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Environmental Net Effects Assessment of Saline Water

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Table of Contents

Tables within Text

Figures within Text

Appendices

EXECUTIVE SUMMARY

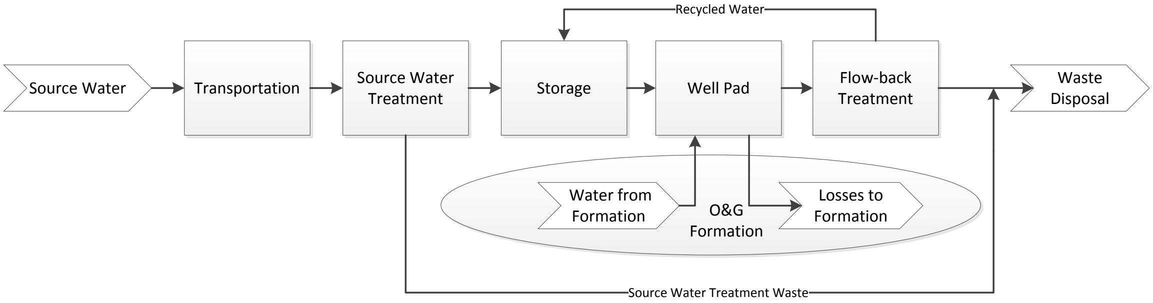
This study provides a high-level assessment of the environmental net effects (ENE) of saline water use in the full lifecycle context of hydraulic fracturing operations. The ENE of saline water is determined based on a comparison against non-saline water as the "base case".

A comparison between non-saline and saline water was chosen, as these two sources represent the most common type of water used for hydraulic fracturing operations. In addition, government agencies and stakeholders are gradually encouraging industry to shift their use of water from non-saline (typically surface water) to saline water (typically deeper bedrock aquifers) sources.

This study is intended to be used for regional and high-level assessment purposes and to guide further work around this topic.

The following flow diagram (Figure A1) defines the stages of the hydraulic fracturing process that were examined. Although a specific environmental effect may occur at numerous points throughout the lifecycle of this activity, each environmental effect was only considered for one block in the flow diagram.

Figure A1. Water Use in Hydraulic Fracturing



Environmental Criteria

The following environmental criteria were used to assess the impact of saline and non-saline source water use within each block depicted above (where applicable):

Ecosystem: Impacts on living organisms (biodiversity) and their habitats due to construction, operations, and reclamation activities.

- **Construction-related Impacts:**
  - **Terrestrial Habitat Disturbance:** Amount and extent of physical land disturbance (i.e., clearing trees, excavation, river diversion).
  - **Aquatic Habitat Disturbance:** Impact to the aquatic ecosystem, including lakes and streams, as well as wetlands and riparian habitats due to a physical disturbance.

- **Operations-related Impacts:**
  - **Large Water Withdrawals:** Withdrawal of large volumes of water from surface water and groundwater sources for operational use.
  - **Spills and Leaks:** unintended releases from pipelines, well pads, or containment structures (i.e., storage unit or pond).
  - **Terrestrial Impacts:** Potential health impacts to terrestrial wildlife and waterfowl, specifically during the operation of storage facilities (i.e., ponds) and waste disposal facilities (i.e., landfills).
- **Reclamation Impacts:**
  - **Reclamation:** Effort required to return disturbed land back to an acceptable or equivalent state.

Air Quality: Greenhouse gas (GHG) emissions resulting from production and consumption of energy (i.e., diesel fuel use, and electricity provided through the grid system) and the corresponding GHG emissions (gases emitted into the air from industrial processes).

Waste: Volume of liquid and solid wastes generated as a result of treatment of the water (source water and produced water), which may require additional land disturbance for the construction of treatment and disposal infrastructure (i.e., landfills, deep well disposal systems, brine ponds).

Industry Survey

A targeted survey was prepared and provided to 15 member companies of Canadian Association of Petroleum Producers (CAPP) to gather relevant industry experience regarding water use in hydraulic fracturing operations. The results were used to augment and support the findings of this study.

Environmental Net Effects of Sourcing Water

The ENE of both saline and non-saline water sources with respect to water source infrastructure is mainly determined by the facility and source well footprints, access roads and other supporting infrastructure. For example, a river or lake infiltration system can disturb the riverbed and the local aquatic habitat during construction, operation and decommissioning. Alternatively, based on industry experience, a greater number of groundwater wells would be required to match the output volume of one river or lake intake resulting in greater footprint disturbance intensity.

For this study, the saline water source was compared to the most common non-saline water source currently used by industry (river: infiltration gallery) in order to determine the major ENE differences between saline and non-saline water for source water. It should be noted that the quality of these two types of water sources could vary significantly, resulting in a large ENE gap. Alternatively, in a scenario where a higher quality saline water source is compared to a lower quality non-saline water source, this gap may be minimized.

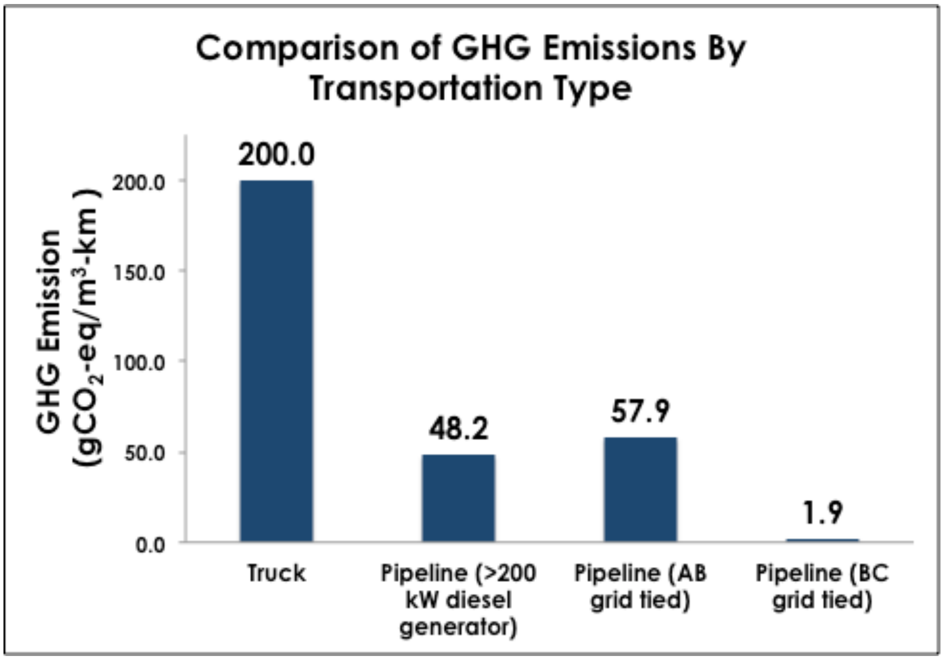
Environmental Net Effects of Transportation

The ENE between saline water and non-saline water, with respect to transportation, is mainly dependent on the effects of spills or leaks. Any spill or leak can cause environmental damage resulting from soil erosion, siltation of streams, and the introduction of foreign substances, or dissolved constituents to an area (i.e., salts and resulting soil salinization issues).

The land disturbance footprint is greater when transporting water via pipeline versus trucking. Access roads are built for site access; therefore, no additional disturbance from the trucking of water is normally required. Alternatively, construction of a pipeline requires clearing of vegetation and excavation, which causes greater land disturbance. In addition, it may be difficult to identify an appropriate water source in close proximity to operations, potentially resulting in the installation of a pipeline over a significant distance.

As shown in the following figure, there is also a large difference in the amount of GHG emissions produced by trucking water compared to pipeline transport.

Figure A2. GHG Emission By Transportation Type for Water Transport



Environmental Effects of Water Treatment

The water treatment ENE is directly related to the specific source water chemistry and downstream quality requirements for each specific application. These two factors are the primary indicators of the required treatment process, and therefore the associated ENE. Saline water may have a greater net environmental impact compared to non-saline water due to the additional energy requirements for treatment commonly needed to meet compatibility with fracking operations. This equally extends to the waste by-products that need to be managed as a result of the treatment process.

Environmental Net Effects of Disposal (Waste Generation from Source Water Treatment)

The major ENE difference for the disposal of waste generated from saline versus non-saline source water treatment is typically the volume of chemicals used for the treatment process. With the exception of the removal of total suspended solids (TSS), which results in the production of large volumes of solid waste, the need for chemicals to render saline water to a useful quality presents the risk of spills and releases into the environment and the associated detrimental effects.

Environmental Net Effects of Water Storage

The major ENE difference between saline and non-saline water storage is the increased impact to the surrounding environment in the event of a spill or leak of, or exposure to, chemicals in the saline water. To prevent such an impact, saline water is typically stored in engineered ponds (lined and monitored), C-ring containment structures, or above ground tanks, with mitigative measures in place. However, the need to engineer in containment leads to higher impact due to the requirement of additional physical footprint, containment infrastructure, and the associated equipment and activities for leak prevention and monitoring.

Environmental Nets Effects of Well Pads

The selection of saline or non-saline source water does not have a significant impact on the hydraulic fracturing fluid or the system infrastructure, as both non-saline and saline water require some form of treatment to ensure compatibility with hydraulic fracturing additives prior to storage on pad.

Environmental Net Effects Downstream of Wells

Variations in produced water quality have been found to be more dependent on the contact time with the formation, the volume of produced water, and the geological formation characteristics than on the quality of the source water used in the fracturing operations (Blauch, 2011).

Conclusion

This study takes a high level approach to comparing saline water and non-saline water in the hydraulic fracturing process, but recognizes that there may be a notable quality difference between the two sources themselves that may influence the overall ENE when compared. As such, it cannot be strictly determined, on a broad scale, if saline or non-saline water has a lower ENE as a more comprehensive approach to source water selection that takes into account regional demands and system capacity is required.

1 INTRODUCTION

Integrated Sustainability Consultants Ltd. (Integrated Sustainability) was retained by the Petroleum Technology Alliance of Canada (PTAC) to provide a high-level assessment of the Environmental Net Effects (ENE) of saline and non-saline water use in the full lifecycle context of hydraulic fracturing operations. This study evaluates the ENE of saline and non-saline source water use in hydraulic fracturing, and also provides a comparison of these two source types.

The basis of this study is provided in Table A, which outlines the assumptions and exclusions used when evaluating the various environmental criteria.

Table A. Study Basis

Parameter	Description
Hydraulic Fracturing Water Volume Requirements	50,000 m^3 per well (based on average water requirements of wells in both the Horn River Basin and Montney resource plays; OGC 2012)
Hydraulic Fracturing Water Quality Requirements	Water quality requirements were taken from the Decision Tree and Guidance Manual Fracturing Fluid Reuse Project (M-I SWACO, 2012) (see section 10.1)
Treatment System Capacity:	6,600 m^3/d (based on previous project experience, completing one well approximately every 8 days)
Saline Water	Total Dissolved Solids greater than 4,000 mg/L (as classified in the *Water Act* of Alberta)
Non-Saline Water	Total Dissolved Solids less than 4,000 mg/L (as classified in the *Water Act* of Alberta)
Exclusions	▪ Environmental effects of manufacturing and transport of construction materials and equipment to site, as well as the construction of facilities and associated infrastructure ▪ Environmental effects of waste generated from construction activities (i.e., steel, concrete) ▪ Environmental effects of all construction and operation activities not related to the handling of water (i.e., drilling on a well pad) ▪ Consideration of social, technical and economic criteria

2 PURPOSE

The purpose of this assessment is to outline the potential environmental impacts, and their relative magnitudes, associated with the use of saline and non-saline water sources. Although saline water use may be perceived as a more sustainable solution, certain environmental drawbacks exist that must be considered when identifying an optimal water source strategy for hydraulic fracturing operations. The benefits, as well as the drawbacks, will be explored further in this document to help inform regulatory bodies as they develop new policies to sustainably manage water resources.

3 REGULATORY FRAMEWORK

Conventional oil and gas reserves in Canada are maturing and in a state of decline; therefore unconventional reserves, including shale gas and crude oil from tight reservoirs, are becoming increasingly important to meet future energy demands. In Alberta, major tight oil and shale gas deposits include the Colorado Group, Montney, and Duvernay. In British Columbia, specifically in the northeast, major plays include the Horn River Basin and Montney. Currently, the preferred method for extracting unconventional reserves is horizontal drilling followed by multi-stage hydraulic fracturing, which requires significant volumes of water. Historically, the main sources of water have been non-saline surface water. The rapidly growing demand for water within this industry, coupled with the mounting negative public perception of large-scale non-saline water use, has pushed provincial governments to encourage industry to explore alternatives to non-saline water sources. These sources include deep saline water, which resides below the base of groundwater protection and, due to the high level of mineralization (or total dissolved solids content) and poorer quality, is not fit for human consumption or agricultural use.

3.1 Definitions

The following are key terms used throughout the report as defined by Alberta Environment and Sustainable Resource Development (AESRD):

- Environmental Net Effects (ENE): Comparison of overall environmental costs (risks) and benefits (opportunities) of alternative water sources (AESRD, 2006);
- Saline: Water that has a total dissolved solids content exceeding 4,000 milligrams per litre (mg/L) (AESRD, 2006); and
- Non-saline: Water less than 4,000 mg/L of total dissolved solids. Often referred to as freshwater (AESRD, 2006). It is considered to be water sourced from non-saline groundwater or surface water sources such as rivers, lakes, or dugouts.

British Columbia has adopted the Alberta definition for saline groundwater (BC MOE, 2005).

3.2 Alberta Regulations

In Alberta, the provincial *Water Act* (Province of Alberta, 2000) grants the authority over all water, saline and non-saline, to the Crown in right of Alberta.

3.2.1 Sourcing

Under the *Water Act*, location-specific licenses are required for all diversions, which covers both withdrawal and storage of non-saline surface water and non-saline groundwater used in oil and gas activities. The current exemption of saline groundwater from licensing requirements is designed to encourage industry to utilize saline water instead of non-saline water, whenever possible.

As part of the province's Water for Life Strategy, AESRD developed the Water Conservation and Allocation Guideline for Oilfield Injection (2006), which provides direction for when the use of non-saline water resources may be essential to an Enhanced Recovery Scheme. At the time of this report, a new draft of a water conservation policy is under development, and will be expanded to include unconventional upstream oil and gas development. Under the 2006 guideline, industry is required to demonstrate that the most appropriate source of water is being used for injection practices, with a focus on saline groundwater use over non-saline groundwater or surface water. Government bodies in both Alberta and BC closely regulate the withdrawal of water from surface and groundwater sources in order to minimize environmental impacts. For example, withdrawals from surface water sources, such as lakes, are regulated to ensure that water levels do not drop below a given elevation. This is done in order to maintain ecological needs and to prevent damage to aquatic and terrestrial habitats reliant on water in the hyporheic and riparian zones. For groundwater sources, static water level elevations must be regularly reported to monitor the effect of withdrawal on the local aquifers and prevent excessive drawdown and impact to the system (including other nearby users). This study is designed to assist companies in identifying the most environmentally appropriate water sources from options that already meet stringent regulatory requirements.

Policies and guidelines are not enforceable in the same way as legislative requirements; however, they do provide context for understanding the water management decisions by government agencies and industry.

3.2.2 Storage

The Alberta Energy Regulator (AER) regulates the production, handling, and use of water produced in association with natural gas, oil, and bitumen recovery, In conjunction, AESRD regulates the environmental outcomes and sustainable development of natural resource recovery. Current guidelines for storage are mainly focused on produced water generated from oil and gas processes versus saline groundwater sources. Due to similarities in quality and potential environmental impacts, some industry members have used produced water and landfill guidelines as a reference to identify saline water storage requirements. In the absence of strict, water quality based storage guidelines for saline groundwater, produced water storage requirements represent a conservative approach that can be followed. For the purposes of this study, this conservative approach is used for the evaluation of water storage ENE. The following table provides a summary of key guidelines for produced water storage in Alberta under AER (Millennium EMS Solutions, 2013) and AESRD.

Table B. Guidelines for Produced Water Storage in Alberta

Regulatory Body or Guideline	Guideline Focus	Guideline Requirements
AER Directive 055 (2001)	Produced Water Storage	Excavation must be lined with secondary containment. Leak detection/collection system is required. Cannot be located within 100 m of high water mark for surface water or wells. Limitations on storage duration.
AER Directive 058 (2006)	Wastewater Storage	30 m delineation from domestic use aquifer (DUA), 10 m delineation from fractured bedrock. Cannot be within a recharge area of an unconfined aquifer. Must be further than 300 m from a surface water body. Must remain 1.5 m above seasonal high water table. TDS must be less than 2,000 mg/L in groundwater.
AESRD Standard for Landfills in Alberta (2010)	Produced Water Storage	Recent shift in Alberta to use landfill requirements for siting of produced water storage (Section 2 of the guidelines).

In addition, both Alberta Infrastructure and Technology (AIT, 2010) and AER (1978) have developed guidelines for the storage of brine (defined as water that contains more than 5,000 milligrams per litre of chlorides), which is regulated under the *Environmental Protection and Enhancement Act* (EPEA) and the *Water Act*. These guidelines can also be used as references for saline water storage requirements.

AIT has developed some basic requirements for the storage of brine water generated from roadway runoff. If the water is stored in a containment pond, the following are required:

- Pond lining and secondary containment;
- Storage and freeboard requirements are to be based on normal storm events; and

- Discharge from ponds is not allowed.

Under AER Guidelines for Alberta Brine Storage Reservoirs (1978), brine storage reservoirs are required to have two synthetic liners with an early leak detection system/collection system in between the two liners. If immediate repair of the liner upon leak detection can be proven, a single synthetic liner with an early leak detection/collection system and a secondary clay liner may be accepted as an alternative.

Non-saline water storage requirements are covered by the *Water Act*. The storage of large volumes of non-saline water requires an approval from AESRD. There are no specific guidelines for non-saline water storage; however, under Section 3.4.1 of Directive 55, aboveground or underground tanks used to store water meeting surface water discharge criteria (Section 11 of the Directive) do not need to meet secondary containment requirements. As per the Directive 55 Addendum, these criteria were used to define non-saline water.

3.2.3 Disposal

In Alberta, AER regulates the disposal liquid wastes, which often remain untreated and injected into deep permeable formations. In contrast, non-saline water is either disposed of into aquifers of a similar character or to the surface environment with the approval of AESRD. For surface water releases, a federal approval under the *Fisheries Act* may also be required.

AER Directive 65: Resources Applications for Conventional Oil and Gas Reservoirs (AER, 2014) and Directive 51: Injection and Disposal Wells (AER, 2012) provide more information on the establishment of water disposal schemes. AER requirements for resource activities covered by Directive 065 are set out in the *Oil and Gas Conservation Act*.

3.2.4 Transportation

Pipelines

Pipes used to convey water usually do not fall under the scope of the *Pipeline Act*, unless a pipe is used to convey water in connection with "a facility, scheme or other matter authorized under the *Oil and Gas Conservation Act* or the *Oil Sands Conservation Act,* a coal processing plant or other matter authorized under the *Coal Conservation Act*." If the pipe conveying water does fall under this definition, the pipeline needs to be licensed by the AER prior to construction and use.

Under *Pipeline Rules*, Alberta Regulation 91/2005 (Province of Alberta, 2005), if a leak or break in a pipeline is detected, the licensee has a duty to contain and clean up the spill of any deleterious liquids that escape the pipeline, including saline water. The AER may dictate the appropriate clean-up method to be used.

Trucking

The Dangerous Goods, Vehicle and Rail Safety Branch of Alberta Ministry of Transportation is responsible for the compliance and enforcement of the Provincial *Dangerous Goods Transportation and Handling Act* (Government of Alberta, 2000) *and Dangerous Goods Transportation and Handling Regulation* (Government of Alberta, 1997). The *Federal Transportation of Dangerous Goods Regulation* (Government of Canada, 2012), has also been adopted by Alberta. Both regulations set safety standards and shipping requirements for dangerous goods, in addition to providing a means of communicating the nature and level of danger associated with various chemicals and other products. If saline groundwater is mixed with produced water, the product might be considered a Class 3 Dangerous Good, in which case it is the responsibility of the consignor to prepare a dangerous goods shipping document when offering dangerous goods for transportation. The water/oil mixture must also be carried in specific trucks/tankers, such as a TC 407/412/350 (AIT, 2009).

3.3 British Columbia Regulations

The provincial *Water Act* provides the legislative mandate for water management and regulation for all uses of surface water in BC. The BC Oil and Gas Commission (OGC) has authority to authorize access to surface and subsurface water specific to oil and gas activities within the province.

3.3.1 Sourcing

Currently, authorizations for surface water used by the oil and gas sector are made through an Approval for short-term water use (up to 24 months), or under a Water License for longer-term uses issued by the OGC (OGC, 2013).

Groundwater use is not currently regulated in BC; however, on May 29, 2014 the new *Water Sustainability Act (*Province of British Columbia, 2014*)* received Royal Assent, and is expected to come into force in 2015. The new act will replace the existing *Water Act (*Province of British Columbia, 1996*)*, and once implemented; non-saline groundwater will become a regulated water source. Under the new act, non-saline groundwater users will require licences and will pay annual fees; however, most "domestic" water wells will be exempt from licensing. Saline groundwater is expected to remain unregulated.

3.3.2 Storage

The OGC has set out different storage requirements for non-saline and saline water. While non-saline water can be stored in unlined, earthen pits, saline water must be stored in either closed top tanks, open top tanks, or lined earth excavations (as outlined in OGC Information Letter 09-07 (OGC, 2009)). Storage may be limited in some cases to a maximum of 90 days for hydraulic fracturing operations, with the actual limitation based on the water source.

Under the current *Water Act*, construction and use of a storage pond is a right acquired under a licence, and requires completion of a Dam and Reservoir Information form along with a water licence application.

3.3.3 Transportation

There is no difference in pipeline regulations for transporting saline water and non-saline water when the water is to be used for upstream oil and gas activities. The OGC has taken a conservative approach to water pipeline requirements, by only allowing water intended for domestic use to be permitted as a non-saline water pipeline (OGC, 2014).

Permits to establish pipelines over Crown land are found under the *Water Act* in Section 26 (Government of British Columbia, 1996) and issued where companies wish to transfer water via temporary aboveground pipelines or other preapproved temporary methods. The construction works approved under Section 26 are for transporting water approved under a short-term water licence approval.

3.3.4 Discharge or Disposal

The OGC does not allow surface discharge of saline water. Saline water returned from oil and gas production operations is forbidden to be released into surface waters such as lakes and streams, or into near surface aquifers that are used for potable water supply. Only deep well disposal of saline water is allowed. One exception is for coalbed gas operations, whereby the BC Ministry of Environment (BC MOE) allows for the discharge of produced (saline) water to surface only if TDS concentrations are less than or equal to twice the TDS of the underlying groundwater, up to a maximum of 4,000 mg/L (BC MOE, 2008).

4 HYDRAULIC FRACTURING PROCESS OUTLINE

Hydraulic fracturing operations are able to use various source waters, which may include rivers, lakes, groundwater, or effluents from wastewater treatment facilities. This water is transported to the point of use via pipelines or trucks, and stored onsite until it is needed. This main purpose of the water is to convey proppant (typically a well-graded sand) into the hydrocarbon-bearing formation to prop open the fractures after hydraulic stimulation activities and allow gas to flow from the reservoir rock to the production well, and then to the surface for processing. A small volume of chemical additives is used in the hydraulic fracturing solution to ensure the proppant remains in suspension, and to reduce the friction of the solution being injected. This allows for high flow velocities and pressures as the proppant is delivered down the well and into the target formation.

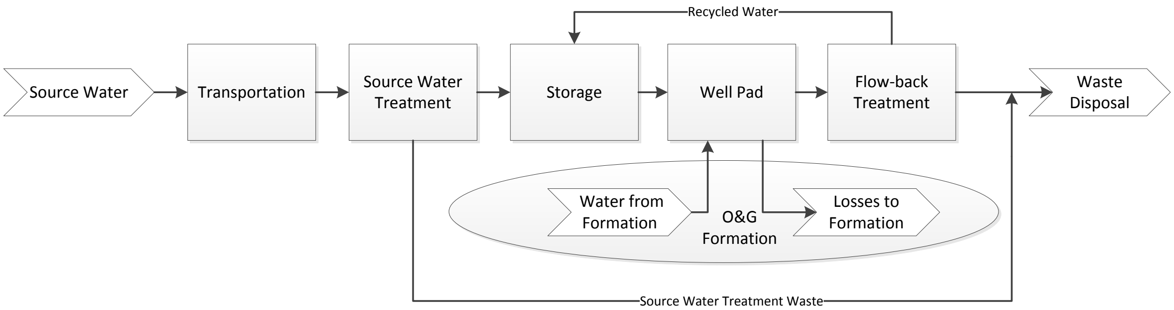
There are many options for chemical additives in the hydraulic fracturing process (Section 10), and each of these additives has a different requirement for source water quality. Since the potential source waters for hydraulic fracturing can vary greatly in chemical quality, source water treatment may be required to meet the constraints of the chemical additives.

Following hydraulic fracturing operations, the well is depressurized, and a portion of the injected fluid returns to the surface. Depending on the characteristics of the fractured formation, connate water (i.e., water trapped during formation deposition) contained within that formation that may also flow to surface. These fluids together are collectively referred to as produced water or flow-back. While in the reservoir, the injected fluid has the potential to dissolve minerals from the formation and come in contact with hydrocarbons that will return to the surface with the produced water stream. This fluid, along with any wastewater generated at the water treatment stage, will typically be disposed of by injection into a subsurface formation via a disposal well, and may require additional treatment to ensure compatibility with the connate waters in the disposal formation.

A block flow diagram (Figure A) was created to clearly define where potential environmental effects, due to the use of saline or non-saline water, might occur in the lifecycle of water during the hydraulic fracturing process. Although a specific environmental effect may occur at numerous points throughout the lifecycle, each environmental effect will only be considered for one block of the flow diagram (i.e., water is stored at many locations throughout its use in operations, therefore the effects will be the same at all locations - as such the ENE of storage will only be considered within the discrete storage block). Within each block of the lifecycle, the environmental effects of the most common methods utilized by industry have been described. In some instances, alternative technologies are mentioned to demonstrate more beneficial practices.

Full descriptions of the environmental effects associated with each block of the diagram below are outline in Appendix 1.

Figure A. Hydraulic Fracturing Block Flow Diagram



5 CAPP MEMBER SURVEY

As part of this study, a survey was provided to 15 member companies of the Canadian Association of Petroleum Producers (CAPP). The purpose of this survey was to gather relevant industry experience regarding water use in hydraulic fracturing operations. The results were used to augment and support the findings in this study. A copy of the survey is provided in Appendix 2 for reference.

Through a comparison of the responses it was determined that:

- No hydraulic fracturing operations are currently using water from saline aquifers; however, all companies are currently evaluating the use of saline water for source water purposes. Based on the survey responses, the aquifers currently being evaluated for saline water extraction are the Cadotte, Cardium, and Beloy formations in the Duvernay area, and the Debolt Formation in the Horn River Basin;
- One company had historically used treated saline water accessed from the Debolt Formation, making up approximately 98% of the water required for hydraulic fracturing. This operation is no longer active;
- All companies surveyed are currently reusing produced water. Produced water makes up between 40 to 75% of the water required hydraulic fracturing;
- All companies have internal business drivers to reduce non-saline water use and employ an ENE approach. It is not always possible to access saline water aquifers; therefore, many companies are limited to re-using produced water to reduce non-saline water use;
- All companies noted that water (non-saline and/or run-off) is held in storage ponds that meet regulatory requirements, which include provision of a primary and secondary containment system, leak detection, and perimeter fencing; and
- All companies noted that pipelines are the preferred method for transporting produced water, and therefore would be the preferred method of transporting saline source water (although trucking is at times necessary due to location limitations).

The desired water quality for use in hydraulic fracturing operations was found to vary by company and location, but most respondents indicated that total dissolved solids (TDS) were not a limiting factor, while in all cases the hydrogen sulfide (H_2S) concentration limit was 0 ppm. Typically, both biocides and scale inhibitors were used. Some operations also required demulsifiers and friction reducers as additives.

6 ENVIRONMENTAL CRITERIA DESCRIPTION

The following section outlines the specific environmental effects that were reviewed, and provides a description of each associated criterion used in this study.

6.1 Ecosystem

An ecosystem is a dynamic structure of plant, animal, and microorganism communities and their non-living environment, interacting as a functional unit (MEA, 2005). Ecosystems are habitats (i.e., forests, grasslands, rivers, farmland, and urban parks) that support various species. Biodiversity is the variability among living organisms within a species, between species, and between ecosystems. According to Costanza, *et al.* (1997), ecosystems provide a myriad of essential services, including, but not limited to:

- Water resources protection;
- Atmospheric and climate stabilization;
- Soils formation and protection;
- Nutrient storage and recycling;
- Erosion control and sediment retention;
- Biological controls; and
- Ecosystem maintenance (i.e., vegetation maintains water and humidity levels).

In the context of this study, the evaluated impacts on living organisms and their habitat are due to:

- Construction activities associated with:
  - Water source withdrawal (i.e., water intakes or points of diversion, access roads, pipeline right-of-ways): and
  - Water use (i.e., infrastructure and facilities to transport, store, and treat water).
- Operational activities:
  - That may have an ongoing impact on biodiversity (i.e., water intakes); and
  - That may result in a leak or spill from a pipeline, well pad, or containment structure (i.e., storage unit or pond) and may affect the biological community or its associated habitat.
- Reclamation activities that are meant to re-establish habitats and support vegetation and wildlife as self-sustaining ecosystems.

6.1.1 Construction-related Impacts

Terrestrial Habitat Disturbance

Ecosystems and terrestrial biodiversity communities (species that inhabit the land i.e., waterfowl, birds, wildlife, vegetation) are impacted when endemic habitats are lost or substantially altered. Terrestrial disturbance occurs during construction activities; this may result in physical land disturbance such as:

- Clearing and grubbing;
- Grading;
- Draining;
- Excavation;
- Landscape alteration (i.e., construction of embankments); and
- Moving, depositing, stockpiling, or storing of soil, rock, or earth materials.

In the case of the hydraulic fracturing process, with a focus on the difference between saline and non-saline water use, the following activities result in land disturbance, which may impact an ecosystem and its terrestrial community:

- Obtaining water from saline and non-saline water sources;
- Transporting water to and from facilities;
- Storing water; and
- Treating water (Note: land disturbance associated with storage of waste generated from the treatment of water is captured under the category: Waste, Section 6.3).

The level of previous disturbance, whether an area is greenfield (undeveloped land that retains its natural ecosystem state) or brownfield (previously developed land), will influence the impact to the terrestrial community. Impacts are mainly applicable to facilities that will be constructed on greenfield sites. Ecosystem and terrestrial biodiversity impacts may include:

- Degradation or direct loss of vegetation;
- Introduction of invasive species through vehicular traffic and construction equipment causing soil degradation, erosion, and disease of native and domesticated species and leading to extirpation or extinction;
- Increased erosion and sedimentation;
- Deterioration of soil quality (decreased moisture content, reduced water infiltration);
- Changes in natural drainage patterns; and
- Changes/disruption to migration patterns.

In addition, land disturbance is a function of infrastructure and facility size and is dependent on:

- Volume of source water required;
- Seasonal availability of the source water; and
- Source water quality.

Aquatic Habitat Disturbance

Construction and operation of a water intake system may potentially impact in-stream aquatic habitats (i.e., benthic zones around lakes, rivers, and streams) as well as the out-of-stream habitat features such as wetlands and riparian areas.

A water intake system may potentially disturb the benthos, which is a community of microorganisms that live in the benthic zone (the bottom of freshwater bodies). The benthos is critical to the ecosystem as it cycles nutrients throughout the system and is part of the food supply for many fishes and other vertebrates. In most ecosystems, specifically rivers and lakes, the benthos comprises the lowest trophic level of organisms that are the most sensitive to construction disturbances. The removal of these microorganisms in one zone of the river/lake bed may alter the downstream communities, as nutrients will not be cycled in the area that was disturbed. The higher trophic level organisms will also lose a food source in the area of disturbance, and may draw more food from other food sources (i.e., downstream locations) thus reducing the benthos in other sections of the stream.

Wetlands are defined as lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water (i.e., marsh, fen, peatland) (Cowardin et al., 1979). Wetlands are important to aquatic systems as they:

- Improve water quality by filtering runoff and removing sediment, excess nutrients, and other types of pollutants;
- Attenuate storm water flow;
- Facilitate infiltration and recharge groundwater supplies;
- Provide a barrier to erosion, as the root systems of wetland plants stabilize soil and enhance soil accumulation;
- Provide food and serve as nurseries that provide protection against predators; and
- Serve as sinks, sources, or transformers of chemicals through a process known as biogeochemical cycling.

Riparian areas are areas along streams, lakes, and wetlands that link water to the adjacent land. The blend of streambed, water, trees, shrubs, and grasses directly influences and provides fish habitat (Ministry of Environment, 2014). Riparian areas affect the structure of aquatic systems by performing a number of functions including:

- Trapping/removing sediment from runoff;
- Stabilizing stream beds and reducing channel erosion;
- Recharging groundwater supplies;
- Trapping/removing phosphorus, nitrogen, and other nutrients that can lead to eutrophication of aquatic ecosystems; and
- Maintaining habitat for fish and other aquatic organisms by moderating water temperatures and providing shelter during high-flow events.

In addition, riparian areas regulate the food resources both through regulation of light for primary production within the water body and by degree of debris falling into the water body (Swanson, 1994).

Aquatic habitat disturbance, as a result of water intake system construction, has the potential to alter, degrade, and eliminate fish habitats, as well as impact fish populations.

6.1.2 Operations-related Impacts

Large Water Withdrawals

During the operation of water intake systems, the aquatic habitat and related communities may be affected if large volumes of water are withdrawn. Such diversions can lead to stream flow depletions, disruption of natural flow regimes, large drawdowns in aquifers, and interference with functional flows to wetlands and other water dependent ecosystems.

While water withdrawals directly affect the availability of water, water withdrawals can also affect water quality for surface water and groundwater systems. For example, withdrawals of large volumes of water can adversely impact groundwater quality by mobilizing naturally occurring substances, promoting bacterial growth, causing land subsidence, and mobilizing lower quality water from surrounding areas or formations (Cooley and Donnelly, 2012). In order to minimize these potential environmental impacts, large water withdrawals are currently managed in Alberta and BC through a regulatory regime and approval conditions under current legislation. The current style of allocation in Western Canada establishes priority based on 'first in time, first in right'. Licences are awarded to users that fulfill the necessary requirement of existing policies, guidelines, and management frameworks (i.e., Lower Athabasca Regional Plan) and demonstrate responsible water use with limited impact to the water source during the full lifecycle of use. With respect to surface water, regulations in both provinces are designed to ensure that the remaining water flow volumes match the hydrological regime of the river and allow for natural high and low flows to occur. For example, on the Lower Athabasca River in Alberta, when water flow in the river is sufficient, instantaneous withdrawals from all users is limited to a maximum of 15% of the total flow rate (Alberta Environment, 2007). When water flow is not sufficient (i.e., winter low flow period), maximum withdrawal rates are lowered to prevent impact to aquatic and terrestrial ecosystems.

Spills and Leaks

A spill is as a single event, resulting in the release of a significant volume of water from a contained area to the surrounding environment. In contrast, a leak is a continuous, slow release of water from a contained area to the surrounding environment (Millennium, EMS Solutions, 2013). During operations, ecosystem impacts, including impacts to groundwater, may result from an unintended leak or spill from a pipeline, well pad, or containment structure (i.e., storage unit or pond). Causes of water spills along a pipeline may include leaking valves, pump failures, leaking pipes, leaking tanks, transfer hoses, o-ring and seal failures, leaking vehicles and human error (National Research Council, 2003). Soil and/or surface water contamination from leaks and spills could potentially lead to a degradation of vegetation, soil quality, and water quality (surface water and groundwater). Gawel (2006) outlines that impacts to soil and plant life as a result of a spill or leak may include:

- Soil particle dispersion, which results in loss of soil and pore structure, reduced air and water movement, reduced bioactivity, reduced nutrient transfer, and increased water runoff and erosion;
- Changing osmotic potential limiting a plant's ability to absorb water, and thus impacting growth and survival;
- Inundation of terrestrial and riparian areas. The initial effect of inundation on plants is through the root system. The waterlogged soil becomes anoxic and this leads to oxygen stress and eventual elimination of the primary root system (Nilsson and Berggen, 2000); and
- Ionic balance of the soil solution impacting absorption of soil nutrients.

In addition, vegetative uptake and translocation of toxins in plant tissue may eventually be released into the food chain, impacting terrestrial wildlife and waterfowl.

Impacts to water quality and aquatic ecosystems as a result of a spill or leak into surface water sources are dependent on the characteristics of the water source; however, impacts may include:

- Deterioration of water quality;
- Sediment accumulation through erosion and sediment transport;
- Degradation of riparian zones; and
- Decline in biodiversity through dominance of species (i.e., salt-resistant or tolerant species), potentially altering ecosystem structures.

Terrestrial Impacts

Currently, requirements for waterfowl and wildlife deterrent measures to prevent access to facilities that may potentially cause harm (i.e., ponds, landfills) are regulated under Section 8.1 of AER Directive 055: Storage Requirements for the Upstream Petroleum Industry (AER, 2001). This Directive stipulates that mitigative measures are required to be in place for storage facilities. Additionally, Directive 58: Oilfield Waste Management Requirements for the Upstream Petroleum Industry (AER, 2006) includes the installation perimeter fencing to prevent wildlife access.

In the case of mitigation failure, there may still be potential impacts to terrestrial wildlife and waterfowl. Exposure to potential toxic substances (i.e., highly saline water and waste materials) may adversely impair health and condition, leading to biological effects such as reduced growth, reproduction defects, and mortality.

6.1.3 Reclamation Impacts

Land reclamation is an integrated approach to returning disturbed land back to an acceptable or equivalent state prior to the initial disturbance. Regulatory requirements vary with respect to the extent of reclamation required. This criterion has been used to compare the levels of effort that would be required for reclaiming disturbed areas. For example, within the water storage phase, a pond will require more effort to reclaim the impact footprint to an acceptable or equivalent state than an aboveground tank as the pond may require backfilling and site re-grading, while the tank may be more easily removed with only site re-vegetation required.

6.2 Air Quality

This criterion considers greenhouse gas (GHG) emissions resulting from production and consumption of energy (i.e., diesel fuel use, and electricity provided through the grid system) and the corresponding GHG emissions (gases emitted into the air from industrial processes) associated with:

- Transportation of water and waste products; and
- Treatment of water.

To accurately compare multiple sources of air emissions for this study, individual fuel types are converted to CO_2 emission equivalents (refers to a number of GHGs collectively considered). The CO_2 equivalent of diesel fuel use is calculated using the revised Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (1996). The CO_2 equivalent of electricity from the grid for both Alberta and BC is obtained from the National Inventory Report 1990-2009: Greenhouse Gas Sources and Sinks in Canada (Environment Canada, 2011).

The total water volume required during hydraulic fracturing operations, the proximity of the available water source, and the source water quality will dictate the quantity of GHGs resulting from water and waste conveyance and the water treatment processes.

6.3 Waste

Waste generated during water treatment, such as solids, sludge, and liquid waste may require additional land disturbance for the construction of treatment and disposal infrastructure and facilities (i.e., landfill, deep well disposal site or network, brine ponds). An additional environmental concern is the potential for spills and leaks associated with waste storage, transfer, and disposal (i.e., liquid waste spills during storage and transport to the site, and leachate discharge to the environment from landfills, respectively).

As discussed in Section 13 of this study, there is commonly minimal difference in the volume of waste generated when comparing the concentrated produced water treatment reject streams from the use of saline with the use of non-saline source water. As such, only impacts associated with the disposal of source water treatment reject streams have been considered in this study.

Waste generated from construction activities (i.e., steel, concrete) have also been excluded from this study.

7 ENE COMPARISON METHODOLOGY

An ENE comparison chart is included in each section to provide a visual overview when assessing the effects of changing from a non-saline water source to saline source water for hydraulic fracturing operations. These charts are designed as a high level summary of the ENE outlined in each section.

The scoring is based on the information within the scope of each section (Appendix 1), and reflects a comparison of the use of saline source water as compared the base-case (non-saline source water) for each ENE criterion (Section 6). The ENE from each criterion is scored (Table C) on a scale of -3 (extreme environmental advantage of using saline source water) to 3 (extreme environmental disadvantage of using saline source water). The ENE scoring is an indication of the magnitude of the advantage or the disadvantage rather than a scalar value; the ENE scoring in one category cannot be directly compare the scoring in a different category, nor can they be compared with the ENE scoring of different sections of the report (i.e., a +1 score for saline water use under "footprint" in Section 8 should not be considered to negate the net effect of a -1 score for saline water under "reclamation". Likewise it should not be considered to negate a -1 score under "footprint" in Section 11).

As this is a high level overview, the scores are relative to their own category and specific criterion. To determine the exact ENE of changing from a non-saline source water to a saline source requires a site-specific assessment of:

- Water quality and quantity;
- The hydraulic fracturing fluid additives being used; and
- The sensitivity of the receiving environment.

For each resource category, the impact analysis should follow the same approach in terms of impact findings. When possible, quantitative information is provided to establish impacts.

Qualitatively, these impacts will be measured as outlined below:

Table C. ENE Comparison Scoring Rubric

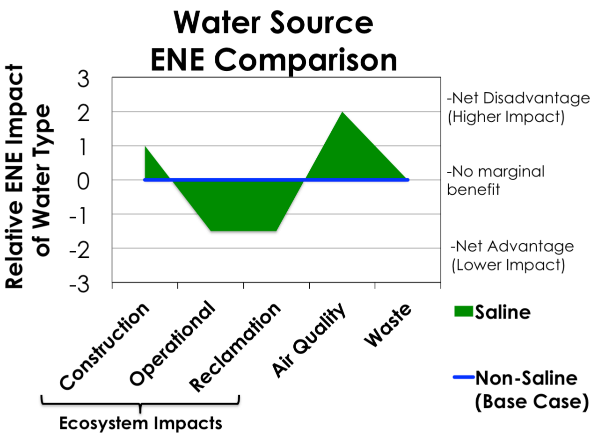
Score	ENE Score Interpretation
3	Major environmental disadvantage as compared to base case.
2	Moderate environmental disadvantage as compared to base case.
1	Minor Environmental disadvantage as compared to base case.
0	No significant net effect between as compared to base case.
-1	Minor environmental advantage as compared to base case.
-2	Moderate environmental advantage as compared to base case.

Score	ENE Score Interpretation
-3	Major environmental advantage as compared to base case. No impact.

8 SOURCE WATER

Source Water Overview

The major environmental impact of both saline and non-saline water sources with respect to water source infrastructure is the facility and source well footprints, access roads, and other supporting infrastructure. For example, a river or lake infiltration system can disturb the riverbed and the local aquatic habitat during construction, operation, and decommissioning. Alternatively, based on industry experience, a greater number of groundwater wells would be required to match the output volume of one river or lake intake resulting in greater disturbance footprint intensity.



The sources for water considered in this assessment include:

- River water;
- Lake water;
- Shallow groundwater (non-saline aquifer); and
- Deep groundwater (saline aquifer).

The most common infrastructure to extract water from these sources has been used to determine the environmental impacts of saline and non-saline water intake systems. New technologies and system designs exist to reduce the environmental impact of water extraction; however, the evaluation of those technologies is outside the scope of this study.

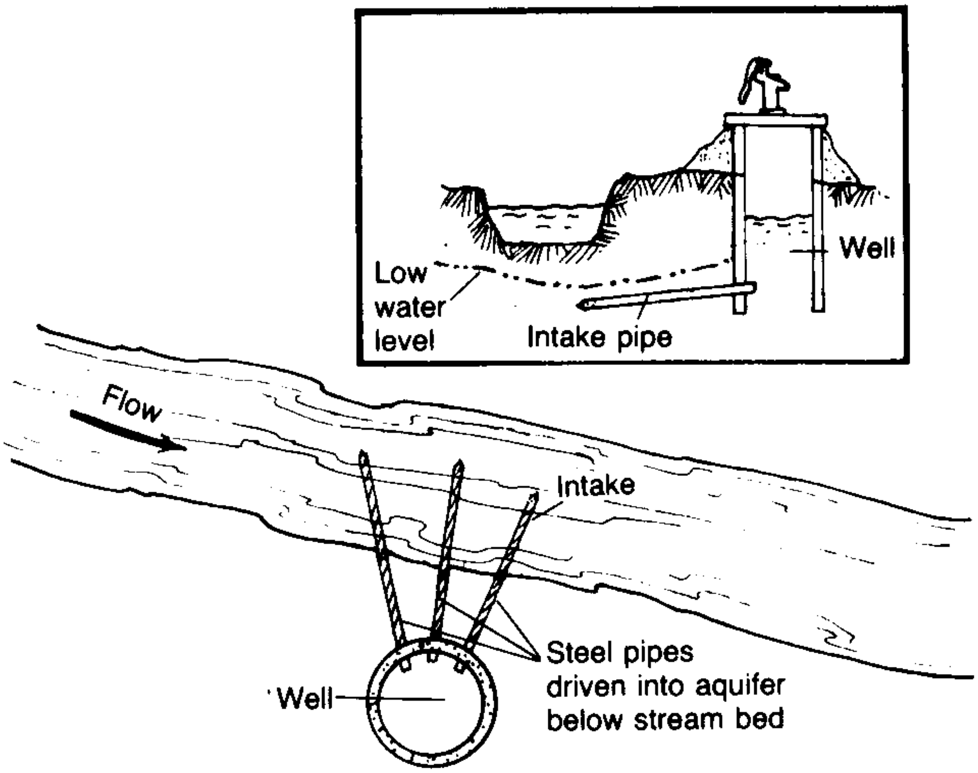
8.1 Infrastructure Description

8.1.1 River: Infiltration Gallery

An infiltration gallery is a common form of river intake and consists of perforated pipe installed approximately 2 m below the riverbed (Figure B). The intake pipes are often connected to a wet well. The intake pipes can be installed by directional drilling, or alternatively the in-river installation area can be excavated for pipe installation. Typically for an in-river installation, the backfill material beneath and covering the pipe is often foreign granular material consisting of different layers with different grain sizes to minimize ingress of fine sediment, but local materials can also be used.

Infiltration galleries are often utilized when there is a concern with river depth (for navigation purposes), suspended solids management, ice management, or fish protection. The main source of failure is the ingress of fine material or the accumulation of anchor ice, which lowers the hydraulic conductivity of the backfill material and deliverability of the system. Back flushing using water or air is a system requirement for maintenance, especially for river systems conveying large amounts of fine sediment.

Figure B. River Infiltration Gallery

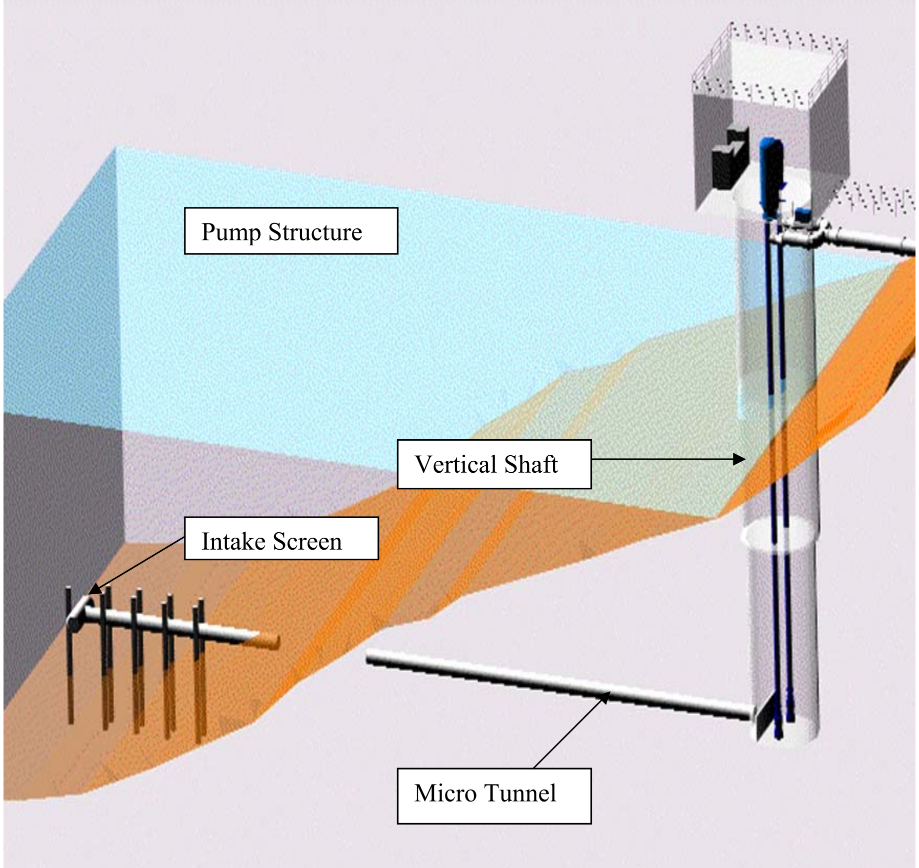


Source: USAID, n.d. Water for The World: Designing Water Intakes for Rivers and Streams – Technical Note No. RWS. 1.D.3.

8.1.2 Lake Water: Lake Tap

A lake tap is a common form of water intake structure and consists of a large diameter vertical shaft, approximately 30 to 60 m deep, that is connected to the lake with a horizontal inlet tunnel (Figure C). Pipe inlets in the lake typically need to be a minimum of 4.5 m off the lake bottom to reduce the intake of silt and sand. Such an inlet would include a properly sized fish screen to prevent intake of fish into the system.

Figure C. Lake Water – Lake Tap



Source: East Canyon Reservoir Water Intake Structure Final Environmental Assessment

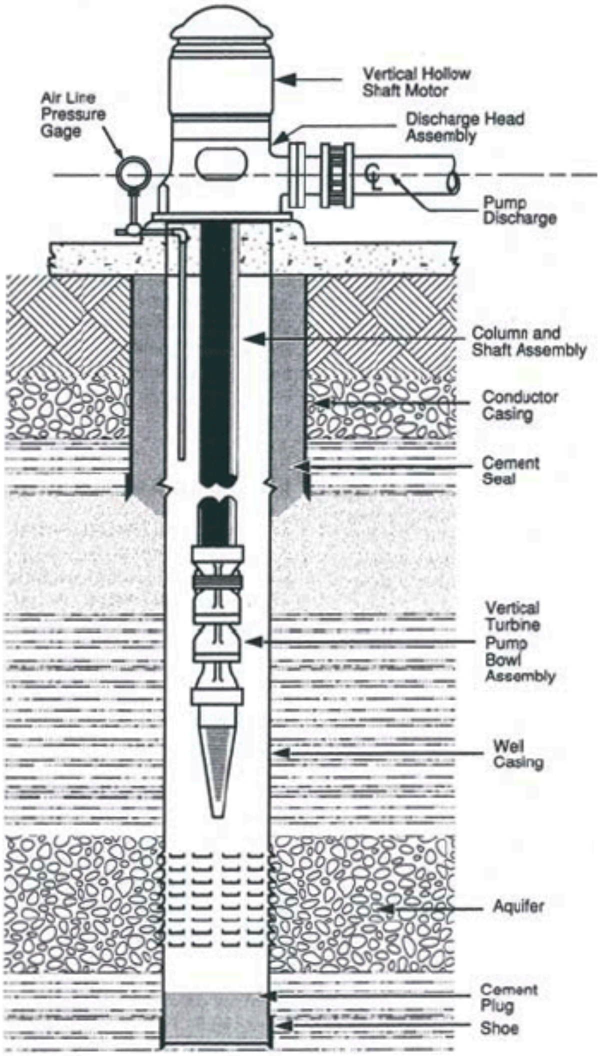
8.1.3 Non-Saline Water Aquifer: Shallow Water Well

A typical groundwater well installation is depicted in Figure D. Groundwater is a renewable resource and is recharged from the surface; however, the timeframe for recharge can be quite long depending on the depth of groundwater systems being replenished and the ability of formation to receive and transmit water.

Since groundwater percolates through soil layers, it tends to acquire various dissolved minerals and metals, as well as soluble organics. Regardless, natural groundwater quality in aquifers tends to be quite stable and consistent across large areas. During groundwater withdrawal, waters of different quality can nevertheless be pulled in to different parts of an aquifer as a result of capture during water withdrawal activities.

Compared to deeper groundwater systems, shallower groundwater sources generally have a greater chance of being connected to surface water sources and thus can be influenced by activities occurring on the surface (i.e., chemical spills, leaks from ponds).

Figure D. Non-Saline Water Aquifer – Shallow Water Well



Source: WRD, 2014.

According to the Government of Alberta, average non-saline ground water well production in the province is on the order of 140 m³/day, based on geological information obtained from the Edmonton-Calgary Corridor (Barker et al., 2011). The Edmonton-Calgary corridor contains several important natural gas producing basins and therefore non-saline groundwater yield rates from this area have been used for the basis for this study. The potential yield in this area ranged from 10 m³/day to 275 m³/day with a tendency towards the higher rates in the western regions where the natural gas production is primarily located.

An average value of 140 m³/day was used in this study to estimate water availability (Section 8.2).

The low yield values reported for groundwater wells in the Edmonton-Calgary corridor is due to the data being reported from local drinking water wells. Given proper permitting of a groundwater well for industrial purposes, there is the potential for achieving higher yields through the use of larger wells and advanced drilling and completion techniques, including horizontal drilling and optimal well siting for maximum production.

8.1.4 Saline Aquifer: Deep Water Well

Given their depth, saline aquifers tend to be isolated from the near-surface environment, which means there is generally limited interaction between near surface aquifers and/or surface water bodies. Interaction can occur if pathways, such as faults, connected fracture systems, or induced pathways (poorly sealed oil and gas wells penetrating the aquifers) exist between these deep aquifers and shallower aquifers. In the absence of these potential connections, the removal of saline groundwater should not have an effect on the availability of non-saline groundwater (shallow wells) or surface water bodies.

The production rate of saline water wells is dependent on well location and formation specific factors including permeability, porosity, zone thickness, hydrostatic pressure, and lithostatic pressure. To determine a representative yield from a saline deep groundwater well, information from the Montney gas development in BC was used. The representative production rate was calculated using a well data and deliverability model from Petrel Robertson (2011). The well production values from this study ranged from 1.2 m^3/day to 4,433.3 m^3/day, and averaged 82 m^3/day. The average value is relatively low, and likely due to case study wells not all being optimized for saline water production but rather for hydrocarbon exploration and production purposes.

For simplicity in calculations throughout this study, a rounded value of 100 m^3/day has been used.

8.2 Environmental Impacts of Water Sourcing

The following section highlights the potential environmental impacts associated with the construction, operation, and reclamation of each water source option.

8.2.1 Ecosystem: Construction-related Impacts

Terrestrial and Aquatic Habitat Disturbance

Table D compares the footprint of each type of infrastructure using a reference. Since the reference design cases all report different volumes of water, the footprint was normalized to show the area required to produce 40,000 m^3/day of water.

Table D. Source Water Infrastructure Footprint Comparison

Criteria	River–Infiltration Gallery	Lake- Lake Tap	Shallow (Non-Saline) Aquifer	Deep (Saline) Aquifer
Footprint of reference design (Ha)	0.49	0.22	0.0025	0.0025
Flowrate of reference design (m^3/day)	115,200	42,250	140	100
Footprint required to produce 40,000 m^3/day (ha)	0.17	0.21	0.7	1.0

River: Infiltration Gallery

The reference design case for the river infiltration gallery is based on the East Canyon Reservoir Water Intake in Utah - a 115,200 m^3/day facility that occupies 0.49 ha of land (USDI, 2009). The normalized footprint required to produce 40,000 m^3/day of water is 0.17 ha, resulting in the lowest footprint of the four water source options.

The environmental impacts associated with constructing a river infiltration gallery are:

- In-river construction (cofferdam required to re-route river). Dredging to remove the riverbed can cause direct mortality of the benthic organisms within the area dredged, as well as create turbidity plumes of suspended particulates that can reduce light penetration, interfere with respiration and the ability of visual predators to locate and capture prey, impede the migration of anadromous fishes, negatively impact spawning beds, and affect the growth and reproduction of filter feeding organisms (Wilber and Clarke, 2001);
- Surface infrastructure required (wet well), creating a physical disturbance to vegetation in the area;
- Unintended introduction of invasive plant species; and
- Access road construction.

Lake Water: Lake Tap

The reference design case for the lake tap option is based on the Navajo Generating Station Water Intake in Utah, which is a 42,250 m^3/day facility and occupies 0.22 ha of land (USDI, 2005). The normalized footprint required to produce 40,000 m^3/day of water is 0.21 ha; the lake tap has a larger footprint when compared with the infiltration gallery, but a smaller footprint than groundwater sources.

The environmental impacts associated with constructing a lake tap are:

- Lake-side (vertical shaft and micro tunnel) and in-lake construction, including dredging, leading to physical disturbance of the lakebed that can cause direct mortality of the benthic organisms within the area dredged;
- Surface infrastructure required (pump house), and related impacts to vegetation in the area;
- Unintended introduction of invasive plant species; and
- Access road construction.

Non-Saline Water Aquifer: Shallow Water Well

In order to determine baseline footprint impacts of shallow non-saline water wells, the average groundwater well yield in Alberta of 140 m^3/day was used (AESRD, 2012). Standard industry practice for development of water wells requires temporary surface disturbance of approximately 50 m x 50 m depending on the drilling rig requirements. Standard practice for permanent well infrastructure is 5 m x 5 m area (0.0025 ha) wellhead area. The normalized footprint required to produce 40,000 m^3/day of water is 0.7 ha. As such, the well systems required to provide non-saline groundwater will have a larger overall footprint when compared to river or lake water intakes, but similar to saline (deep) water wells.

The environmental impacts associated with constructing a system of shallow water wells are:

- Land disturbance of the test-drilling program (to establish aquifer productivity and identify any potential interference with other users);
- Depending on the number of wells needed to be drilled to establish appropriate volumes, the overall construction footprint can be quite large (including pipelines to tie-in multiple wells and convey water to the point of use);
- Multiple parcels of land and many wells would be required to meet the flow requirements of the project which increases the footprint disturbance;
- Introduction of invasive species; and
- Access road construction.

In addition, during the operation of shallow water wells the monitoring of conditions in and around the producing aquifer would require a network of observation wells (water levels and water quality), stream gauges and possibly spring gauges, and meteorological stations, which would lead to additional land disturbance.

Saline Water Aquifer: Deep Water Well

In order to determine baseline footprint impacts of saline water wells, the average yield of 100 m^3/day was used. Standard industry practice for development of water wells requires temporary surface disturbance of approximately 50 m x 50 m depending on the drilling rig requirements. Standard practice for permanent well infrastructure is 5 m x 5 m area (0.0025 ha) wellhead area. The normalized footprint required to produce 40,000 m^3/day of water is 1.0 ha; the well systems required to provide saline groundwater will have a larger overall footprint when compared to river or lake water intakes, but similar to shallow non-saline water wells.

The environmental impacts associated with constructing a system of saline water wells are:

- Land disturbance of the test-drilling program (to establish aquifer productivity and identify any potential interference with other users);
- Depending on the number of wells needed to be drilled to obtain an appropriate volume, the overall construction footprint can be quite large (including pipelines to tie-in multiple wells and convey water to the point of use);
- Drilling rigs used to access deep saline aquifers have a larger footprint than shallow aquifer rigs, resulting in a more significant construction impact;
- Multiple parcels of land and many wells may be required to meet the flow requirements of the project, which increases the footprint disturbance;
- Drilling deep wells requires placing cement casings around non-saline zones. Prior to establishing the surface casing, there is a risk of drilling fluids impacting these non-saline zones;
- Introduction of invasive species; and
- Access road construction.

Similar to shallow non-saline water wells, monitoring of the groundwater conditions would require a network of observation wells and associated pads and access roads, which would lead to additional land disturbance.

8.2.2 Ecosystem: Operations-related Impacts

Aquatic Habitat Disturbance/Large Water Withdrawals

River: Infiltration Gallery

The environmental impacts associated with the availability of river water are highly dependent on both the physical character and flow dynamics of the river and the location chosen for the infiltration gallery. Each river experiences different flow volumes, sediment and nutrient loading and cycling, suitable habitat for wildlife, and seasonal flow variations.

The potential environmental impacts associated with operating an infiltration gallery that may impact the aquatic and terrestrial habitat are:

- Alteration of stream flow volumes (reduced flow can endanger fish populations);
- Alteration of channel depth/width (impact to habitat availability and/or suitability); and

- Alteration of sediment / nutrient transport characteristics during water treatment system back-flushing.

The main environmental concern is the potential for removing water volumes in excess of the available water during seasonal low flow periods, leaving insufficient water to sustain ecosystem needs. This could lead to a decrease in suitable aquatic habitat, lowering of the local water table, or restricting the supply of water to certain riparian species or functions, as well as affect a variety of organisms that may potentially impact their life stages (i.e., fish spawning).

Lake Water: Lake Tap

Environmental impacts associated with the availability of lake water are highly dependent on both the physical character and dynamics of the lake, as well as the location chosen for the lake tap. Similar to rivers, the main environmental concern associated with the availability of water is the potential for sourcing water volumes beyond the lake's natural capacity to deliver and sustain ecosystem needs at the same time, specifically during seasonal low-level periods.

The environmental impacts associated with operating a lake tap that may impact aquatic and terrestrial habitat are:

- Accidental intake of fish or other small aquatic organisms;
- Change to lake dynamics affecting mixing and thermoclynes;
- Potential decreases to lake levels affecting biodiversity in the lake. Depending on the size of the lake and the amount of water being withdrawn this could affect the ability of fish to overwinter in certain areas and adversely affect populations; and
- Affect trophic structures as well as species diversity and richness in the lake.

Non-saline Water Aquifer: Shallow Water Well

The availability of non-saline ground water aquifers is primarily dependent on the aquifer characteristics and any local users of the same groundwater source. Only groundwater aquifers that are hydraulically connected to surface water sources (i.e., lakes, rivers and wetlands) may result in an environmental impact on these ecosystems. Groundwater sources that are not hydraulically connected to aquatic ecosystems may be exploited without a visible effect on shallower environments. The overuse of shallow groundwater aquifers, which are hydraulically connected to surface water sources, can impact streams, wetlands, springs, lakes and rivers.

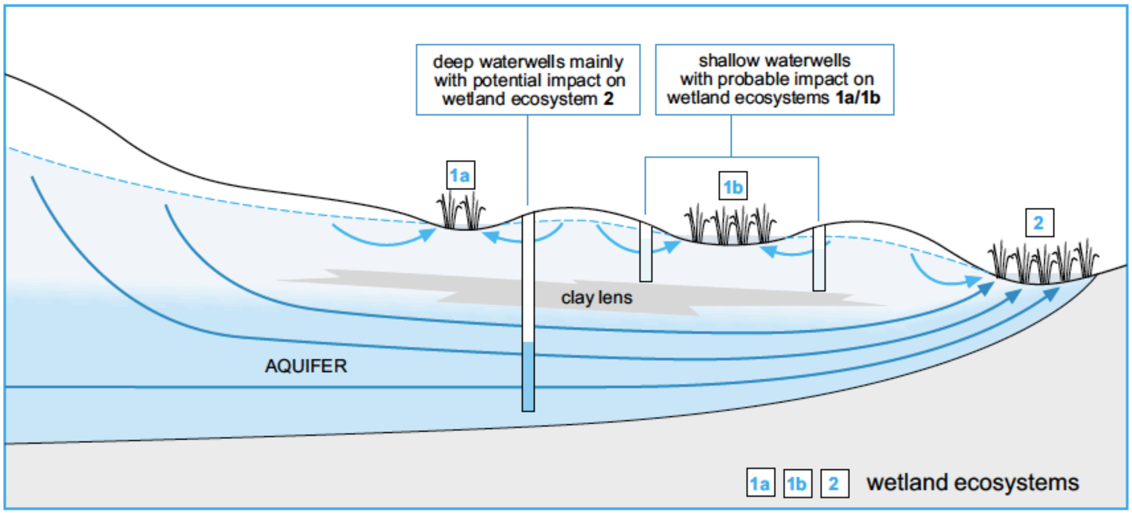
The potential environmental impacts on aquatic ecosystems from the overdrawing of non-saline groundwater from shallow aquifers are:

- Increases in infiltration and groundwater recharge from the surface water body, thereby decreasing the available water in the surface water body;
- Alteration of flow patterns in shallow streams, disrupting sedimentation patterns and affecting riparian habitats;

- Decreasing or stopping water contributions from springs to surface water bodies; and
- Dewatering of wetlands, resulting in habitat disruption and adverse effects to vegetation.

Figure E depicts the potential impacts on wetlands from pumping at various locations within an aquifer.

Figure E. Potential Interference of Groundwater Pumping on Wetland Habitat (World Bank, 2006)



Saline Water Aquifer: Deep Water Well

Typically, deep saline aquifers are not hydraulically connected to aquatic ecosystems (Section 8.1.4). That being the case, there risk of environmental impacts to aquatic systems is considered low to negligible.

8.2.3 Ecosystem: Reclamation Impacts

Reclamation

River: Infiltration Gallery

The first step in construction of an infiltration gallery is the construction of a cofferdam to allow dredging and installation of the pipes below the riverbed. This is followed by the replacement of riverbed material and the construction of a wet well. There would therefore be two reclamation phases involved when infiltration galleries are used:

- The reclamation of the cofferdam-impacted area and the regeneration of the river bed (short-term); and
- The eventual decommissioning of the infiltration gallery and the deconstruction of the wet well (long-term).

The environmental risks of the short-term reclamation of the cofferdam-impacted area include:

- The replacement of river bed material and the re-establishment of the river bed benthos;
- The replacement of river bank soil, the control of erosion during vegetation re-establishment, and the risk of discharging eroded solids into the river ecosystem;
- Grading the site to ensure minimal impacts on the hydrology due to construction operations;
- The replacement of riparian zone vegetation that was impacted during cofferdam construction; and
- The risk of invasive species to re-populating either the benthic or riparian zones.

The environmental risks of the long-term reclamation of the wet well include:

- Construction equipment access to the site for wet well demolition;
- Back-filling of the wet well and grading to return to pre-disturbance runoff patterns, accompanied with the risk of invasive species populating of disturbed site; and
- Re-establishment of the site vegetation to prevent erosion.

Once the infiltration gallery is no longer required, the perforated pipe sections would be capped and sealed, and the surface infrastructure removed.

Lake Water: Lake Tap

Lake tap construction requires initial construction and burial of the underground piping that connects the wet well to the screened intake in the lake, as well as the installation of the wet well. After the lake tap is installed, the ecosystems disturbed during construction can be reclaimed, prior to complete site reclamation after intake decommissioning. There will, therefore, be two reclamation phases involved when lake taps are used:

- Initial reclamation of the construction site (short-term); and
- The eventual decommissioning of the screened intake and the deconstruction of the wet well (long-term).

The environmental risks of the short-term reclamation of the lake tap construction area include:

- The replacement of lake shore material, removal of pipe installation, and the re-establishment of the riparian vegetation;
- The replacement of any benthic material disturbed during installation of the intake pipe and screen in the lake;
- The replacement of terrestrial soils, the control of erosion during vegetation repopulation and the risk of discharging eroded solids into the lake ecosystem;

- Grading the site to ensure minimal impacts on local hydrology due to construction operations; and
- The risk of allowing invasive species to repopulate either the aquatic or terrestrial zones.

The environmental risks of the long-term reclamation of the wet well include:

- The replacement of lake shore material, removal of pipe installation, and the re-establishment of the riparian vegetation;
- The replacement of any benthic material disturbed during removal of the intake pipe and screen in the lake;
- Back-filling of the wet well and grading to return to pre-disturbance runoff patterns, accompanied with the risk of invasive species population of the site; and
- Replacement of the site vegetation to prevent erosion.

Water Aquifer: Shallow and Deep Water Wells

Groundwater well construction and decommissioning follow the same steps whether for deeper saline or shallower non-saline groundwater. There is an initial larger disturbance as equipment is brought to site to construct the well, followed by reclamation of the lease area and a smaller surface disturbances for regular maintenance access. Once the well is no longer required, the disturbance will again increase as equipment is brought in to excavate the area around the well, cap and seal the well, and finally reclaim the remaining area. There are, therefore, two reclamation phases when wells are used as water sources:

- Initial reclamation of construction site (short-term); and
- Complete reclamation of well site (long-term).

The environmental risks of the initial reclamation of the well construction site include:

- Replacement of the vegetation that was impacted by the drilling equipment;
- Grading to minimize the impacts of construction on the hydrology at the site; and
- The risk of allowing invasive species to repopulate the reclaimed site.

The longer-term environmental risks relating to reclamation of the well site after decommissioning include:

- Excavation and capping of the well;
- Re-establishment of the vegetation that was impacted during construction and decommissioning;
- Re-establishment of vegetation impacted by road development; and
- Re-grading the site to pre-disturbance runoff conditions.

8.2.4 Air Quality

Energy consumption and associated emissions for the operation of water source infrastructure options have been captured in Section 9.1 Pipeline Transportation, as the main power consumption associated with this type of infrastructure is pumping. It is important to note that the pumping power requirements, and therefore energy consumption and associated emissions, for deeper saline water wells have the potential to be higher than all other water source infrastructure options due to added depth of the aquifers (i.e., lifting costs) and required treatment.

8.3 ENE Comparison of Water Sourcing

As shown in the Water Source ENE Comparison chart and Table 1 in Appendix 3, when comparing a saline water source to the most common non-saline water sources (river: infiltration gallery) the ENE of changing from a non-saline to saline groundwater source are:

- Larger land disturbance;
- No aquatic habitat disturbance;
- Minimal to no expected impact to fish and aquatic communities;
- Less disturbance during reclamation activities; and
- Greater energy intensity and associated GHG emissions.

While this comparison focuses on changing from a non-saline to a saline source, the water quality of each source must also be considered, as a quality difference amongst saline and non-saline sources themselves may influence the overall ENE. For example, a low quality saline water source may have a significantly different ENE when compared to a high quality saline water source.

In addition, the chemical composition between saline and non-saline sources (with respect to constituents requiring removal) may also influence the overall ENE. For example, consider a scenario with one low quality non-saline groundwater source and the other a high quality saline water source. Although saline, the higher quality source may have an equal or lower ENE compared to the non-saline source, thereby minimizing the ENE gap between the two sources.

9 TRANSPORTATION

The following section highlights the environmental impacts associated with transporting water throughout the hydraulic fracturing process. Historically, trucks have been the most common method of water transport. However, transfer via fixed pipeline has gained significant traction in the industry (Fletcher, 2014), and all of the CAPP companies surveyed (Section 5) stated that pipelines were the common water transport option. The environmental impacts of transporting either saline water or non-saline water depends on many factors including:

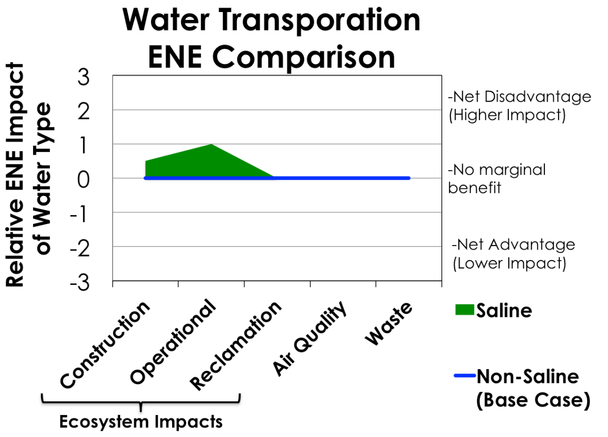
- Volume of source water required;
- Proximity of a available and reliable water source to hydraulic fracturing operations;
- Water quality of the source water;
- Mode of transportation;
- Availability of existing pipelines; and
- Right-of-ways or roads.

Typically, investment in a fixed pipeline is likely to be appropriate for longer durations and distances between a water source and a set of well pads (Fletcher, 2014).

9.1 Environmental Impacts of Water Transportation

Transportation Overview

The major water transport ENE difference between saline and non-saline water is impact to the ecosystem in the event of a spill or leak of saline water during operations. The major determinant of impact is the mode of transportation used (i.e., pipeline versus truck transport), as this factor highly affects the degree of ecological and GHG emissions impacts.



9.1.1 Ecosystem: Construction-related Impacts

Terrestrial Habitat Disturbance

The land disturbance required for construction and installation of infrastructure for the transport of water is not directly correlated to the salinity of the water, but rather to the location and number of source water locations required to meet the water needs of the project. For example, assuming the same distance from the well pads to saline and non-saline water sources, if 10 saline water wells are required to yield the same flow rate as one non-saline river intake, the land disturbance associated with the transportation of water from a saline source will be greater.

The land disturbance required for transporting water with a truck versus a pipeline considers only the disturbance associated with access roads and the pipeline right-of-way, respectively. Access roads are constructed to the site as part of the overall site development; therefore no additional land disturbance would be required for trucking water to the site.

A typical pipeline right of way is 15 m wide, with pipelines typically installed up to 3 m below ground. The trench itself is typically excavated to between 8 and 12 m deep to allow for pipe bedding materials to minimize settlement (AESRD, 2014). Prior to construction, planners are expected to conduct pre-installation surveys to identify the best routes based on terrain conditions, wildlife habitat, river crossings, archaeological resources, soil type including depth and variability, farm management areas, forest and native vegetation resources, and proximity to inhabited areas.

Possible environmental risks of constructing and installing a pipeline include the following (Canadian Environmental Assessment Agency, 2010):

- Soils can be eroded, compacted and mixed, or contaminated;
- Alterations of surface runoff, along with accompanying risks to safety and environment (increased siltation effects on fish habitat);
- Vegetation (including old growth forests and rare plants) can be affected by surface disturbance, changes in water flows, or introduction of invasive species;
- Risks to wildlife can be caused by the removal, alteration, and fragmentation of habitat, changing access and sightlines for predators, and the creation of barriers for movement;
- Water quality could be affected by erosion and river crossing excavations; and
- Blasting, grading, and tunnel construction for pipeline placement could alter both surface and groundwater flow conditions.

9.1.2 Ecosystem: Operations-related Impacts

Spills and Leaks

The ENE between saline water and non-saline water, with respect to transportation, is mainly dependent on the effects of spills or leaks. Any spill or leak can cause environmental impact as a result of soil erosion, siltation of streams, or the introduction of large volumes of harmful or deleterious substances to an ecosystem. The introduction of a large volume of water, either saline or non-saline, as a result of a spill may also adversely impact the environment if the spill drastically changes the local water composition and habitat characteristics. Inundation of terrestrial and riparian areas can result in waterlogged soil that becomes anoxic, which leads to oxygen stress and eventual elimination of primary root systems of plants (Nilsson and Berggen, 2000). Introducing saline waters into areas with no salt tolerant vegetation can also result in vegetation death. Appendix 4 provides salinity tolerance ratings for a range of surface vegetation and tree species (Agdex, 2001). Typically, vegetation that has a low drought tolerance will also have a low salinity tolerance.

Saline water can also degrade the soil's chemical quality. High sodium, sulfate and chloride concentrations in the water can cause degradation of the soil's physical properties causing the soil particles to disperse. As a result, saline spills and leaks can lead to low permeability conditions, poor soil structure and crusting of the surface, which can lead to poor drainage and reduced recharge (Alberta Environment, 2001).

Surface and groundwater may also be affected by a saline water spill. In some instances, water that was once used for agriculture, human consumption, industrial use or recreational activities may become unaesthetic, unsafe, and unusable.

There may also be an impact to aquatic life if a spill of saline water were to occur near a surface water body. Many aquatic plants and riparian vegetation are salt-sensitive, with tolerances to salinities as low as 2,000 mg/L TDS (total dissolved solids). Invertebrates are among the most sensitive of freshwater organisms to salinity increases, with adverse effects seen at salinities as low as 1,000 mg/L. Microalgae community diversity also decreases with increasing salinity, which can disrupt all trophic levels (Hart et. al, 2003).

The specific effect of a spill or leak is dependent on:

- The volume of the spill or leak;
- The overall quality of the water (i.e., types and concentrations of constituents);
- The type of soil impacted by the spill or leak; and
- The type of vegetation and receiving ecosystem.

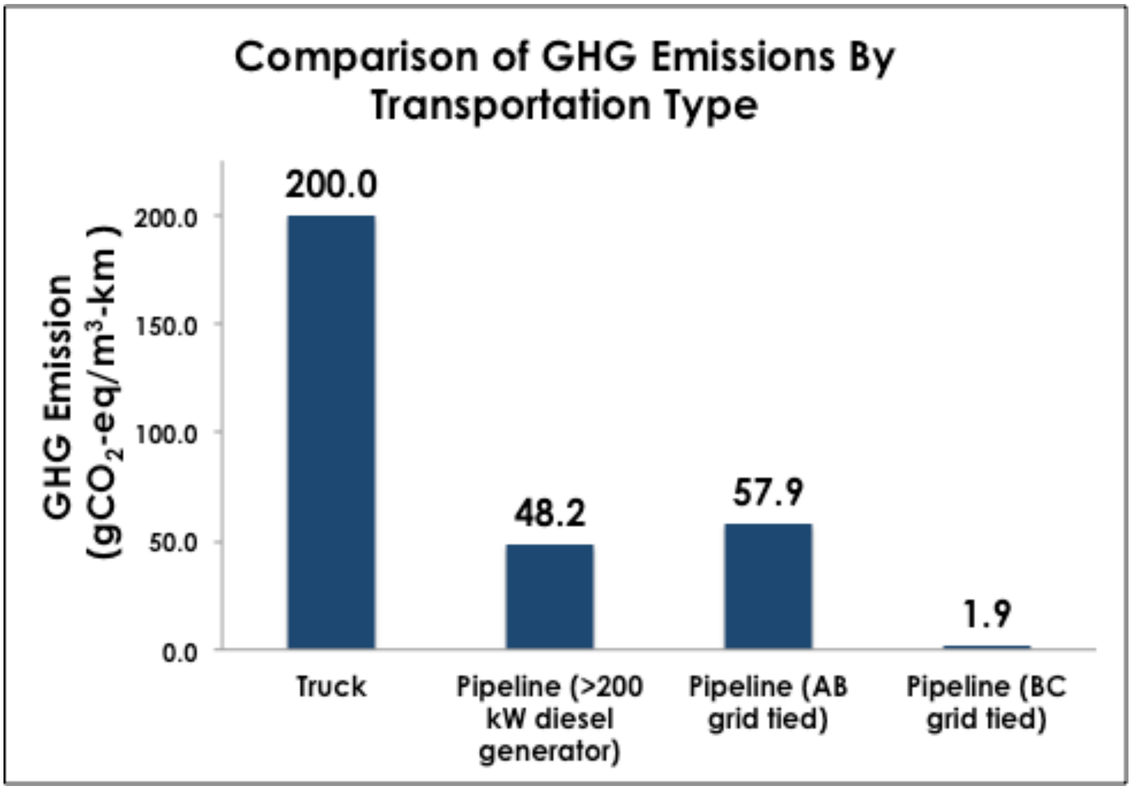
According to AER, pipelines in Alberta carrying fluids, other than gas, fail an average of 25 times per year for every 1,000 km of linear development (AER, 2007). Of these releases 93.8% have been classified as leaks as opposed to ruptures (spills). Further, 96% of all release types resulted in less then 100 m^3 of spilled liquid (100,000m^3 for gas releases). The resulting release probability for each km of pipeline is 2.5% per year. The AER report goes on to comment about general trending towards lower probabilities of leaks each year. Improvements in pipeline design including higher corrosion resistance will decrease leak and spill potential.

9.1.3 Air Quality

The difference in energy requirements for transporting saline water and non-saline water can be considered to be marginal. The highest salinity water considered in this study has a TDS of 90,000 mg/L. The density of this water is less than 8% greater than that of non-saline water and based on hydraulic modeling, results in an increase in energy requirements of less than 8%. The largest determinant of environmental impacts associated with these two cases relates to the method of transportation used. When identifying water source options for a particular project, it is possible that different sources of water will dictate a preferred mode of transport when taking into consideration access, distance, pipeline right of ways, etc. Ultimately, this type of transportation system governs the cost of transport more than the type of source water being transported.

The GHG emissions of transporting water is expressed in the amount of GHG emissions (in g of CO_2 equivalent) required to transport 1 m^3 of water a distance of 1 km. Figure F provides a visualization of the GHG emissions resulting from the transportation of water by either truck or pipeline. The fuel for trucking was assumed to be standard diesel fuel. For pipelines, the GHG emissions are highly dependent on the power source used. A large difference in the GHG emissions between pumps connected to the Alberta grid and the BC grid can be seen. This is due to Alberta's power being produced primarily by coal and natural gas as opposed to BC's power generation, which is produced primarily by hydroelectricity.

Figure F. GHG Emissions By Transportation Type



Assumptions for GHG Emissions calculation:
1) No elevation changes
2) Equal physical qualities between saline and non-saline water including density and viscosity
3) Typical water velocity of 2 m/s
4) Pump efficiency of 75%
5) Suction head of 1.5 meters to meet typical NPSH requirements
6) Each kilometre of pipe is assumed to include 1 gate valve, 1 check valve, and 1 flow meter
7) 10" Carbon steel pipe
8) GHG intensity does not account for emissions resulting from the production of diesel fuel
8) Average highway driving conditions for truck transport. Unpaved roads and adverse field conditions could increase energy intensity but are not accounted for here.
10) Truck transport does not account for return trips that may be required for moving large quantities of water.

9.2 ENE Comparison for Transportation

As shown in Water Transportation ENE Comparison chart and Table 2 under Appendix 3, the ENE of changing from non-saline source water to a saline groundwater source for transport are:

- Larger land disturbance; and

- Greater impact of spills and leaks.

As discussed in section 8.2, while this comparison focuses on changing from a non-saline to a saline source, the water quality of each source must also be considered.

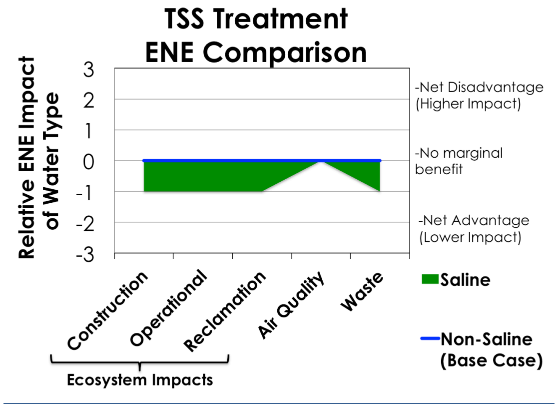
10 WATER TREATMENT

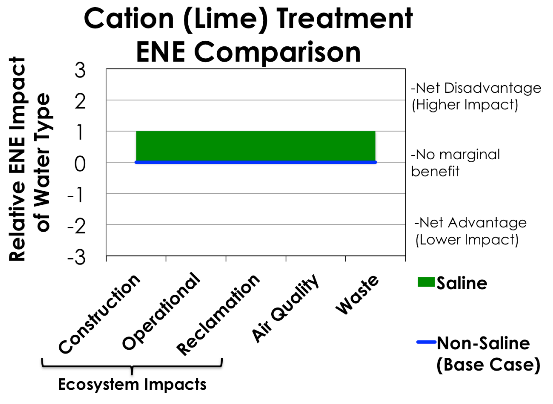
Water Treatment Overview

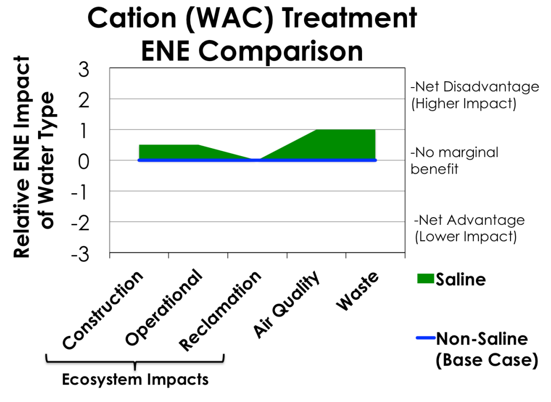
The water treatment ENE is directly related to the specific source water chemistry and downstream quality requirements for each specific application. These two factors are the primary indicators of the required treatment process and therefore the associated ENE. Saline water may have a greater net environmental impact compared with non-saline water due to the additional energy requirements for treatment commonly needed to meet compatibility with hydraulic fracturing operations. This equally extends to the waste by-products that need to be managed as a result of the treatment process.

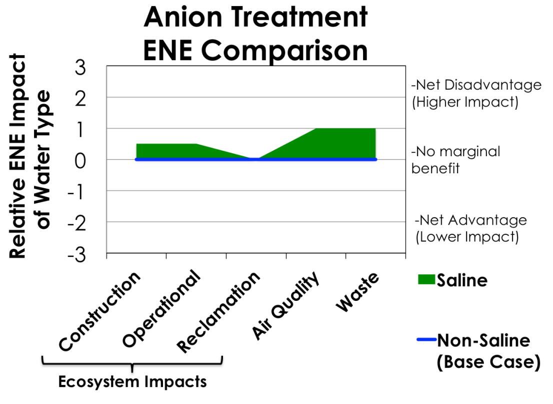
Treatment Process Impacts

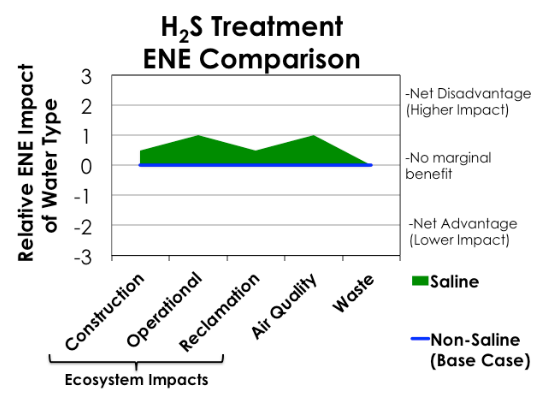
The following graphs represent the most common water treatment strategies used to treat source water to hydraulic fracturing water quality standards. They compare non-saline and saline water for each type of treatment that may be required.

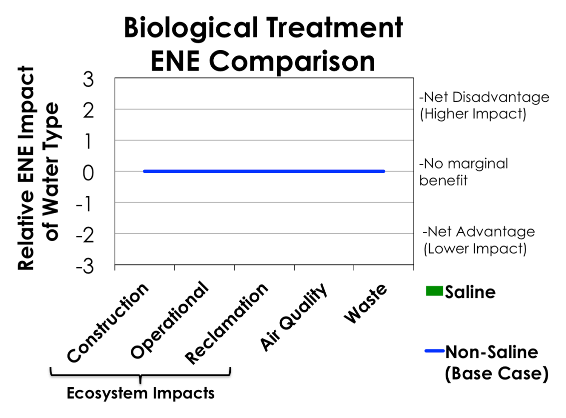












Requirements for source water, in terms of both quantity and quality, are dependant on:

- The type of hydraulic fracturing additives being used;
- The quantity of produced water that is going to be reused; and
- The chemical characterization of the produced water that is going to be reused.

10.1 Compatibility with Hydraulic Fracturing Additives

The type of hydraulic fracturing additives (slickwater, linear gel, crosslink fluid or viscoelastic fluids) that will be used dictates the required hydraulic fracturing source water quality and quantity. Typical hydraulic fracturing water quality standards for additives used can be found in Table E.

These parameters are set by the manufacturer to ensure no adverse chemical reactions occur, inhibiting the efficacy of the chemical additives. The temperature and pH of the solution can influence the reaction kinetics of hydraulic fracturing fluid additives and impact the quality of the fracturing fluid. The concern with carbonates, sulfates and alkaline earth metals is scale formation, which can be detrimental to downstream infrastructure (including, but not limited to, storage facilities, pumps and pipelines) and, if scaling compounds with slow kinetics are present, there is risk of scale formation down-hole and in the formation resulting in a decrease in well production.

Table E. Makeup Water Requirements for Hydraulic Fracture Types

	Hydraulic Fracturing Additives			
Water Quality Parameter	Slickwater	Linear Gels	Crosslink Fluids	Viscoelastic Fluids
Temperature (°C)	3-40[a]	15-40[a]	15-40[a]	20-40[a]
pH	5.0-8.0[a]	6.0-8.0[a]	6.0-8.0[a]	5.0-12.0[a]
Chloride (mg/L)	<90,000[a]	<50,000[a]	<30,000[a]	<33,000[a]
Hardness (mg/L $CaCO_3$)	<15,000[a]	n/a	n/a	n/a
Total Suspended Solids (mg/L)	50 (<100µm)[a]	50 (<100µm)[a]	50 (<100µm)[a]	50 (<100µm)[a]
Total Dissolved Solids (mg/L)	n/a	n/a	n/a	n/a
Iron (mg/L)	n/a	<25[a]	<25[a]	n/a
Bicarbonate (mg/L)	<scaling	<scaling	<600[c]	<scaling
Sulfate (mg/L)	<scaling	<scaling	<scaling	<scaling
Water Usage[b]				

[a] M I SWACO (2012)

[b] Johnson and Johnson (2012)

[c] Wasylishen (2013)

10.2 Compatibility with Produced Water

The reuse of produced water as hydraulic fracturing fluid decreases overall source water requirements; however, the compatibility of the produced water, either treated or not, with the source water must be evaluated. As well, the compatibility of the resultant mixed stream with the hydraulic fracturing additives must be understood.

Produced water constituent concentrations are dependent on the geochemistry of the formation being hydraulically fractured. In general the produced water will have elevated TDS concentrations, however the specific characterization will vary. Similarly, the source water characterization will vary dependent on the water source. Both produced and source water can be expected to be chemically stable (all constituent concentration will be below saturation) and therefore there will be limited risks of solids formation unless either the oxidation state of the water changes or new constituents are added to the water. A water source with high concentrations of scale-forming cations will typically be characterized by low concentrations of scale-forming anions, and the opposite can also be expected. The scale formation potential is present when scale-forming cation-rich waters are blended with scale-forming anion-rich waters. Mitigation of the scaling risk can be achieved either through treatment of the produced water or the source water.

After commingling the two streams, the resultant stream must be compatible with the hydraulic fracturing additives (Section 10.1). Should the mixed streams not meet these requirements, further treatment will be required.

10.3 Allowable Extent of Produced Water Reuse

Further to the basic requirements of the hydraulic fracturing solution, the concentration of residual hydraulic fracturing additives in the produced water must also be addressed. The steady-state concentration factor (SSCF-Equation 1) is typically used to estimate the effect of produced water reuse on the concentration of residual hydraulic fracturing additives.

$$SSCF = \frac{1}{1 - \%reuse} \qquad (1)$$

The SSCF assumes that 50% of the additive is retained in the formation (through adsorption or absorption) and 50% remains in the produced water, and that the dose of additive during hydraulic fracturing operations is constant and independent of residual additive concentrations in the produced water. The SSCF is, therefore, only dependent on the percent produced water reuse.

It is generally accepted that the highest allowable SSCF for hydraulic fracturing fluids is 2 (50% reuse of produced water), due to the potential for increased frac fluid viscosity from the increased polymer concentration (MI-SWACO, 2012). In polymer-based hydraulic fracturing solutions (slickwater, linear gels, and cross-linked fluids) the polymer can be broken prior to reuse, which removes the risk of increased concentration factors.

Cross-linked fluids also incorporate potentially persistent borates and buffers, so the SSCF of these additives will also need to be addressed. The effect of the borates and buffers on the cross-linker additive is specific to the types of chemical compounds, which can be different in all hydraulic fracturing additives. Site-specific field-testing is required to determine the extent of produced water reuse in these scenarios, and if the SSCF values become too high, disposal or treatment of the produced water may be required.

Viscoelastic fluids are surfactant-based additives, as opposed to the other water-based hydraulic fracturing additives that are polymer based. The hydrocarbon products of the wells typically break the surfactant additives, and therefore SSCF values due to produced water reuse are rarely a concern. Therefore there can be a concern with residual hydrocarbons in the produced water, which can potentially act as surfactant breakers.

10.4 Source Water Treatment

Treatment may be required to ensure that the source water is compatible with the produced water and the hydraulic fracturing additives to ensure effective proppant transport to the target formation. Both the extent and methods of treatment will be specific to the hydraulic fracturing additives used and the source water characteristics. Saline water will typically require greater extents of treatment when compared with non-saline source water; therefore, more chemicals will be required to achieve treatment objectives, which can result in increased waste production.

In addition to ensuring that the source water is compatible with the hydraulic fracturing additives, there may be a requirement for a treatment step or chemical additive to eliminate hydrogen sulfide (H_2S) and control biofouling. H_2S in the source water can result in corrosion of equipment and piping. Biofouling can be a concern due to the production of biofilms and the clogging of small pores in the formation, or due to waste products from the biological activity (i.e., H_2S produced by sulfate reducing bacteria).

10.5 Source Water Treatment Descriptions

This section provides a summary of the treatment options that are effective in treatment of the required parameters.

10.5.1 TSS Removal

TSS removal involves coagulation (the destabilization of colloidal particles in the water), flocculation (the agglomeration of destabilized particles) and removal of the solids from the solution. Typical TSS removal systems include:

- Chemical injection system(s);
- Mixing chambers; and
- Settling tanks.

These types of source water treatment systems require the following chemicals:

- Coagulants (typically either iron or aluminum based); and
- Flocculants (polymers).

TSS removal systems generate a waste sludge that requires dewatering and disposal.

10.5.2 Scale Forming Cation Removal (Lime and Soda Ash Softening)

Lime and Soda Ash softening of water to remove scale-forming cations requires lime addition to increase the pH of the solution to produce a metal-carbonate precipitate. If the carbonate concentrations in the source water are insufficient to react with all scale forming cations, then soda ash will also need to be added. Chemical addition is followed by removal of the formed precipitate, and then the pH is neutralized. Typical lime softening systems include:

- Chemical injection system(s);
- Mixing chambers;
- Settling tanks; and
- Neutralization gas injection system.

Lime and soda ash water treatment systems require the following chemicals:

- Lime (CaO, or $Ca(OH)_2$);
- Soda ash ($NaCO_3$); and
- pH neutralizing gas (CO_2).

Lime and soda ash softening generates a large volume of sludge (typically double the amount of injected chemicals) due to the precipitation reactions. This sludge will require dewatering and disposal.

10.5.3 Scale Forming Cation Removal (Weak Acid Cation Exchange)

Weak acid cation exchange (WAC) softening of water to remove scale-forming cations requires an ion exchange reactor packed with resin. The resin removes scale-forming cations from the source water and replaces them with sodium. Once the exchange capacity of the resin is exhausted, the resin is recharged in two stages, acid regeneration (to replace the scale forming cations on the resin with protons) and sodium hydroxide (to replace the protons on the resin with sodium). The regeneration of the resins produces a brine waste that requires disposal. Typical WAC softening systems include:

- Ion exchange reactor(s);
- Regeneration chamber; and
- Chemical dosing pumps for regeneration.

WAC water treatment systems require the following chemicals:

- Acid regenerant (HCl);

- Sodium hydroxide (NaOH); and
- Resin to replace any that is lost during the regeneration process.

The regeneration of the resins produces a brine waste that requires disposal. The volume of brine waste produced depends on the frequency of regeneration. The frequency of regeneration is dependent on the concentration of scale forming cations in the source water. The brine waste will typically be disposed of in a deep disposal well.

10.5.4 Scale Forming Anion Removal (Strong Base Anion Exchange)

Strong base anion exchange (SBA) works on a similar principle to WAC; the scale forming anions are removed from the source water and replaced with hydroxide ions from the resin. Once the exchange capacity of the resin is exhausted, the resin is regenerated using a sodium hydroxide solution to remove the anions from the resin and replace them with hydroxide ions. The regeneration of the resins produces a brine waste that requires disposal. Typical SBA systems include:

- Ion exchange reactor(s);
- Regeneration chamber; and
- Chemical dosing pumps for regeneration.

SBA water treatment systems require the following chemicals:

- Sodium hydroxide (NaOH); and
- Resin to replace any that is lost during the regeneration process.

The regeneration of the resins produces a brine waste that requires disposal. The volume of brine waste produced depends on the frequency of regeneration. The frequency of regeneration is dependent on the concentration of scale forming anions in the source water. The brine waste will typically be disposed of in a deep disposal well.

10.5.5 H_2S Removal

The removal of H_2S from source water will require the addition of an oxidizer to convert the dissolved H_2S to either sulfate (dissolved ion), or elemental sulfur (solid precipitate). The end product of the oxidation reaction depends on the oxidizing compound being used, as well as the pH of the solution. Production of dissolved sulfate may cause scale formation, if the required scale forming cations are present in the source water, and therefore the specific H_2S removal mechanism should be selected based on source water chemistry. H_2S removal does not typically produce a waste stream, and if elemental sulfur is produced, the waste volumes are small (as compared with other types of source water treatment systems). Typical H_2S removal systems include:

- Chemical injection system(s); and
- Mixing chambers.

H_2S removal from source water requires the following chemicals:

- Chemical oxidizer (i.e., scavengers, ClO_2, H_2O_2).

10.5.6 Biomass Removal

Treatment systems for biomass and biological growth control involve either inactivation of the biomass (to stop reproduction) or oxidation and lysis of the biomass (destruction of the cell). Inactivation of the biomass will stop the growth of the bacterial colonies, but will leave the bacteria intact and in the source water; this remaining biomass will act as a suspended solid. The oxidation and lysis of the biomass will degrade the cells to dissolved ions in the source water. The removal of biomass from the source water does not typically produce a waste stream. Typical biomass removal systems include:

- Chemical injection system or UV disinfection lights; and
- Contact chamber.

Biomass removal from source water requires the following chemicals:

- Chemical oxidizer (i.e., NaOCl, ClO_2, H_2O_2).

10.6 Environmental Impacts of Source Water Treatment

Table F provides a summary of the environmental impacts associated with each treatment option. The values are based on a facility with a capacity of 6,600 m³/day, the system size and energy will typically be lower per cubic meter of water treated as the size of the system increases.

Table F. Environmental Impacts for Water Treatment Systems

Constituent of Concern	TSS	Scale forming cations	Scale forming cations	Scale forming anions	H_2S	Biomass
Treatment Process	Coagulation, flocculation, and settling	Lime and Soda ash softening	Weak Acid Cation Exchange (WAC)	Strong Base Anion Exchange (SBA)	Scavenger or oxidizer addition	Oxidizer addition
Ecosystem: Construction Impacts	Skid mounted chemical injection system, settling chamber, chemical storage site, solids drying and sludge storage site	Skid mounted chemical injection system, settling chamber, chemical storage site, solids drying and sludge	Skid mounted units, chemical storage site, Brine waste storage site	Skid mounted units, chemical storage site, Brine waste storage site	Skid mounted chemical injection system, chemical storage site, potential solids drying and sludge storage site	Skid mounted chemical injection system

Constituent of Concern	TSS	Scale forming cations	Scale forming cations	Scale forming anions	H_2S	Biomass
Land Disturbance	Short-Term: 30' x 50', Long-Term: sludge disposal landfill	storage site Short-Term: 30' x 50', Long-Term: sludge disposal landfill	Short-Term: 25' x 8' Long-Term: no long term disturbance	Short-Term: 25' x 8' Long-Term: no long term disturbance	Short-Term: 12' x 12', Long-Term: sludge disposal landfill (if solids produced), no long term disturbance if solids are not produced	Short-Term: 5' x 5' Long-Term: no long term disturbance
Ecosystem: Operations-related Impacts	Chemical spill risk	Chemical spill risk	Chemical spill risk	Chemical spill risk	Chemical spill risk	Chemical spill risk
Chemical Requirements	Coagulant, flocculant	Lime, soda ash	Acid regenerant sodium hydroxide regenerant	Sodium hydroxide	Scavenger or oxidizer	Oxidizer
Ecosystem: Reclamation Impacts	Containment of sludge disposal landfill	Containment of sludge disposal landfill	None	None	Containment of sludge disposal landfill	None
Air Quality: Energy Consumption and Emissions[1]	0.30 kWh/m^3 0.16 g CO_2/m^3 Transportation of chemicals	0.7 kWh/m^3 0.38 g CO_2/m^3 Transportation of chemicals	0.85 kWh/m^3 0.46 g CO_2/m^3 Transportation of chemicals	0.85 kWh/m^3 0.46 g CO_2/m^3 Transportation of chemicals	1.00 kWh/m^3 0.54 g CO_2/m^3 Transportation of chemicals	0.30 – 0.5 kWh/m^3 0.16 – 0.27 g CO_2/m^3 Transportation of chemicals
Waste	Sludge (landfill); solids waste	Sludge (landfill); solids waste	Brine (deep well disposal); transport of	Brine (deep well disposal); transport of	Sludge (landfill), or zero waste;	Zero waste

Constituent of Concern	TSS	Scale forming cations	Scale forming cations	Scale forming anions	H_2S	Biomass
	disposal	disposal	liquid waste, liquid waste spill risk	liquid waste, liquid waste spill risk	transportation of solids waste (if solid waste is produced)	

[1] Energy requirements only consider the treatment energy. Does not include waste disposal or maintenance. Energy usage rates are from USEPA (1998)

10.6.1 Toxicity of Source Water Treatment System Chemicals

All of the source water treatment systems require chemical storage, which carries with it the risk of chemical spills. The specific toxicity of the spills will be dependant on the size of the spill and the sensitivity of the receiving environment. The environmental impact of all of the chemicals discussed in Section 10.5 can be separated into four categories:

- Flocculant polymers;
- Metals (iron and aluminum based coagulants);
- Acids and bases (lime, soda ash, hydrochloric acid and sodium hydroxide); and
- Oxidizers (H_2S and biomass removal compounds).

Flocculant Polymers

Flocculant polymers are used in dilute concentrations as flocculants in the water treatment process to agglomerate solids to form large flocs that will easily be settled from solution. In concentrated forms these same polymers are used as slick-water hydraulic fracturing additives, at high concentrations these polymers will retain solids in solution and decrease the viscosity of solutions. Therefore, concentrated spills of flocculant polymers can transport soil and debris as they migrate along the surface and deposit the debris and soil as the spill reaches a surface water body. This will alter sedimentation patterns in the water body. Some flocculent polymers are toxic to wildlife and fish; therefore there is a risk of wildlife impacts from a spill as well as the aquatic habitat impacts.

Metals

Both iron and aluminum are toxic to aquatic wildlife with toxic concentrations occur with concentrations in the parts per million (ppm) range, with higher trophic level organisms typically being less sensitive to metal contamination. In the terrestrial environment metals can be retained in soils, percolate with infiltration into groundwater systems and be taken up by vegetation. As with salinity (Appendix 4) the specific toxicity of metals to plants is highly dependant on the type of vegetation.

Both iron and aluminum ions have large charges and particle sizes. Metals with these characteristics are able to attract and dissociate water molecules, bonding to the produced hydroxide molecule and releasing the proton (H^+). This proton release will decreased the pH of the solution and in the event of iron or aluminum based coagulant spill will act in the same way as acid spills in the environment.

Acids and Bases

Spills of acids and bases will alter the pH of the receiving environment. Altering the pH of the environment can have many different effects. pH changes can directly affect wildlife, plants and microbiological constituents in the soil, riparian zones and benthic zones of the receiving environment, with mortality occurring with changes of pH of less than 1 in sensitive species. The pH change can also alter the solubility, and therefore the bioavailability, of metals for uptake by vegetation or dissolution into ground and surface water sources. Metals, as previously discussed can be toxic to the environment at the ppm level.

Oxidizers

Oxidizing compounds are used in low concentrations to destroy biomass in the sources water through cell lysis. A spill of concentrated oxidizers will have a far greater effect on the receiving environment. Oxidizers will not only lyse single celled microorganisms that are present in the soil or source water body, they will destroy the cells of multi cellular organisms as well, including vegetation, fish and wildlife.

10.7 ENE Comparison of Source Water Treatment Systems

As shown in Water Treatment ENE Comparison charts and Table 3 in Appendix 3, the following section describes the ENE of changing from non-saline source water to a saline groundwater source for various water treatment options.

As discussed in section 8.2, while this comparison focuses on changing from a non-saline to a saline source, the water quality of each source must also be considered.

10.7.1 TSS Removal

The extent of solids removal is highly dependent on the water source; with surface waters typically requiring more solids removal than groundwater sources. There is, however, a risk of reduced ions in the groundwater forming precipitates as they oxidize under surface conditions; therefore, solids removal may be required with groundwater as well.

The solids loading in a given surface water source (non-saline) may have high seasonal variability due to spring thaw and runoff. TSS removal systems that are used with surface water sources are typically large to accommodate the high concentrations during spring runoff and therefore are oversized for the majority of yearly operations. Non-saline groundwater sources are not typically characterized by large fluctuations in TSS and, therefore, system sizing is smaller. Saline groundwater sources, similar to non-saline sources, are typically characterized by low TSS concentrations and low variability in TSS concentrations.

For the removal of TSS, the ENE of changing from a typical non-saline source water to a saline groundwater source is:

- Smaller treatment system footprint;
- Less chemical usage;
- Lower chemical storage volumes;
- Lower risks of chemical spills; and
- Less waste production and eventual disposal in landfills.

10.7.2 Scale Forming Cation Removal (Lime and Soda Ash Softening)

Non-saline source water will typically have lower concentrations of scale forming cations than saline source water and will therefore require less softening in these systems. Surface water sources and shallow, non-saline, groundwater sources can be subject to variations in scale forming cation concentrations during spring runoff; therefore, the systems will need to be sized for peak concentrations and may be oversized during times of low concentrations.

For the removal of scale forming cations in lime and soda ash softening systems, the ENE of changing from a typical non-saline source water to a saline groundwater source are:

- Larger treatment system footprint;
- Higher chemical usage;
- Larger chemical storage volumes;
- Higher risks of chemical spills; and
- Greater waste production and eventual disposal in landfills.

10.7.3 Scale Forming Cation Removal (Weak Acid Cation Exchange)

Non-saline source water will typically have lower concentrations of scale-forming cations than saline source water and will therefore require less softening in these systems. Surface water sources and shallow, non-saline, groundwater sources can be subject to variations in scale forming cation concentrations during spring runoff; therefore, the systems will need to be sized for peak concentrations and may be oversized during times of low concentrations.

For the removal of scale forming cations in WAC softening systems, the ENE of changing from a typical non-saline source water to a saline groundwater source are:

- Higher chemical usage;
- Larger chemical storage volumes;
- Higher risks of chemical spills; and

- Greater waste production and eventual disposal in deep disposal wells.

10.7.4 Scale Forming Anion Removal (Strong Base Anion Exchange)

Non-saline source water will typically have lower concentrations of scale forming anions than saline source water and will therefore require less treatment in these systems. Surface water sources and shallow, non-saline, groundwater sources can be subject to variations in scale forming anion concentrations during spring runoff; therefore, the systems will need to be sized for peak concentrations and may be oversized during times of low concentrations.

For the removal of scale forming anions in SBA systems, the ENE of changing from a typical non-saline source water to a saline groundwater source are:

- Higher chemical usage;
- Larger chemical storage volumes;
- Higher risks of chemical spills; and
- Greater waste production and eventual disposal in deep disposal wells.

10.7.5 H_2S Removal

H_2S is typically only present in deep saline wells, since the reducing conditions required for H_2S production are not present in shallow groundwater wells or in surface water sources. It can be assumed that H_2S treatment is not required for non-saline water sources, and is only required for some deep, saline groundwater sources.

For the removal of H_2S, the ENE of changing from typical non-saline source water to a saline groundwater source are:

- Larger treatment system footprint;
- Higher chemical usage;
- Larger chemical storage volumes; and
- Higher risks of chemical spills.

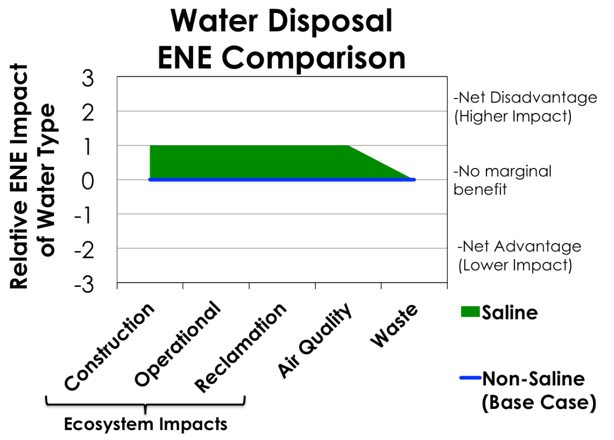
10.7.6 Biomass Removal

Both saline and non-saline source water can support biological life, and therefore biomass removal can be required for both of these water sources. The treatment system will not change for either non-saline or saline source water. There is no ENE of changing from non-saline to saline source water when treating for biomass removal.

11 DISPOSAL (WASTE GENERATED FROM SOURCE WATER TREATMENT)

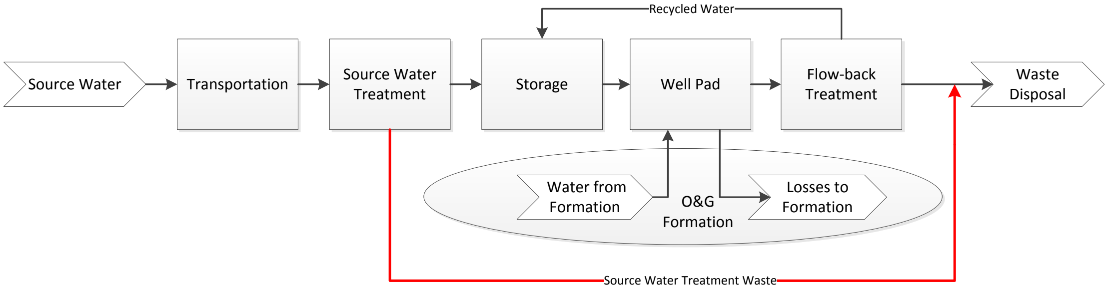
Waste Disposal Overview

The major disposal ENE difference for waste generated from saline versus non-saline source water treatment is typically the volume of chemicals used for the treatment process. With the exception of TSS removal, which results in the production of large volumes of solid waste, the need for chemicals to render saline water to a useful quality presents the risk of spills and releases into the environment and the associated detrimental effects.



The following section summarizes the ENE associated with waste generated from source water treatment. Figure G highlights this stage in the hydraulic fracturing process.

Figure G. Block Flow Diagram Highlighting Waste Generated from Source Water Treatment to Waste Disposal



Waste generation typically occurs in the water treatment processes when the removal of constituents is required or when ion exchange resins requiring re-generation. The ENE of changing from a non-saline to a saline water source is correlated to the type and volume of waste product produced by the treatment process. This is dependent on the water treatment processes that are needed to treat the source water to the requirements of the hydraulic fracturing fluid additives.

There are two main types of waste products that result from the treatment processes outlined in Section 10, sludge and brine. Based on the chemical and physical composition of the waste streams, different options for disposal may be required.

A potential waste disposal requirement for non-saline water would most likely result from the use of river water during spring runoff periods. For example, the TSS in the Peace River seasonally peaks at over 300 mg/L and has been recorded at over 1,500 mg/L during certain years (Environment Canada, 2003; Golder, 2008). The solids concentration would need to be reduced to 50 mg/L to meet the requirements outlined in Table E (Section 10.1). The treatment of 6,600 m^3/day of river water at this loading rate would produce approximately 9.5 m^3/day of dry solids. These solids will be part of water mixture ranging from 0-100% weight-by-water, depending on the degree of dewatering achieved in the treatment process.

A potential waste disposal requirement for saline water would result from the use of Montney formation water. The Montney formation water can have iron concentration of 155 ppm, and bicarbonate concentrations of 902 ppm. These two constituents are above the hydraulic fracturing fluid additive requirements outlined in Table E, which has limits of 25 ppm and 600 ppm, respectively, for iron and bicarbonate. Under reduced conditions, as would be expected in deep saline aquifers, the dominant iron species is ferrous bicarbonate ($Fe(HCO_3)_2$). A simple aeration system can oxidize the iron to insoluble ferric hydroxide ($Fe(OH)_3$), thereby removing the iron as a precipitate. This oxidation reaction (Equation 2) will also decrease the concentration of bicarbonate.

$$4Fe(HCO_3)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3 + 2CO_2 \qquad (2)$$

Aerating sufficiently to remove all of the iron will also reduce the bicarbonate concentration to below the 600 ppm limit outlined in Table E.

This treatment system will produce 500 mg/L of solids that require disposal. Based on a daily treatment volume of 6,600 m^3, the total disposal volume will be 0.8m^3/day. These solids will be part of water mixture ranging from 0-100% weight-by-water, depending on the degree of dewatering achieved in the treatment process.

11.1 Infrastructure Description

11.1.1 Landfill

Depending on the composition of the solid waste, there are a number of different classifications of landfills that may be applicable. In Alberta the landfill classifications are as follows:

- Class Ia/Ib – Hazardous and Non-Hazardous Solid Oilfield Wastes;
- Class II – Non-Hazardous Solid Oilfield Waste; and
- Class III – Non-Hazardous, Chemically Inert Solid Oilfield Waste.

Chemical sludge from processes requiring re-generation including lime sludge are commonly accepted at Class II landfills. These are the primary solid waste products from the water treatment processes outlined in Section 10. Dry solids, free of chemical contamination from rivers or lakes are commonly disposed of in a Class III landfill.

11.1.2 Liquid Injection Well

Liquid waste can be disposed of in deep aquifer injection well. These wells are drilled or recompleted in deep underground reservoirs that have sufficient porosity, permeability and chemically compatible compositions to accept large volumes of saline wastewater.

According to AER Draft Directive 051: Wellbore Injection Requirements issued in August 2012 (AER, 2012), a representative sample of the waste fluid being injected into an approved well must have a:

- pH between 4.5 and 12.5;
- Flash point greater than 60 °C;
- Polychlorinated biphenyl (PCB) concentration of less than 2 milligrams per kilogram (mg/kg); and
- Non-halogenated organic fraction of less than 10% by mass (less than 100 000 mg/kg), unless it is:
  - Untreatable sand or crude oil / water emulsion, or
  - Antifreeze or dehydration fluid that contains greater than 60% water by mass.

If a waste product from the treatment process does not meet these conditions it may require further treatment prior to disposal.

11.2 Environmental Impacts of Disposal

11.2.1 Ecosystem: Construction-related Impacts

Terrestrial Habitat Disturbance

To calculate the total land disturbance of a landfill, the common industry practice is to assume 0.16 m^2 of land required for each m^3 of solid waste. Using the above assumption of 9.5 m^3/day of dry solids from river water, with project duration of 20 years, the total footprint area is approximately 70,000 m^2.

Similar to source water wells, the land disturbance footprint for injection wells is approximately 0.25 ha with the addition of a pump house (0.5 ha total).

11.2.2 Ecosystem: Operations-related Impacts

Spills and Leaks

Each waste product has the risk of being spilled or leaked into the local environment. As discussed in section 9, a spill of concentrated waste product or intrusion of impacted water, through a breach in the containment system, into the groundwater system can have a long lasting effect on the area.

Landfill facilities are designed to capture all leachate products; however, the potential for contamination of the local environment is always a concern. The adverse environmental impacts caused by the spill or leak will depend on a number of factors, including:

- Waste composition;
- Leachate quality and quantity, which is based on:
  - Intensity of precipitation; and
  - Simultaneously occurring physical, chemical and biological activities within the landfill.
- Volume of waste released into the environment; and
- Level of reclamation used to treat the contamination.

The release of hazardous and nonhazardous components of leachate may render an aquifer unusable for drinking-water purposes and other uses. Leachate impacts to groundwater may also present a danger to the environment and to aquatic species if the leachate-contaminated groundwater plume discharges to surface water bodies (i.e., wetlands or streams).

Although few studies have been completed on the topic, there is potential that injection wells may contaminate non-saline surface water systems and surface intervals. Poor casing cementing of the injection well during construction may pose a risk of interaction with these water. Risks of interaction can also occur if pathways exist between these deeper injection intervals and shallower aquifers, such as natural faults or fracture systems and induced pathways relating to poorly sealed oil and gas wells penetrating the same saline interval.

11.2.3 Ecosystem: Reclamation Impacts

Reclamation

Abandonment and reclamation of a landfill typically involves:

- The final capping and re-vegetation of the capped waste area;
- Removal of support infrastructure such as buildings, scales and access roads;
- Reclamation and re-vegetation of disturbed areas; and
- Monitoring of the integrity of the facility through environmental indicators such as surface and groundwater quality.

Capping of the landfill generally includes construction of an impermeable soil cap, comprising a low permeability soil layer, subsoil, topsoil and a natural vegetation seeding mixture. A geosynthetic liner may be required when capping salt-based wastes to prevent salt migration upwards through the cap system.

The reclamation of an injection well site is similar to the reclamation of a source well site as discussed in Section 8.2.3; there is an initial larger disturbance as equipment is brought to site to construct the well, then most of the disturbance is reclaimed while the wells are operating, with small disturbances remaining for regular maintenance access. Once the well is no longer required, the disturbance will again increase as equipment is required to excavate the area around the wells, cap and seal the wells, and finally the complete disturbance can be reclaimed. There will, therefore, be two reclamation phases when wells are used as water sources:

- Initial reclamation of construction site (short-term); and
- Complete reclamation of well sites (long-term).

The environmental impacts of the initial reclamation of the well construction site include:

- Replacement of the vegetation that was impacted by the drilling equipment;
- Grading to minimize the impacts of construction on the hydrology at the site; and
- The risk of allowing invasive species to repopulate the reclaimed site.

The environmental impacts of the long-term reclamation of the well sites after decommissioning include:

- Excavation and capping the well;
- Replacement of the vegetation that was impacted during decommissioning;
- Replacement of the vegetation at the well site;
- Replacement of the vegetation at the roads; and
- Re-grading the site to return to pre-disturbance runoff conditions.

11.2.4 Air Quality

In most cases, waste produced in the water treatment process will be transported by truck to an offsite facility. This transportation results in effectively the same environmental impacts as the transportation of water, which is outlined in Section 9.1.3. The air emission intensity from water transportation is weight based, and therefore can be converted to air emission intensity of solid waste transport. The intensity for transportation of solid waste by truck is 200 gCO_2-eq/ton-km.

Injection of water into deep aquifers will require the use of high-pressure injection pumps. The energy required by these pumps will depend primarily on the depth and composition of the aquifer.

11.3 ENE Comparison for Disposal

As shown in Water Disposal ENE Comparison chart and Table 4 in Appendix 3 the ENE of changing from non-saline source water to a saline groundwater source for disposal are:

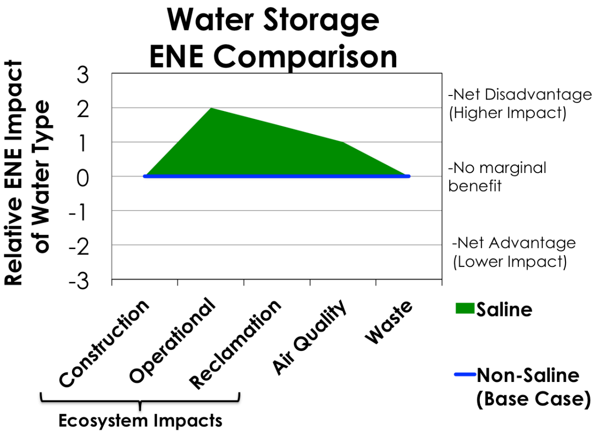
- Larger land disturbance;
- Greater impact of spills and leaks;
- Greater long-term reclamation requirements due to larger footprint area; and
- Greater energy requirements and GHG emissions due to larger shipment of waste.

As discussed in section 8.2, while this comparison focuses on changing from a non-saline to a saline source, the water quality of each source must also be considered.

12 WATER STORAGE

Storage Overview

The major ENE difference between saline and non-saline water storage is the increased impact to the surrounding environment in the event of a spill or leak of, or exposure to, chemicals in the saline water. To prevent such an impact, saline water is typically stored in engineered ponds (lined and monitored), C-ring containment structures, or above ground tanks, with mitigative measures in place. However, the need to engineer in containment leads to higher impact due to the requirement of additional physical footprint, containment infrastructure, and the associated equipment and activities for leak prevention and monitoring.



The following section highlights the environmental impacts associated with water storage within the hydraulic fracturing process. Storage needs and size requirements are dependent on the availability of water source as well as take the following into consideration:

- Reliability of water infrastructure;
- Variability in water quality;
- Potential cumulative effects (i.e., numerous users withdrawing from our source);
- Regulatory requirements/constraints; and
- Environmentally induced reliability challenges (i.e., seasonality and low river levels).

Possible storage options for water include:

- Ponds;
- Portable storage tanks; and
- Aboveground C-Ring tanks with geo-membrane liners.

Standard (80 m^3) portable storage tanks were excluded from the assessment due to the volume of stored water being considered (50,000 m^3), which would result in a large number of tanks being required to store water (more than 600 tanks). The extremely large footprint, fabrication costs, and shipping of these tanks would not be practical when compared with other storage options.

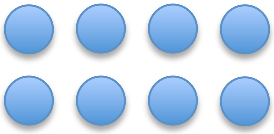
12.1 Environmental Impacts of Storage

12.1.1 Ecosystem: Construction-related Impacts

Terrestrial Habitat Disturbance

For the purpose of comparing the physical footprint of each of these water storage options, a volume of 50,000 m^3 has been assumed. Table G provides a summary of environment impacts specific to land disturbance associated with common options for water storage to be used for hydraulic fracturing operations.

Table G. Environmental Impacts of Land Disturbance for Storage

Factors	Unlined Pond	Lined Pond	C-Ring Tanks
System Description: Compatibility	Non-saline Water Only	Non-saline/Saline Water	Non-saline/Saline Water
Terrestrial Habitat Disturbance (ha)	Permanent: 2.7 ha 	Permanent: 2.7 ha 	Temporary: 2.5 ha 
Construction Impacts	Pond, fence, embankment, infrastructure pad	Pond, fence, embankment, infrastructure pad	Tanks, liner, infrastructure pad

Ponds

A typical storage pond would be either square or rectangular in shape, approximately 4 m deep with 1 m of freeboard. As per section 3.2.2, saline water ponds would likely require secondary containment in the form of a liner; however, non-saline water ponds can remain unlined. A pond area of approximately 17,000 m^2 (or 1.7 ha) would be required to store 50,000 m^3 of water. The overall development footprint, however, will be larger to account for a perimeter fence, an embankment on all sides, and an infrastructure pad on one side resulting in a total development area of approximately 27,000 m^2 (or 2.7 ha). The environmental disturbance and reclamation is more extensive with a pond than with aboveground water storage, due to excavation requirements associated with the pond construction, including access-ways for equipment.

Aboveground C-Ring Tanks

The land disturbance impacts associated are less intensive than with a pond. An aboveground C-Ring tanks to contain approximately 10,000 m^3 of water would be 75 m in diameter and 2.5 m high. Excavation is not required to install the C-Ring tanks. Clearing of the area and basic levelling to an approximate area of 4,500 m^2 is required to install an aboveground C-Ring tanks. To meet the assumed 50,000 m^3 volume, 5 C-Ring tanks of this size would be required, resulting in a total footprint area of approximately 25,000 m^2 (2.5 ha).

12.1.2 Ecosystem: Operations-related Impacts

Spills or Leaks

Limited information about pond failure is available but a study of failure rate of tailings dams (Martin, 2000), was used to determine the overall probability of lined pond failures. The study of 3500 active tailings ponds produced a major failure (spill) probability of 0.1% per year and minor failure (leak) probability of 1% per year. In these cases, spills and leaks of saline water could potentially lead to significant aquatic and terrestrial habitat impacts. With respect to ENE as a result of spill and leaks, the reader is referred back to Transportation Section 9.1.

There is no recent data on the probability of a leak from a C-Ring tank; however, the ability to prevent, detect and mitigation leaks is greater for aboveground C-Ring tanks when compared with ponds, as leaks and spills can be visually detected.

Terrestrial Impacts

An additional environmental impact associated with pond storage is the potential adverse impacts to wildlife and waterfowl if exposed to high salinity water. Table H (USDI, 1998) outlines the salinity concentrations at which biological effects were noted on a sample set of duck species.

Table H. Salinity Toxicity Data (USDI, 1998)

Species	Salinity Concentrations in Water	Effects/Comments	Reference
Mallard	~11,000	Reduced growth	Swanson et al. 1984
	8,800 – 12,000 (as sodium)	100% mortality	Mitcham and Wobeser 1988
	9,000 – 12,000	No effect	
	10,000 – 15,000	Level of concern	Nystrom and Pehrsson 1988
	15,000	100% mortality (7-day old	

Species	Salinity Concentrations in Water	Effects/Comments	Reference
		ducklings)	Swanson et al. 1984 Barnes and Nudds 1991
Mottled Duck	9,000	Threshold level for adverse effects	Moorman et al. 1991
	12,000	Reduced growth, 10% mortality	
	15,000	90% mortality	
	18,000	100% mortality	
Peking Duck	20,000	Level of concern	Nystrom and Pehrsson 1998

12.1.3 Ecosystem: Reclamation Impacts

Reclamation

Ponds

If the pond is located on Crown Land the area must be reclaimed at the end of its useful life. The following reclamation activities are typically required for ponds:

- All the water must be pumped out and treated prior to release or disposed of elsewhere;
- Any liners and piping infrastructure removed;
- The disturbed area must be backfilled;
- Topsoil placed; and
- Area re-vegetated with species native to the area.

Above-ground C-Ring Tanks

The reclamation associated with aboveground C-Ring tanks is less extensive than with ponds; at the end of its useful life:

- All the water must be pumped out and treated or disposed of elsewhere;
- The C-Ring tank infrastructure is removed; and
- Topsoil is placed, graded, and reseeded.

12.2 ENE Comparison for Storage

As shown in Water Storage ENE Comparison chart and Table 5 in Appendix 3 the ENE of changing from non-saline source water to a saline groundwater source for storage are:

- Greater impact of spills and leaks;
- Higher risk to waterfowl and wildlife if mitigation measures for storage fail;
- Greater long-term reclamation requirements due to removal of liner (in the case on ponds) and the remediation of saline spills (if applicable); and
- Greater energy requirements and GHG emissions due to leak detection requirements.

As discussed in section 8.2, while this comparison focuses on changing from a non-saline to a saline source, the water quality of each source must also be considered.

13 WELL-PAD

The selection of saline or non-saline source water does not have a significant impact on the hydraulic fracturing fluid and the system infrastructure, as both non-saline and saline water require some form of treatment to ensure compatibility with hydraulic fracturing additives prior to storage on pad. Therefore, the ENE of the completions process will be the same for both non-saline and saline source water provided that they are treated to the same standards.

14 DOWNSTREAM OF PRODUCTION WELLS

Variations in produced water quality have been found to be more dependent on the time retained in formation, the volume of produced water, and the geological formation than on the quality of the source water used in the fracturing operations (Blauch, 2011). Longer downhole residence times result in greater pH changes in the solution and greater dissolution of formation minerals and other soluble constituents into the produced water. Therefore the use of either saline or non-saline source water will have a negligible effect on the produced water quality due to the high mineral concentrations downhole.

15 CASE STUDY: WATER SOURCE OPTIONS WITHIN THE DUVERNAY AND MONTNEY SHALE GAS REGIONS

A case study identifying potential water source options within the Duvernay and Montney Shale Gas Regions is provided as Appendix 5 of this report. This case study is based on the 2013 work completed by Integrated Water Resources titled "Integrated Assessment of Water Resources for Unconventional Oil and Gas Plays, West-Central Alberta".

16 CONCLUSION

This study was designed to assess the environmental impacts of saline water use in hydraulic fracturing, as well as the ENE of choosing between saline and non-saline water sources. The study focused on the portion of the water lifecycle that is most affected by the choice of source water, which includes all stages of the hydraulic fracturing lifecycle up to and including storage. The following table provides a summary of the results.

Table I. Summary of Results

ENE Location	ENE Overview
Source Water	The major environmental impact of both saline and non-saline water sources with respect to water source infrastructure is the facility and source well footprints, access roads, and other supporting infrastructure. For example, a river or lake infiltration system can disturb the riverbed and the local aquatic habitat during construction, operation, and decommissioning. Alternatively, based on industry experience, a greater number of groundwater wells would be required to match the output volume of one river or lake intake resulting in greater disturbance footprint intensity.
Transportation	The major water transport ENE difference between saline and non-saline water is impact to the ecosystem in the event of a spill or leak of saline water during operations. The major determinant of impact is the mode of transportation used (i.e., pipeline versus truck transport), as this factor highly affects the degree of ecological and GHG emissions impacts.
Water Treatment	The water treatment ENE is directly related to the specific source water chemistry and downstream quality requirements for each specific application. These two factors are the primary indicators of the required treatment process and therefore the associated ENE. Saline water may have a greater net environmental impact compared with non-saline water due to the additional energy requirements for treatment commonly needed to meet compatibility with hydraulic fracturing operations. This equally extends to the waste by-products that need to be managed as a result of the treatment process.
Disposal	The major disposal ENE difference for waste generated from saline versus non-saline source water treatment is typically the volume of chemicals used for the treatment process. With the exception of TSS removal, which results in the production of large volumes of solid waste, the need for chemicals to render

ENE Location	ENE Overview
	saline water to a useful quality presents the risk of spills and releases into the environment and the associated detrimental effects.
Storage	The major ENE difference between saline and non-saline water storage is the increased impact to the surrounding environment in the event of a spill or leak of, or exposure to, chemicals in the saline water. To prevent such an impact, saline water is typically stored in engineered ponds (lined and monitored), C-ring containment structures, or above ground tanks, with mitigative measures in place. However, the need to engineer in containment leads to higher impact due to the requirement of additional physical footprint, containment infrastructure, and the associated equipment and activities for leak prevention and monitoring.

The comparison completed in this study focuses on two distinct water sources - saline and non-saline. This comparison was chosen as these two sources represent the most common type of water used for hydraulic fracturing operations. In addition, government agencies and stakeholders are gradually encouraging industry to shift their use of water from non-saline (typically surface water) to saline water (typically deeper bedrock aquifers) sources.

For this study, the saline water source was compared to the most common non-saline water source currently used by industry (i.e., river: infiltration gallery) in order to determine the major ENE differences. It should be noted that the quality of these two types of water sources could vary significantly, resulting in a large ENE gap. Alternatively, in a scenario where a higher quality saline water source is compared to a lower quality non-saline water source, this gap may be minimized. Therefore, when evaluating alternate water sources as options for hydraulic fracturing operations, it is important to consider water quality as well as the following factors:

- Availability of water source (seasonally and long-term);
- Regional demand for source water supplies (surface water and groundwater);
- ENE of all sources throughout the lifecycle of development (as outlined in this study);
- Economic considerations (capital and operating expenditures);
- Social impacts of source water use (local land owners, greater stakeholders etc.); and
- Technical and operational considerations for successful execution of project build-out and water usage.

Each hydraulic fracturing operation presents a different variation of all these factors, both in space and time. As such, it cannot be strictly determined, on a broad scale, if saline or non-saline water has a lower ENE. Each project-specific case and/or resource play will require careful consideration of these factors to determine the most sustainable water source to be used.

17 GOING FORWARD

The preceding study has assessed the ENE of saline versus non-saline water within hydraulic fracturing operations. Going forward, Integrated Sustainability recommends that a full water source evaluation tool be developed that builds on this work and considers the technical, operational, economic, social factors (including regulatory), and related environmental influences to inform source water decision-making. The assessment of alternative water sources has been indicated by AER as a key requirement in future water management plans (AER, 2006).

The result of such a tool would be the ability of operators to reduce the time required to make highly informed decisions that consider the most relevant factors involved with making source water decisions. Inclusion of this decision process in regulatory submissions will provide regulators with a clear picture of the environmental due-diligence completed by the operator. Multiple companies using the same submission format would see benefits in the approval process due to standardization of submissions. By providing baseline environmental and social models to all gas producers, including those without adequate resources to develop their own knowledge-based tools, a more sustainable approach to development can be achieved by all.

The proposed tool would provide a framework for site-specific evaluation of impacts associated with each individual water source, and all of the downstream impacts that may result. Within this assessment, it is recommended that both qualitative and quantitative factors associated with various water source options (i.e., obtaining, transporting, treating, and disposing of water) be considered for the duration of a project. Customizable weightings associated with each aspect of the process would be included to reflect the individual goals, constraints, and preferences specific to each project and/or company.

In order to most accurately match the development nature of hydraulic fracturing operations, the tool would be specifically designed to account for the seasonal and transient nature of development operations. Operators would be able to input forward-looking development plans and identify sensitivities around changes in operations, such as peak water demand or disposal.

As addressed in this study, the following criteria for each water source option shold be considered and assessed:

Environmental

- Biodiversity impact as a result of land (physical footprint) disturbance;
- Aquatic disturbance;

- Reclamation requirements;
- Waterfowl and terrestrial wildlife impacts;
- Waste(s) generated;
- Risk and effects of spills and leaks (i.e., saline water, treatment chemicals); and
- Energy footprint (i.e., fuel consumption and related GHG emissions).

Technical

- Water quantity and quality;
- Water treatment requirements;
- Effect of new technologies;
- Operability;
- Ease of integration into existing operations;
- Operational sensitivity to water quality changes; and
- Expandability/scalability.

Economic

- Cost of water sourcing facilities and associated infrastructure (i.e., access roads and pipelines);
- Cost of treatment ($/m^3) and other operational costs (i.e., transportation, storage, disposal);
- Cost escalation;
- Net present value; and
- Cost factor sensitivity.

Social

- Public acceptance (i.e., noise, dust, traffic impacts)
- Social license to operate; and
- Corporate reputation.

Alternatively, a Multi-Criteria Analysis (MCA) method can be used to conduct an assessment of numerous source water options. The MCA provides an evaluation of technical, operational, economic, environmental, and social considerations that may influence future selection of an appropriate water source. The MCA framework helps to compare options based on a set of pre-defined criteria. The outcome of the comparison produces a total score for each option, which then provides a ranked summary to determine the desirable water source solution.

18 CLOSURE

Integrated Sustainability would like to thank the Petroleum Technical Alliance of Canada for the opportunity to support this high-level assessment of the Environmental Net Effects of Saline Water in support of hydraulic fracturing operations. If you have any questions please contact the undersigned at any time.

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