnessed an increase in their property values of between $30,000 and $48,000 due to the stabilization of lake water levels (No Kim, Boxall, and Adamowicz 2016). A similar analysis could be conducted in Saskatchewan.

Reduced water treatment costs

Improving water quality may also reduce treatment costs at the drinking water treatment facility at Buffalo Pound Lake. These net benefits could be quantified using facility cost information.

Industrial water uses

The additional water supply in Buffalo Pound Lake could be used for industrial and commercial uses such as potash mining. The economic value of this water supply can be quantified as the gain in producer surplus for industrial and commercial users.

4.3. Water pricing and financing

What price to charge users for water directly relates to questions of project financing. These issues are particular pertinent given the recent discussions and transfer of irrigation assets in Saskatchewan regarding who should pay the maintenance and rehabilitation costs of irrigation infrastructure around Lake Diefenbaker. The irrigation infrastructure requires millions of dollars of investment in upkeep and the question of who should pay is ongoing. The provincial government was looking for irrigation districts to shoulder more of the financial burden while irrigators did not want to be responsible for assets in need of repair.

A comprehensive assessment of various water infrastructure financing options and Canadian case studies is provided in the recent Canadian Water Network report, *Balancing the Books: Financial Sustainability for Canadian Water Systems*.[1] There is generally a move towards full cost recovery for Canada's water and wastewater treatment systems.

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[1] Report available at http://cwn-rce.ca/report/balancing-the-books-financial-sustainability-for-canadian-water-systems/

Understanding the net benefits of the project to different users can inform pricing strategies to help finance the infrastructure. One option is to have the people that benefit from the project contribute to the financing.

For irrigation net benefits, full cost recovery would entail agricultural producers paying the full costs of water supply to their lands. However, there is a potential tension in the policy goals of full cost recovery and adoption of irrigation. Higher water charges for agriculture would worsen the economic profitability of irrigation while lower water charges are likely inconsistent with recovering the full costs of water supply. This tension highlights the trade-off between water pricing as a financing and conservation tool and water pricing as a tool to increase the adoption rates by potential irrigators.

For non-irrigation water uses, there are other options to have the people and firms that benefit from the project contribute to its financing. But we need to know how much different users are actually benefiting from the project. For homeowners of Buffalo Pound, an annual property tax could be levied to capture some of the property price increase that could result from improved water quality and water level stabilization in Buffalo Pound Lake.

The experience in Chestermere Lake near Calgary demonstrates this possibility. An agreement was reached between local property owners and the irrigation agency to stabilize water levels in exchange for an annual service fee to the irrigation agency. The stabilization of lake levels resulted in an increase in waterfront property values totalling $58 to $94 million (No Kim, Boxall, and Adamowicz 2016). Over 5 years, the resulting total tax revenue resulting from this property value increase was estimated to be between $265,000 and $430,000 which represents 16% to 26% of the total annual service fee paid to the irrigation agency over this period.

Industrial users of water from Buffalo Pound may also be able to contribute to project financing through water charges. For example, the current industrial water charge set by the Water Security

Agency is $46.20 per 1,000 cubic metres for water taken from the South Saskatchewan River, Lake Diefenbaker, Buffalo Pound Lake and the Qu'Appelle River.[2]

4.4. A back of the envelope economic assessment

Given all the uncertainties and unknowns regarding the projects economic benefits and costs, assessing the economic viability of the project with current information is a challenge. There is a clear need for a comprehensive benefit cost analysis. In the meantime, a simple calculation can shed some insights at what is at stake.

Two pieces of information that are perhaps the most well studied are the overall project costs and the potential number of acres that could be irrigated. We can use these two pieces of information to conduct a partial economic analysis as an illustrative calculation. If we exclude the non-irrigation net benefits in the Saskatchewan River Basin and Buffalo Pound Lake and the Qu'Appelle system, or alternatively assume that the aggregate net benefits of all of these effects are zero, we can focus on the required net benefits to irrigation that would be needed for the overall project to have positive net benefits. Project costs associated with the water conveyance project range from $1.1 to $1.5 billion in present value terms and the project is expected to expand irrigation by about 110,000 acres. If we assume the lower end of project costs of $1.1 billion, then the costs of the project is around $10,000 per irrigated acre. Thus, the net benefits of irrigation relative to dryland farming would need to be at least $10,000 per acre for the net present value of the project to be positive. As a comparison, according to Farm Credit Canada, the average value of Saskatchewan farmland was around $2,000 per acre in 2018[3] which is a useful proxy of the net present value of dryland farming.

If the downstream economic costs in the Saskatchewan River Basin are small and the economic net benefits in Buffalo Pound Lake and the Qu'Appelle system are large, the net benefits of irrigation required for the project to have positive net returns would decrease. For example, if the

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[2] Industrial Water Use Charges taken from the Water Security Agency's website https://www.wsask.ca/Permits-and-Approvals/Regulatory-Info/Industrial-Water-Use-Charges/

[3] https://www.fcc-fac.ca/fcc/about-fcc/reports/2018-farmland-values-report-e.pdf

net present value of non-irrigation benefits are calculated to be $550 million, then the required present value of net benefits of irrigation would be only $5,000 per acre.

References

Bjornlund, Henning, Lorraine Nicol, and K. K. Klein. 2009. "The Adoption of Improved Irrigation Technology and Management Practices—A Study of Two Irrigation Districts in Alberta, Canada." *Agricultural Water Management* 96 (1): 121–31. https://doi.org/10.1016/j.agwat.2008.07.009.

Brown, Jillian R. 1986-. 2017. "Irrigation Development as an Instrument for Economic Growth in Saskatchewan: An Economic Impact Analysis." Thesis, University of Saskatchewan. https://harvest.usask.ca/handle/10388/8145.

Clifton Associates. 2012. "Upper Qu'Appelle Water Supply Project Economic Impact & Sensitivity Analysis."

Kulshreshtha, S., Nagy, C., and Bogdan, A. 2012. "Present and Future Water Demand in Selected Saskatchewan River Basins." Saskatchewan Water Security Agency.

No Kim, Hyun, Peter C. Boxall, and W. L. (Vic) Adamowicz. 2016. "The Demonstration and Capture of the Value of an Ecosystem Service: A Quasi-Experimental Hedonic Property Analysis." *American Journal of Agricultural Economics* 98 (3): 819–37. https://doi.org/10.1093/ajae/aav037.

Parsons, George R. 2017. "The Travel Cost Model." In *A Primer on Nonmarket Valuation*, edited by Patricia A. Champ, Kevin J. Boyle, and Thomas C. Brown, 187–233. The Economics of Non-Market Goods and Resources 6. Springer Netherlands.

Samarawickrema, Antony, and Suren Kulshreshtha. 2008. "Value of Irrigation Water for Crop Production in the South Saskatchewan River Basin." *Canadian Water Resources Journal / Revue Canadienne Des Ressources Hydriques* 33 (3): 257–72. https://doi.org/10.4296/cwrj3303257.

Sampson, Gabriel S., Nathan P. Hendricks, and Mykel R. Taylor. 2019. "Land Market Valuation of Groundwater." *Resource and Energy Economics* 58 (November): 101120. https://doi.org/10.1016/j.reseneeco.2019.101120.

Shah, S.M.A. 2019. Integrated Water Resources Management in a Transboundary River Basin: Model Development and Sensitivity Analysis." M.Sc. Thesis Dissertation, University of Saskatchewan.

Taylor, Laura O. 2003. "The Hedonic Method." In *A Primer on Nonmarket Valuation*, edited by Patricia A. Champ, Kevin J. Boyle, and Thomas C. Brown, 331–93. The Economics of Non-Market Goods and Resources. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-007-0826-6_10.

Treasury Board of Canada Secretariat. 2007. "Canadian Cost-Benefit Analysis Guide : Regulatory Proposals." http://publications.gc.ca/site/eng/456648/publication.html.

United States Environmental Protection Agency. 2016. "Guidelines for Preparing Economic Analyses." Policies and Guidance. https://www.epa.gov/environmental-economics/guidelines-preparing-economic-analyses.

Wang, Jinxia, Henning Bjornlund, K. K. Klein, Lijuan Zhang, and Wencui Zhang. 2016. "Factors That Influence the Rate and Intensity of Adoption of Improved Irrigation

Technologies in Alberta, Canada.” *Water Economics and Policy* 02 (03): 1650026. https://doi.org/10.1142/S2382624X16500260.

Hosseini, N., Akomeah, E., Davies, J.-M., Baulch, H. and Lindenschmidt, K.-E. (2018) Water quality modelling of a prairie river-lake system. Environmental Science and Pollution Research 25: 31190–31204. https://dx.doi.org/10.1007/s11356-018-3055-2

Lindenschmidt, K.-E. and Carstensen, D. (2015) The upper Qu'Appelle water supply project in Saskatchewan, Canada – Upland Canal ice study. Österreichische Wasser- und Abfallwirtschaft 67(5-6): 230-239. http://dx.doi.org/10.1007/s00506-015-0235-x

MPE Engineering (2013) Water Security Agency, Buffalo Pound Dam - Dam Safety, Data Book - Draft.

Terry, J.A. (submitted) Water quality modelling of Buffalo Pound Lake. A PhD thesis submitted to the College of Graduate Studies and Research, University of Saskatchewan.

Terry, J.A. and Lindenschmidt, K.-E. (submitted) Sensitivity of boundary data in a shallow prairie lake model. Canadian Water Resources Journal.

Terry, J.A., Sadeghian, A., Baulch, H.M., Chapra, S.C. and Lindenschmidt, K.-E. (2018) Challenges of modelling water quality in a shallow prairie lake with seasonal ice cover. Ecological Modelling 384: 43-52. https://doi.org/10.1016/j.ecolmodel.2018.06.002

Terry, J.A., Sadeghian, A. and Lindenschmidt, K.-E. (2017) Modelling dissolved oxygen/sediment oxygen demand under ice in a shallow eutrophic Prairie reservoir. Water 9: 131. http://dx.doi.org/10.3390/w9020131