Subsoil Salinity Tool Help File (Version 2.5.3)

Alberta Government

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The Subsoil Salinity Tool (SST) has been developed by Equilibrium Environmental Inc. under direction and guidance from Alberta Environment and Sustainable Resource Development and the Petroleum Technology Alliance Canada (PTAC) Salinity Working Group. The SST can be used to define two proposed levels of site-specific subsoil salinity guidelines (Tier 2A and Tier 2B) for application at salt impacted sites under Alberta Environment and Sustainable Resource Development's Tier 2 guideline framework.

Version 2.5.3

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TABLE OF CONTENTS **PAGE #**

1 INTRODUCTION

This document presents technical background and user guidance for the Alberta Environment and Sustainable Resource Development (ESRD) Subsoil Salinity Tool (SST) Version 2.5.3. The SST tool is a software program designed by Equilibrium Environmental Inc. under contract to ESRD and the Petroleum Technology Alliance Canada (PTAC) for the "*Development of Soil Salinity Guidelines Applicable below the Root Zone*". The SST can be used to define two levels of Tier 2 subsoil salinity guidelines (Tier 2A and Tier 2B) for application at salt contaminated sites. Subsoil in the SST is defined as depths below ground surface of greater than 1.5 m.

1.1 Overview of Alberta Guidelines

Alberta's contaminated sites management framework provides three management options: Tier 1, Tier 2, and Exposure Control. Tier 1 remediation guidelines are generic and can be used at most sites without modification. Tier 2 guidelines allow for the incorporation of site-specific conditions into the guideline calculation process and may involve removing exposure pathways that are not applicable to the site. A Tier 2 process typically involves calculating guidelines using mathematical algorithms provided by ESRD (2014a,b). Tier 2 guidelines can also be calculated using Site-Specific Risk Assessment (SSRA) and alternate mathematical approaches, providing this has been approved by ESRD. Exposure Control involves risk management through exposure barriers or administrative controls, and may include the use of SSRA. Closure can be obtained following a Tier 2 approach, including SSRA, but can not be obtained under the Exposure Control management option. Closure occurs when guidelines have been developed, and remediation activities have occurred to meet the guidelines, which allow for unrestricted use of the land within the municipal zoning and, in the case of specified land, reclamation to equivalent land capability. In comparison, Exposure Control requires the implementation and management of ongoing risk mitigation measures and unrestricted equivalent land use is prevented.

Tier 1 and Tier 2 soil and groundwater remediation guidelines are intended to prevent an unacceptable risk for the occurrence of potential adverse effects. The Tier 1 remediation guidelines are documented in the Alberta Tier 1 Soil and Groundwater Remediation Guidelines by ESRD (2014a). Additional supporting information for salts is provided in the Salt Contamination Assessment and Remediation Guidelines (SCARG; Alberta Environment (AENV), 2001). Tier 1 guidelines for salts are based largely on the protection of plant growth and productivity as well as soil structure. Although Tier 1 guidelines for salts are applicable regardless of the depth of contamination, salt contamination below the root zone often poses a negligible risk to plant growth provided the salt mass does not move back up into the root zone. However, receptors exposed to groundwater may be at risk. The development of Tier 2 guidelines provides an approach for assessing and mitigating risks to receptors not considered at Tier 1.

1.2 Tier 1 Guidelines for Salinity

Tier 1 guidelines for salinity impacts in soil are based on Electrical Conductivity (EC) and Sodium Adsorption Ratio (SAR) values for soils of varying rating categories (Good, Fair, Poor, Unsuitable). The guidelines were developed for the root zone (0 to 1.5 m). However, these guidelines can be applied to subsoil (>1.5 m) and there is no restriction as to how deep the user can apply the ESRD Tier 1 guidelines (*Subsoil Salinity Tool, Plenary Session, Canadian Land Reclamation Association. February, 2008*). The application of Tier 1 guidelines involves a comparison of background against site values in a depth stratified manner (*e.g.*, compare background versus site EC at soil depths of 0.15 to 0.45 m, 1 to 1.5 m, 2 to 4 m, *etc*.). Tier 1 salinity water quality guidelines are available for aquatic life, humans, livestock, and irrigation water. These guidelines can be compared with measured salinity concentrations at receptor locations (*e.g.*, human consumption of water in a domestic useable aquifer, livestock consumption of water in a dugout, aquatic life in contact with water at a groundwater/surface water interface), and may be used for comparison with salinity concentrations in groundwater. As with most Tier 1 guidelines, there is an intended and inherent element of conservatism to ensure that provincial guidelines are applicable to most sites in the province. It should be noted that in specific circumstances, application of the Tier 1 EC and SAR guidelines to subsoils (> 1.5 m) may be less protective than Tier 2 guidelines calculated using the SST, which is a function of the underlying assumptions upon which the Tier 1 guidelines were based.

1.3 Tier 2 Guidelines for Salinity

A Tier 2 approach allows for the refinement of guideline values by taking into consideration the application of more site-specific parameters. For salts that do not biodegrade in the environment and where a mass-balance approach is required, Tier 2 guidelines can be developed based on site-specific information such as climate, depth and width of impact, soil texture, groundwater parameters (depth, flow direction, velocity), and proximity to receptors. Tier 2 guidelines may be less, or more, 'conservative', in comparison to Tier 1 guidelines as a function of site conditions. The term 'conservative' is used in this document in a relative risk manner, does not in any way refer to absolute risk of adverse effect.

Tier 2 guidelines may be developed using the SST for salinity impacts located in subsoils at depths below ground surface of greater than 1.5 m. These guidelines are developed on an ion-specific basis (primarily chloride although sodium is considered), which differs from root zone soils (< 1.5 m) where guidelines are based on EC and SAR parameters. By determining the contribution of chloride ions towards EC in root zone soils, subsoil guidelines can be developed that are not expected to lead to an unacceptable risk of exceeding Tier 1 EC guidelines for the root zone. Similarly, by determining the contribution of sodium and chloride towards Total Dissolved Solids (TDS) concentrations in shallow groundwater, subsoil guidelines can be developed that are not expected to lead to an unacceptable risk of exceeding Tier 1 TDS-based livestock watering and irrigation water guidelines for a dugout into which groundwater may discharge.

Developing Tier 2 guidelines requires more site-specific information in comparison to a more straightforward application of Tier 1 guidelines. This additional information allows the assessor to develop guidelines that are tailored to the particular characteristics of a site. When a site has characteristics that make it more sensitive than the Tier 1 assumptions, the resulting Tier 2 guidelines may be more restrictive than Tier 1 values. Sites which are less sensitive may have Tier 2 guidelines that are less restrictive than Tier 1 values.

Tier 2 guidelines developed using the SST do not require on-going soil or groundwater monitoring after excavation. Confirmatory sampling after excavation will be required to show that Tier 2 guidelines have been met and chemistry characterization of backfill material is required. In addition, reclamation requirements must be met.

In the SST, the deeper portion of the root zone depth interval from 1.0 to 1.5 m is considered a receptor of concern. The SST does not address impacts or calculate guidelines for the root zone depth interval from 0 to 1.0 m. Development of Tier 2 guidelines for salt within the root zone (0 to 1.0 m) is beyond the scope of the SST and requires a Tier 1 assessment against ESRD (2014a) salinity guidelines.

Tier 2 guidelines for subsoil sodium, Sodium Adsorption Ratio (SAR), and facility-related sulphate impacts (*e.g.*, drill sump) are currently beyond the scope of the SST Version 2.5.3. Work is underway to incorporate subsoil SAR and sulphate into the SST in a version to be released at a later date.

1.4 SST Tier 2A and Tier 2B Guidelines

Two levels of Tier 2 guidelines are available in the SST (Tier 2A and 2B). Minimum investigation requirements are associated with each level. Tier 2A does not require monitoring wells and associated groundwater information, and consequently is associated with the application of more conservative assumptions. Tier 2B requires the installation of monitoring wells and characterization of groundwater parameters. Tier 2A and 2B assessments can be submitted to ESRD post-remediation and/or reclamation as part of a reclamation or remediation certificate application.

Pathway-specific subsoil salinity Tier 2A or 2B guidelines are calculated using the SST in order to allow for identification of limiting pathways in terms of risk potential. The SST also calculates groundwater quality guidelines. Hereafter, subsoil Soil Remediation Guidelines for salinity parameters are referenced by the term SRG. Groundwater Remediation Guidelines are referenced by the term GRG.

In order for subsurface salts to be associated with an unacceptable risk for the occurrence of potential adverse effects, salt ions must be transported:

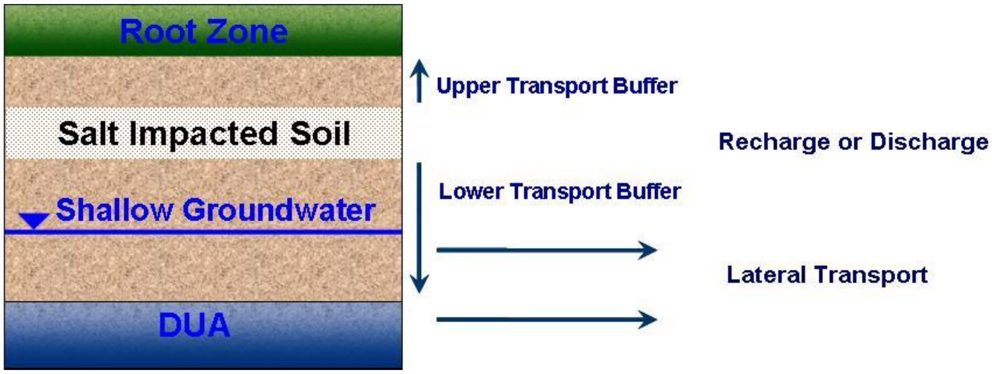
1. Upward into the root zone to affect soil dependent biota;
2. Downward towards a Domestic Use Aquifer (DUA) to affect potable water sources;
3. Into a dugout that could, in the future, be constructed in the impacted area and subsequently water could be consumed by livestock or used for irrigation purposes; and/or,
4. Laterally towards a surface water body that is an aquatic life receptor where aquatic life could be exposed.

Risk to humans, livestock, and wildlife via the incidental ingestion of soil is of lesser concern since guidelines developed by the SST are applicable to subsoil. The SST approach is based on several concepts, some of which are listed below:

- Mass balance-based approach
  - Three dimensional consideration of source mass
  - Mass removal via remediation (excavation and or through a collection system)

- Not exceeding ESRD (2014a) Tier 1 guidelines that apply to receptor locations
  - Root zone EC guidelines
  - Drinking water chloride (and sodium) guideline
  - Livestock watering TDS guidelines
  - Irrigation water EC (as a TDS proxy) guidelines
  - Aquatic life chloride (and sodium) guidelines

- Transport Buffers (see diagram below)
  - unimpacted till located above and below the impacted soil depth profile
  - unimpacted till located between the site and a nearby aquatic life receptor



In some instances, an upper transport buffer may not be present as salinity impacts are present within as well as immediately beneath the root zone. The SST can still be utilized, although the guidelines will be more constrained since the root zone is already impacted, and there is an absence of an upward transport buffer. Excavation and replacement of impacted soil with backfill will reduce constraints on guideline values.

- Chemistry Buffers
  - Contribution of site-related chloride to background root zone EC
  - Contribution of site-related chloride (and sodium) to background TDS in shallow groundwater that discharges into a dugout potentially constructed in the future
  - Contribution of site-related chloride on top of background chloride in shallow groundwater at a discharge point into a water body that is an aquatic life receptor
  - Contribution of site-related chloride on top of background chloride in a DUA

1.4.1 Integration with Tier 1 Guidelines

The SST was developed in a manner such that the subsoil SRGs (as well as GRGs) would not be predicted to lead to an exceedence of ESRD (2014a) Tier 1 guidelines at receptor locations, specifically, the root zone from 1 to 1.5 m, aquatic life at a groundwater/surface water interface, livestock and irrigation water in a dugout, and within a DUA.

For protection of the root zone in Agricultural, Residential, and Natural areas:

- The Alberta Tier 1 guidelines for rooting zone soils are used (refer to table below);
- Tier 1 guidelines are applied to rooting zone soils (0 to 1.5 m) in a manner independent of the SST and based on professional judgement and interpretation of SCARG as well as the necessity of meeting reclamation requirements; and,
- The deeper portion of the root zone from 1.0 to 1.5 m is considered a receptor of concern in the SST. A statistical approach is used to accommodate the spatial variability inherent in soil salinity.
- The SST will calculate the mass of chloride that can redistribute upward into the root zone from subsoil that on average does not increase EC in the root zone (1.0-1.5 m depth) above the upper bound EC value of a Tier 1 salinity rating category (Good, Fair, Poor, Unsuitable) determined from the upper 95th percentile of background EC values.

Parameter		Rating Categories			
		Good	Fair	Poor	Unsuitable
Topsoil[c]	EC dS/m (salinity)	<2[a]	2 to 4	4 to 8	>8
	SAR (sodicity)	<4	4 to 8	8 to 12	>12[b]
Subsoil[c]	EC dS/m (salinity)	<3	3 to 5	5 to 10	>10
	SAR (sodicity)	<4	4 to 8	8 to 12	>12

a Some plants are sensitive to salts at EC < 2 dS/m (e.g., flax, clover, beans, wheat, peas, some garden crops).

b Material characterized by SAR of 12 to 20 may be rated as poor if texture is sandy loam or coarser and saturation % is less than 100.

c Topsoil: surface A horizons on the control area, or the equivalent surface soil on the reclaimed site. Subsoil: B and C horizons and the upper portion of the parent material.

Source: ESRD (2014a) Tier 1
Note – the subsoil guidelines in the table above are applicable to the 1.0 to 1.5 m root zone depth interval in the SST

For protection of the root zone in Commercial and Industrial areas:

- Plant receptors are evaluated based on the soil guidelines for EC and SAR shown below instead of values for the Tier 1 Good soil quality category (refer to the following table).
- For sites where background EC and SAR values are greater than the CCME criteria (*e.g.*, > 4 dS/m), then the soil rating categories EC and SAR guidelines provided in the table above are used for Fair, Poor, and Unsuitable soils.

Parameter	CCME C/I Soil Criteria
EC	4 dS/m
SAR	12

Three exposure pathways are considered for the protection of shallow groundwater:

- For the protection of aquatic life, the CCME (2012) chloride water quality guideline of 120 mg/L is used;
- For the protection of livestock watering, thresholds are based on Canadian livestock watering guideline information. TDS concentrations of less than 3,000 mg/L are classified as good quality. Concentrations between 3000 mg/L and 7,000 mg/L are classified as marginal but useable. Concentrations greater than 7,000 mg/L are considered unusable by livestock and the pathway is eliminated; and,
- For the protection of irrigation watering, a conversion of 1 dS/m = 640 mg/L TDS is used (from Tanji, 1990). Irrigation water with a TDS concentration of 640 mg/L is considered "safe" (ESRD, 2013). Irrigation water with TDS concentration of 640 to 1,280 mg/L (1.0 to 2.0 dS/m) is considered "marginal or possibly safe" (ESRD, 2013). Irrigation water with TDS concentration greater than 1,280 mg/L is considered "unusable" for this purpose.

	Safe	Possibly Safe	Hazardous
EC (dS/m)	< 1.0	1.0 to 2.0	> 2.0
TDS (mg/L)	640	1,280	>1,280

For the protection of a DUA:

- The human aesthetic Tier 1 chloride water quality guideline of 250 mg/L is used.

1.4.2 Sodium

For all of the exposure pathways/receptors considered in the SST, with one exception, risks from sodium are incorporated. Risks from sodium are incorporated for irrigation water in terms of a contribution towards TDS, however, risks associated with increasing surface soil sodicity via application of irrigation water containing elevated sodium concentrations have not been addressed. These risks will be addressed with incorporation of subsoil sodium and SAR guidelines in the SST. Root zone guidelines in the SST automatically incorporate the contribution of sodium towards soil EC. Guidelines for livestock watering automatically consider the influence of sodium towards TDS based on an equi-molar contribution with chloride. For evaluating the aquatic life and DUA pathways, chloride is risk limiting (due primarily to a greater transport potential relative to sodium) and therefore sodium is not considered a risk driver for these pathways.

1.4.3 Tier 2C Guidelines

A Tier 2C approach involves the use of site-specific fate and transport modeling for salinity impacts, typically employed at larger and more complex sites or in situations where the default assumptions in the SST are not sufficiently conservative. The Tier 2C approach will require greater regulatory scrutiny to ensure that site data are properly interpreted for the calculation of guideline values. Triggers for the adoption of a Tier 2C approach for a particular site include those that specifically relate to salinity issues in addition to triggers outlined by ESRD (2014a; with modifications):

1. Site conditions that violate SST model assumptions, necessitating the use of alternate modeling procedures (*e.g.*, Tier 2C), include,
   a. source dimensions greater than 200 m x 150 m for the aquatic life and DUA guidelines that are source dimension dependent;
   b. soil depth profiles composed primarily of sands and gravels (that would meet the definition of a DUA) with negligible overlying till,
   c. Muskeg/peat layers– the SST is not designed to address impacts within the organic layers of peat/muskeg because muskeg is associated with anisotropy with a preferential flow of pore water in the lateral direction - the SST may be used to develop guidelines for mineral soils beneath muskeg/peat layers,
   d. shallow groundwater velocities greater than 10 m/year,
   e. impact depths greater than 10 m,
   f. close proximity to a surface water body that has a functional aquatic ecosystem;
2. Land or water uses not covered by generic land and water use categories and which cannot be addressed at Tier 2 (Tier 2A and Tier 2B), by the addition or unconditional exclusion of exposure pathways (including the presence of unique exposure conditions or more sensitive receptors);
3. Adjustments to site-specific parameters that are not readily measured or verified, that are not relatively stable, and/or that require management or control measures; and,
4. Development of alternate Tier 1 guidelines for receptors of concern.

Guidance is not provided in this manual for calculating Tier 2C guidelines. A Tier 2C approach requires upfront regulatory liaison and monitoring. Contact the relevant regional ESRD representative for further details. Tier 2C assessments must be submitted to ESRD for review prior to remediation and reclamation work for sites applying for a reclamation and/or remediation certificate.

1.4.4 Reporting Requirements

A distinct report must be generated to accompany SST software guideline calculation printouts and submissions as part of a Reclamation Certificate or Remediation Certificate application. The report must contain the following:

1. Clear concise summary of all soil and groundwater analytical data for the site, for salinity parameters including chloride, sodium, magnesium, calcium, sulphate, potassium, bicarbonate/carbonate (where relevant), saturated paste EC, sodium adsorption ratio (SAR), saturation percentage, and pH;
2. Clear concise summary of all soil texture data;
3. Clear electromagnetic survey (EM38, EM31, EM34), vertical conductivity profile, Electrical Resistivity Tomography (ERT), Electrical Resistivity Imagining (ERI), and/or Ohm Mapper diagrams;
4. A plan view diagram containing the geo-referenced locations of all boreholes and monitoring wells;
5. An aerial photo showing the locations of aquatic life receptors relevant to the site location (a scale must be provided);
6. A detailed scientific rationale write-up clearly summarizing data and assumptions for each input parameter that is used by the SST for developing site-specific Subsoil Remediation Guidelines (SRGs) for salinity (chloride);
7. A selection of relevant borehole logs displaying the variability in texture across the site; and,

8. Key information points as well as requirements for clear presentation of additional key tables and figures that support the calculated guidelines, as highlighted in this manual, are denoted with the following symbol. .

Excel copies of soil and groundwater laboratory data, and calculations/data to derive SST input parameters, provided in a concise and organized manner, must be submitted along with the electronic SST submission.

1.5 Acknowledgements

ESRD would like to acknowledge the Petroleum Technology Alliance Canada (PTAC) Salinity Working Group and the following members who played a pivotal role in the development of the ESRD SST:

Gordon Dinwoodie (ESRD)
Chris Meloche, Steve Kullman (Husky Oil Operations Limited)
Rob Staniland, Ted Johnson (Talisman Energy Inc.)
Kathy Cox (Enerplus Group of Companies)
Boris Barkovic (City of Calgary)
Susan Halla (Energy Resources Conservation Board)
Mike Morden (Petro-Canada)
Shawn Willetts (ConocoPhillips)
Michelle Young, Asfaw Bekele (Imperial Oil Resources)
Stephen Bromley (Husky Oil Operations Limited)
Steve Kullman (Husky Oil Operations Limited)

Supplementary field work in support of model testing was conducted by Michelle Wright, Rob Wiebe, and Tom Messier.

The SST development was funded by PTAC, ESRD, and the City of Calgary. Chris Meloche (Husky Oil Operations Limited) and Rob Staniland (Talisman Energy Inc.) initiated the PTAC project. In kind contributions were provided by the Alberta Orphan Well Association, Talisman Energy Inc., Husky Oil Operations Limited, Petro-Canada, and Advantage Energy Income Fund.

We would also like to thank the following Equilibrium team members:

1. Anthony Knafla (M.Sc., DABT) – project management, conceptual model and assumptions, fate and transport modeling, policy recommendations, risk assessment, help manual
2. Greg Huber (M.Sc., P.Eng) – software development, updated numerical approaches, fate and transport modeling
3. Sunita Ranganathan (M.Sc.) – software front-end, software development, reporting feature design, help manual
4. Jimmy Mercado – software programming (Version 2.5.3)
5. Jillian Campbell (M.Sc., P.Biol) – software testing
4. Konstantinon Vasilakos, (PhD) – previous software development, updated numerical approaches, fate and transport modeling (Version 2.5.2)
7. Kit Fraser – document formatting assistance (Version 2.5.2)
7. Michael Callaghan (P.Eng) – previous software design and development, previous fate and transport modelling (Version 2.2, beta Version 1.0)

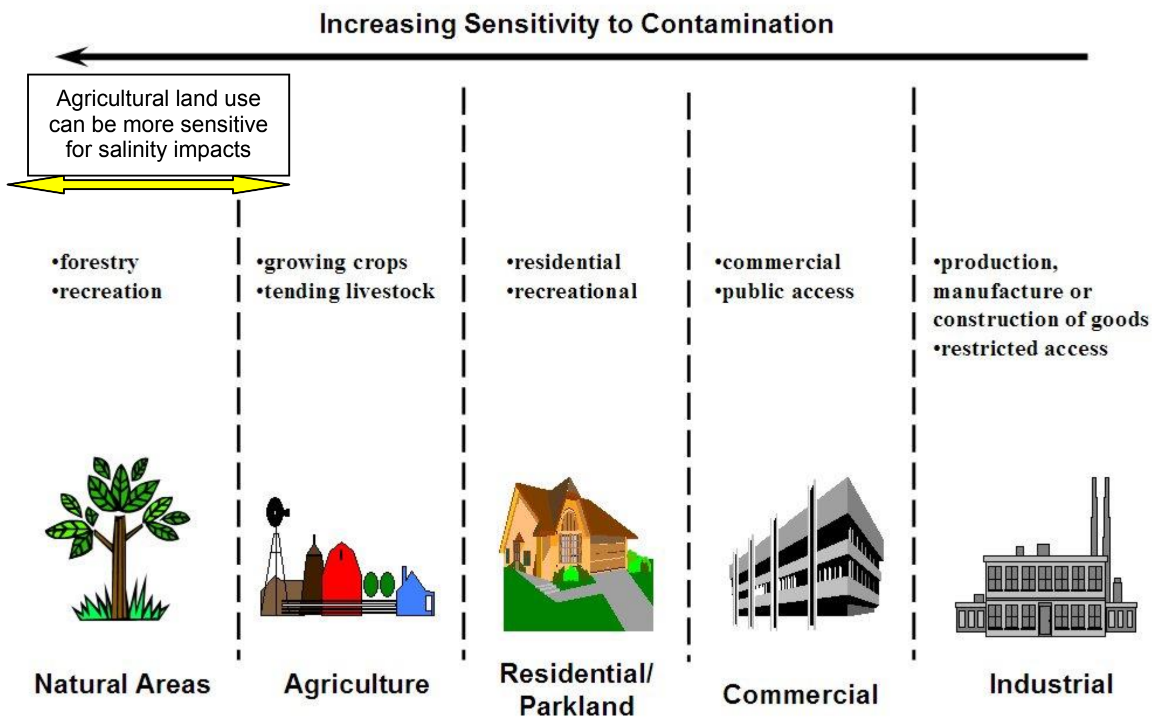
2 SST PROGRAM BASIS

2.1 Introduction

The SST program is essentially a chloride mass balance-based fate and transport guideline calculator. It estimates the redistribution of a chloride impact over time to determine present-day chloride concentrations in subsoil that are not predicted to result in current day or future unacceptable risk of adverse effects for receptors of concern. Tier 2A or 2B guidelines calculated using the SST for subsoil are risk based and developed with the goal of preventing exceedences of ESRD (2014a) Tier 1 guidelines at receptor locations for various land uses.

2.2 Land Use and Receptors/Pathways of Exposure

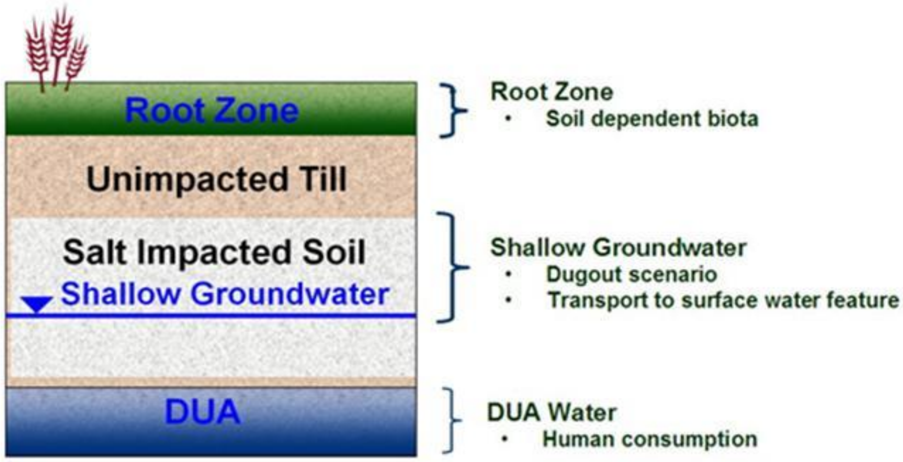
General land use information will determine relevant receptors to be considered, particularly for pathways related to salt transport in shallow groundwater. The land uses defined by Alberta Environment for Alberta are Agricultural, Natural Area, Residential/Parkland, Commercial and Industrial land uses. Land use determines the general sensitivity of a site in terms of potential for risk. For salts, Agriculture Areas can be of equivalent, or greater, sensitivity compared to Natural Areas.



Potential receptors of concern and relevant exposure pathways include

- Direct contact of with chloride in the root zone or chloride transported from subsoil upward into the root zone under discharge conditions, Soil dependent biota (plants) at a depth of 1.0 to 1.5 m below ground surface ;
- Mixing of chloride in groundwater with dugout water and consumption by livestock or irrigation of plants;
- Shallow groundwater transport to an aquatic life receptor and direct contact with aquatic life at the surface water / groundwater interface; and,
- Leaching to a DUA and consumption by humans.

Salts pose a relatively minor risk to humans and livestock via soil ingestion and dermal contact, as well as the inhalation of dust.

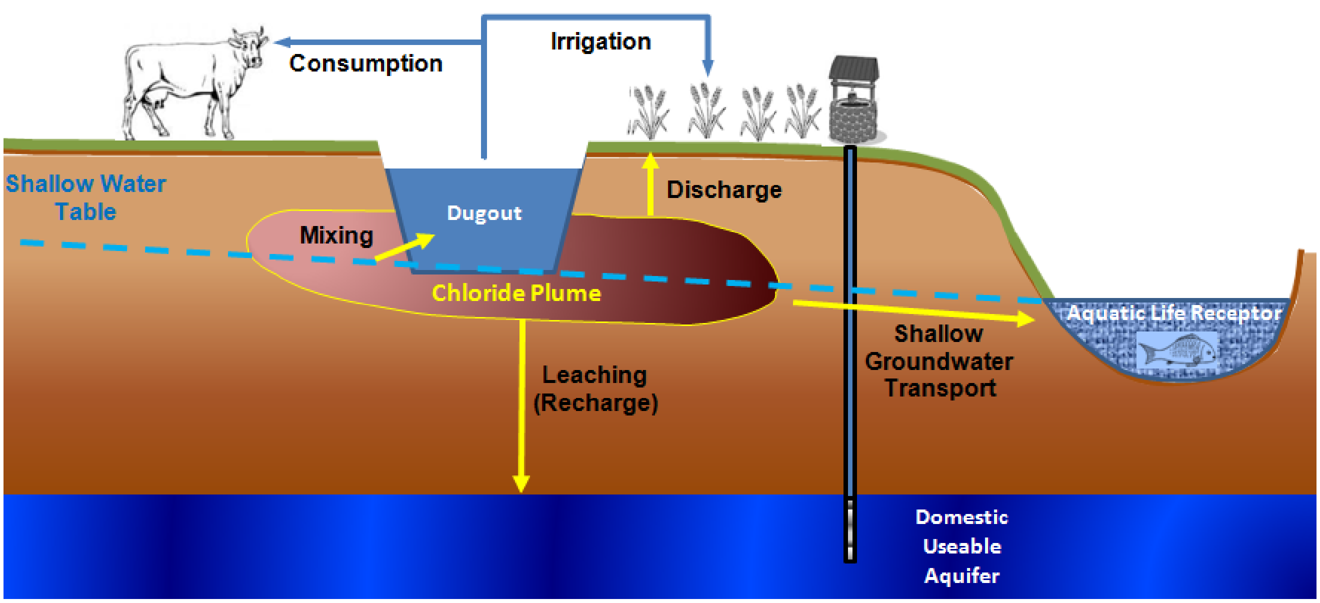


2.2.1 Agricultural Land Use

On agricultural land the primary use is growing crops or tending livestock as well as human residence. This also includes agricultural lands that provide habitat for resident and transitory wildlife and native flora. To allow unrestricted use of the land, a farm residence is assumed to be present anywhere on agricultural land. Similarly, a dugout or a water well could be placed anywhere on the site. For the determination of guideline values for sites in agricultural land use areas, the following receptors and pathways are considered:

- Soil dependent biota (plants) via direct contact in the root zone;
- Dugout and use for livestock watering and irrigation purposes;
- Aquatic life in a nearby surface water receptor; and,
- Humans via consumption of water in a DUA.

⚠ ***It is assumed that a dugout can be located anywhere on site for the calculation of guideline values for shallow groundwater via livestock watering and irrigation water. Similarly, a water well and farm residence can be placed anywhere on site.***



2.2.2 Natural Areas and Residential/Parkland Land Use

Natural areas are defined as being away from human habitation and activities, where the primary concern is the protection of ecological receptors. Human exposure pathways are not considered, with exception of the protection of potable sources of groundwater (DUA) applies for all land uses. Much of Alberta's forested land is considered to be within a Natural area land use. Forested lands that are specified as grazing sites represent a special case that requires an amendment to the normal exposure scenario for Natural areas. On such grazing sites, the protection of groundwater for the livestock watering pathway must be addressed in addition to the regular pathways considered for Natural areas.

The primary activity on Residential/Parkland land use is habitation in a residence or recreational activity. Wilderness in provincial parks is considered a Natural area. For the determination of guideline values for sites in Natural and Residential/Parkland land use areas, the following receptors and pathways are considered:

- Soil dependent biota (plants) via direct contact in the root zone;
- Dugout scenario in natural areas where the land is used for grazing purposes and there is evidence of dugout construction for livestock watering in the area;
- Aquatic life in a nearby surface water receptor; and,
- Humans via consumption of water in a DUA.

Note, for Residential land use where the immediately adjacent land use is Agricultural, the dugout scenario must be considered because equivalent land capability implies that a landowner could construct a dugout on the boundary between Agricultural and Residential land use. Under Tier 2A, adjacent Agricultural land use is considered in any direction from the Residential land. Under Tier 2B, adjacent Agricultural land use is considered in the direction of downgradient groundwater flow.

2.2.3 Commercial and Industrial Land Use

On Commercial land, the primary activity is commercial (e.g., shopping mall) and all members of the public, including children, have unrestricted access. Commercial land uses include day-care centres, buildings for religious services, hospitals, and medical centres. Commercial land does not include operations where food is grown directly in impacted soil on the site. Such operations would fall under Agricultural land use. Industrial land is where the primary activity is the production, manufacture or construction of goods. Public access is restricted and children are not permitted continuous access or occupancy. For the determination of guideline values for sites in Commercial and Industrial land use areas, the following receptors and pathways are considered:

- Soil dependent biota (plants) via direct contact in the root zone;
- Aquatic life in a nearby surface water receptor; and,
- Humans via consumption of water in a DUA.

Note, for Commercial and Industrial land use where the immediately adjacent land use is Agricultural, the dugout scenario must be considered because equivalent land capability implies that a landowner could construct a dugout on the boundary between Agricultural and Commercial/Industrial land use. Under Tier 2A, adjacent Agricultural land use is considered in any direction from the Commercial/Industrial land. Under Tier 2B, adjacent Agricultural land use is considered in the direction of downgradient groundwater flow.

2.3 Conceptual Model

For calculating subsoil (> 1.5 m below the ground surface) chloride guidelines that are not expected to be associated with an unacceptable risk of potential adverse effects towards soil dependent biota in the root zone, the conceptual model used in the SST is based on:

- Vertical salt transport in soil as a function of variables such as vertical hydraulic gradient, and vertical saturated conductivity;
- Magnitude of chloride impacts currently within the deeper root zone interval (1.0 to 1.5 m);
- Estimation of future peak chloride concentrations at the base of the root zone (1.5 m) and contribution to deep root zone (1.0 to 1.5 m) EC;
- Background root zone EC (or backfill soil EC) and determining the upper bound of an appropriate Tier 1 root zone rating category (Good, Fair, Poor, Unsuitable) for establishing the magnitude of salinity buffer in the deeper root zone interval ;

- Soil texture and physical properties; and,
- Future reclamation of the site (the model assumes good plant cover has been established).

For calculating guidelines that are not expected to be associated with an unacceptable risk of potential adverse effects for humans consuming water from a DUA, the conceptual model used in the SST is based on:

- Vertical salt transport in soil as a function of variables such as vertical hydraulic gradient, and vertical saturated conductivity;
- Estimation of peak chloride concentrations in leachate water that could reach a DUA in the future;
- Dilution of leachate water as it enters the DUA;
- The ESRD (2014a) Tier 1 chloride groundwater guidelines for protection of potable water;
- Attenuation of peak concentrations due to lateral transport in the saturated zone above the DUA (simultaneously increases the length of impact at the vadose zone/DUA interface); and,
- No attenuation due to lateral transport within the DUA - it is assumed a well could be placed in a DUA anywhere on site or near the site.

For calculating guidelines that are not expected to be associated with an unacceptable risk of potential adverse effects for aquatic life receptors in a nearby water body, the conceptual model used in the SST is based on:

- Estimation of peak chloride loading onto shallow groundwater at the shallow groundwater table depth;
- Estimation of peak chloride concentrations in shallow groundwater at the high water mark of the nearest relevant aquatic life receptor located some lateral distance from the site;
- The CCME chloride aquatic life guideline;
- Attenuation of peak concentrations due to dispersion and diffusion during lateral transport in x, y, and z directions; and,
- No dilution due to mixing of groundwater and water within the surface water body since aquatic life could come into contact with chloride at the groundwater/surface water interface (*i.e.*, benthic organisms in sediments exposed to undiluted groundwater concentrations).

For calculating guidelines that are not expected to be associated with an unacceptable risk of potential adverse effects for irrigated plants and livestock via the dugout scenario, the conceptual model used in the SST is based on:

- Estimation of peak chloride concentrations in groundwater from 2 to 4 m;
- Contribution of chloride and sodium towards TDS in dugout water;
- The Alberta Agriculture EC (TDS) guidelines for irrigation water, the ESRD (2014a) TDS guideline for livestock water, and a 7,000 mg/L TDS upper bound TDS guideline for livestock water;
- No attenuation due to lateral transport for Agricultural and Natural Areas with grazing leases - it is assumed a dugout could be placed anywhere onsite;
- Attenuation of peak concentrations due to dispersion and diffusion during lateral transport in x, y, and z directions *<u>from Residential, Commercial, and Industrial land to adjacent agricultural land; and,</u>*
- Application of an adjustment factor to account for dilution as groundwater mixes with water and precipitation/runoff in the dugout.

2.4 Tiered Subsoil Salinity Guidelines

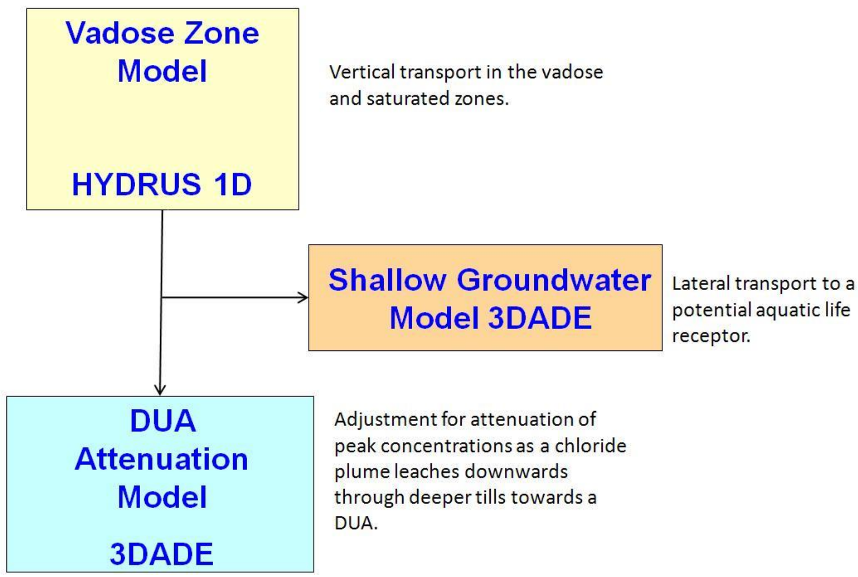
The selection of Tier 2A versus Tier 2B for developing subsoil salinity guidelines depends on site-specific information and characteristics, the value (cost/benefit) of installing a monitoring well network, and other concerns such as site accessibility, landowner concerns, *etc.* Complicated and larger sites are more likely to go to a Tier 2B approach due to the potential value of less restrictive guidelines that may result if site-specific groundwater parameters are less conservative than the default assumptions under Tier 2A.

The primary purpose of the Tier 2A approach is to provide a more rapid method for developing guidelines that do not rely on monitoring well data and measured groundwater parameters. Conservative assumptions are built into the SST to account for the lack of site specific groundwater data. By not requiring a monitoring well network for guideline development, Tier 2A it allows proponents to initiate remediation efforts within a shorter timeframe since the delays associated with time to well development, water elevation stabilization, and two groundwater monitoring events are not incurred. It should be noted that the Tier 2A approach may lead to a greater expenditure of resources (via remediation) to achieve an acceptably low risk for potential adverse effects based on a Tier 2B approach.

The Tier 2B approach allows for more refined predictions of risk based on fewer conservative assumptions. Specifically, Tier 2B includes the collection of groundwater data and calculation of groundwater parameters as opposed to using conservative assumptions for groundwater parameters under Tier 2A.

2.5 Software Models

Two software models were used to estimate the fate and transport of chloride for guideline development: Hydrus-1D (Simunek *et al*., 2005); and, 3DADE (Leij and Bradford, 1994). The manner in which the models were used is shown below. Hydrus-1D was used for modeling the vertical transport of chloride and estimation of break though curves at various vertical soil depth intervals. 3DADE was used for lateral transport of chloride towards and aquatic life receptor and estimation of lateral plume dispersion and peak concentration attenuation as the plume leaches downward to come into contact with a potential DUA.



2.6 Vertical Salt Ion Transport

Chloride can be considered a conservative substance in terms of fate and transport because it does not adsorb to soil, readily form precipitates, or undergo chemical, biological, or radioactive decay breakdown in the environment. Sodium in comparison will adsorb to soil and form precipitates with sulphate, which can influence the rate of transport. Salt transport is governed by the net movement of soil moisture through soil pores, or in other words pore water flow. If more water is drawn upward by plant transpiration and evaporation from the soil surface than is percolating downwards, a net upward water balance may exist. As part of the process of upward movement of water, salts may be drawn into and concentrated within the rooting zone. A significant build up of salts in the rooting zone may decrease plant root performance and plant yield.

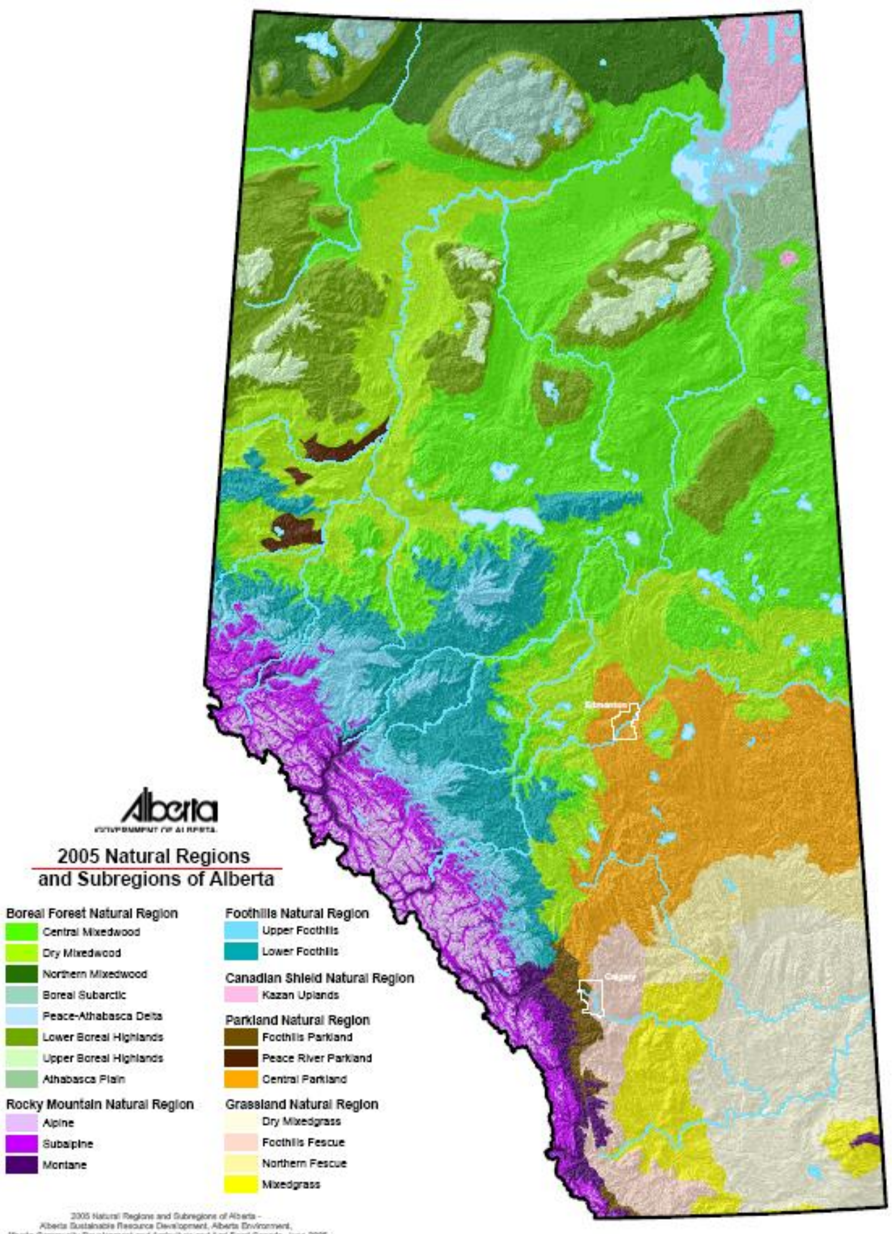
If more water is percolating downwards through the rooting zone than is being drawn up by evapotranspiration, a net downward water balance may exist. Water percolating through the rooting zone and subsoil may leach salts from the soil and carry them downwards to shallow groundwater. In this case, salt loading onto shallow groundwater may be of concern, and the salt mass could subsequently be transported laterally to an aquatic life receptor. If downward leaching of water continues through the shallow groundwater bearing zone to a potential DUA, then loading of salts onto a potable water source may be of concern. Other mechanisms involved in the spread of salts through the soil column include dispersion and diffusion. Dispersion reduces the peak concentration of salts as they flow through soil pores, due to differing lengths of micro- (and macro-) passages. Diffusion is generally not a primary mechanism for salinity mass distribution in the SST and involves the tendency of molecules to move from areas of high concentration to lower concentration over time due to particle kinetics.

The rate of vertical movement of soil water (referred to as a drainage rate) is generally on the order of mm per year. Factors influencing the direction and rate of soil water movement (up or down), include: climate (precipitation and evapotranspiration), soil lithology (hydraulic conductivity and moisture retention), and presence of good plant growth.

Salt ion transport will parallel the advective flow of water in soil and groundwater. A sensitivity analysis was performed to determine the relative importance of various input parameters on the vertical modelling of salinity transport. Eleven parameters were selected for testing. Climate moisture index, soil lithology, drainage rate, and the presence of vegetation were identified as important parameters for the rate of salinity transport, and a subset of the parameters was subsequently incorporated into the SST model for adjustment on a site-specific basis.

2.6.1 Climate Regions of Alberta

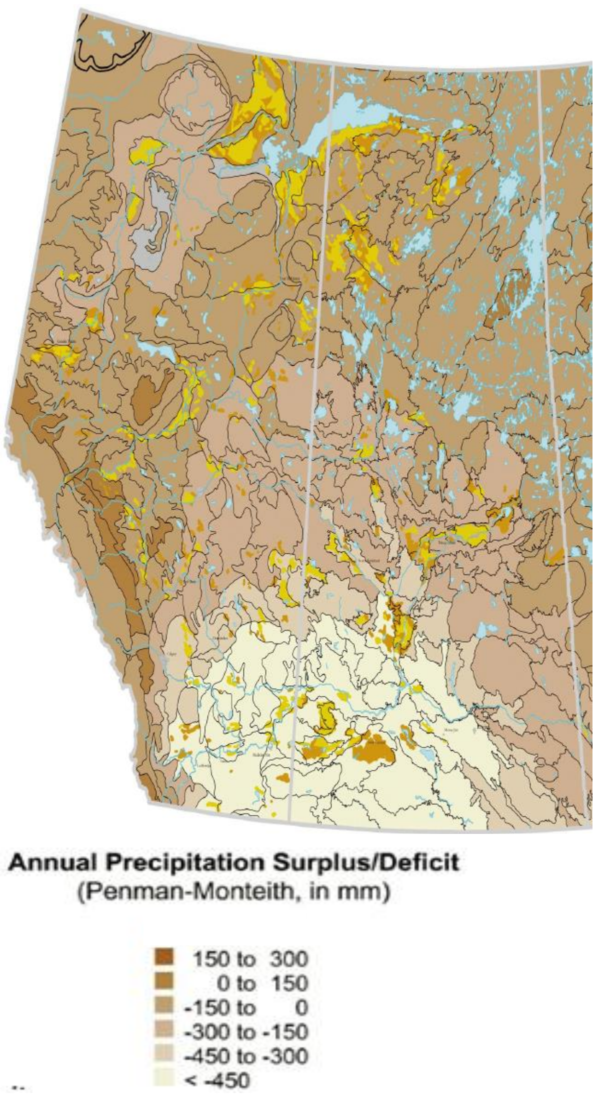
Climate varies across the province of Alberta. For example, the climate of the Foothills Fescue Natural Subregion (location shown in the figure below) in characterized by short summers, warm days, cool nights, and long cold winters, which are moderated by frequent Chinook winds. Information for this Subregion suggests it has the potential for a moisture deficit (Adams *et al.*, 2003). In comparison, the Mixedgrass Subregion is considered relatively hot and dry, similarly affected by Chinook winds, with a stronger potential moisture deficit (Adams *et al.*, 2004). In contrast, the Central Mixedwood Subregion, the largest Subregion in province, is characterized by a relatively cool and wet climate with higher precipitation rates compared to the Dry Mixedwood and Central Parkland Subregions (Moisey *et al.*, 2012).

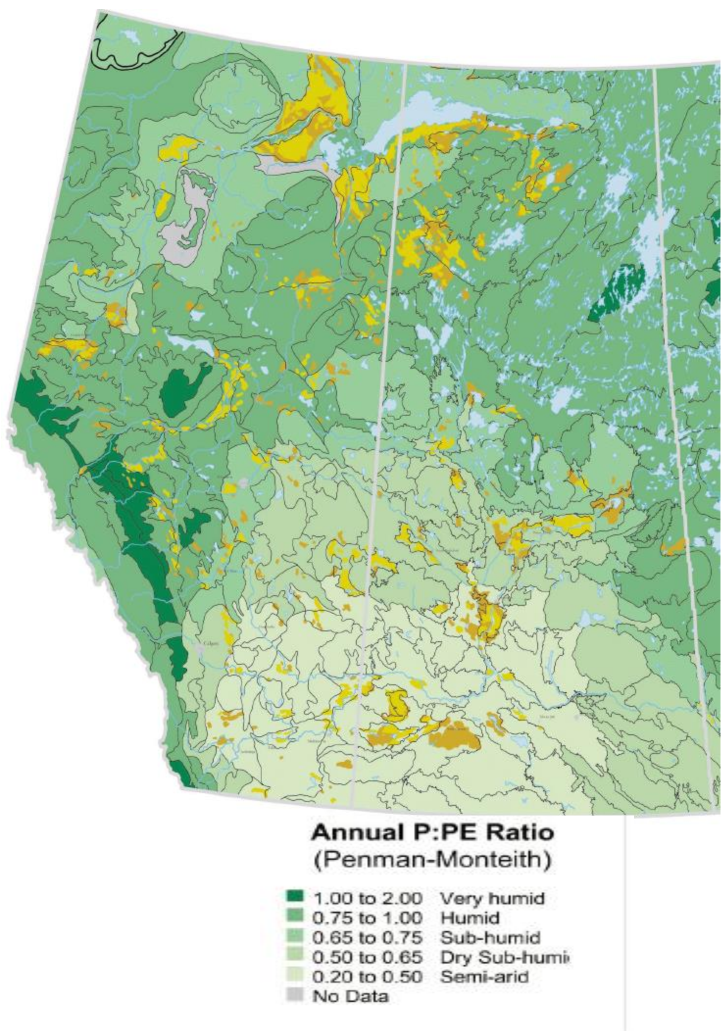


2.6.2 Estimating Water Balance

Climate has a strong influence on water balance. The likelihood of infiltrating precipitation draining below the root zone depends on the balance between precipitation and evapotranspiration. Precipitation (P) and potential evapotranspiration (PE or PET) have been modelled and mapped for Alberta (Thorpe, 2001) using the Penman-Monteith model. In the maps, shown below, values of P:PE greater than 1.0 indicate a stronger potential for recharge conditions (moisture surplus), whereas values less than 1.0 are more indicative of potential discharge conditions.

In general, areas to the south/southeast have stronger moisture deficits (*e.g.*, Grassland Natural Region) and areas to the north/northwest generally have weaker moisture deficits or have surpluses (Foothills, Boreal Forest, and Rocky Mountain Natural Regions). The Upper Foothills was categorized as potentially a Very Humid climate with a moisture surplus (Thorpe *et al.*, 2001). The Lower Foothills, Alpine, Subalpine, Montane, and Central Mixedwood were considered Humid climates with a slight potential moisture deficits based on the calculated P-PET values. The Boreal Subarctic, Northern Mixedwood, Dry Mixedwood, Peace River Parkland, part of the Foothill Fescue, Foothills Parkland, Kazan Upland, Peace-Athabasca Delta, and Athabasca Plains were considered Sub-Humid with a greater potential for a moisture deficit. The remaining Subregions located mostly to the southeast of the province were considered Sub-Humid and Semi-Arid with a moisture deficit potential.





Gold and yellow colored areas represent undifferentiated Eolian deposits (minor dunes) and sand dune areas. Thorpe et al. 2001. Saskatchewan Research Council
http://www.parc.ca/pdf/research_publications/renamed/PARC-07.pdf

The P and PET parameters are key inputs into the HYDRUS model that was used to calculate drainage rates for different conditions in Alberta, and thus determine the resulting SRGs output from the SST. PET overestimates actual evapotranspiration (AET) because it assumes soil water availability is not a limiting factor. PET can be estimated using various input parameters including solar radiation, wind speed, vapour pressure deficit, air temperature, stomatal resistance of a canopy, humidity, aerodynamic resistance, soil energy, and/or surface resistance of soil, *etc*. More complex models consider both transpiration (through plants) and evaporation (from the soil surface) as well as multiple vegetation layers (*e.g.*, treed forest canopy with understory vegetation). PET values are frequently expressed relative to a reference crop.

Differences in PET between different crops can be expressed relative to a reference condition which is based on meteorological parameters. A crop coefficient (K_c), which is empirically derived, accounts for the role of vegetative factors in influencing evapotranspiration. The crop coefficients provided below are applicable to irrigated fields with plants that are not under moisture stress and soils have a minimum of field capacity moisture or greater (Allen *et al.*, 1998, as presented in a United Nations FAO paper for improving agricultural irrigation and drainage calculations). The crop coefficients vary depending on stage of growth and were as low as 0.3, or as high as 1.2 under conditions of frequent wetting. K_c is frequently less than 1 when time-weighted averaged across the growing system (Allen *et al.*, 1998; Allen, 2010). However, for some crops, the K_c values are essentially unity indicating that their potential for evapotranspiration is similar to that of the reference short grass crop. A similar potential would occur for native grassland species if soil moisture was not limiting.

Crop Coefficients (K_c) for Various Plant Species Under Irrigated Ideal Conditions Compared to Reference Short Grass Crop (K_c=1.0)

Crop	Initial Crop Coefficient	Middle Crop Coefficient	End Crop Coefficient
Small vegetables	0.7	1.05	0.95
Cucumber family	0.5	1.0	0.8
Roots and tubers	0.5	1.1	0.95
Legumes	0.4	1.15	0.55
Flax	0.35	1.1	0.25
Oil crops	0.35	1.15	0.35
Cereals	0.3	1.15	0.4
Alfalfa	0.4	0.95	0.9
Rye grass hay	0.95	1.05	1.0
Cattails, bulrushes, killing frost	0.3	1.2	0.3
Cattails, bulrushes, no frost	0.6	1.2	0.6
Reed swamp, moist soil	0.9	1.2	0.7
Reed swamp, standing water	1.0	1.2	1.0
Shallow open water (< 2 m depth)		1.05	1.05

Allen et al., 1998. United Nations Food and Agriculture Organisation
Normalized to a reference short grass crop with good ground coverage (coefficient of 1.0)

AET is less than PET when soil moisture is limiting (Brown, 2010; Fisher *et al.*, 2005; Allen *et al.*, 1998). For example, within 10 days following an absence of rainfall or irrigation in a silty soil with a field capacity moisture of 32% and a wilting point moisture of 12%, PET could be reduced by more than 50% by the 10^{th} day (Allen *et al.*, 1998). By including a soil moisture function, the AET values predicted by Fisher *et al.* (2005) were in close proximity to measured values, and PET was reduced by 58% to be in close approximation to measured AET values. This process (adjusting evapotranspiration based on soil moisture levels) was used in the modelling of salt transport with the HYDRUS model for developing SRGs in the SST, and evapotranspiration decreased as a function of soil moisture level. It should be noted that the potential reduction in PET due to soil salinity level was not considered in the model.

For forest ecosystems, the determination of AET values can be complex. Like agricultural crops, AET values under non-irrigated conditions are lower than irrigated conditions and values further decrease with increasing tree height (Komatsu, 2005). Baldocchi and Ryu (2011) calculated that on average, a forest will evaporate 46 mm for each 100 mm increase in precipitation suggesting a P/AET of 2.2, indicative of a potential moisture surplus and a very humid environment. Furthermore, the authors determined a strong correlation (r^2=0.756) between precipitation and evapotranspiration in forest ecosystems. For forested systems in New Brunswick, Shiau (1968) estimated that the P/PET was approximately 1.5 to 2 during the frost free season based on empirical water basin data, indicating a moisture surplus and the potential for recharge conditions. Komatsu (2005) determined that lower AET was associated with higher tree canopies, suggesting that new forest areas (plantations, post-fire regrowth) or stunted forest will have greater evapotranspiration (less potential for recharge) compared to older mature forests under growth supporting soil and moisture conditions.

Alton *et al.* (2009) determined an AET/PET value of 0.78 to 0.89 from a pooled dataset of broadleaf, needleleaf, grassland, and shrub plants, using Semi-empirical Plant Hydrology and Soil to Plant Atmosphere models. Attarod *et al.* (2011) determined that for a Japanese red pine plantation forest and data collected over the growing season, an AET/PET ratio of 0.7 could be derived using a statistically significant overall best-fit line. Komatsu (2005) found that various coniferous (n=45) and deciduous (n=22) forests have AET values lower than the reference low lying grass PET under fully saturated conditions, and AET/PET values ranged from 0.41 to 0.91, with an average of 0.64 for either the coniferous or deciduous forests. Fisher *et al.* (2005) found that for a Sierra Nevada mountain forest composed primarily of ponderosa pine during drought summer conditions, the Penman-Monteith method produced PET values that overestimated AET by 2-fold or more (AET/PET of 0.5 or less). Douglass *et al.* (2009) from 18 sites in Florida determined the following ratios of AET/PET for lakes, grassland, and forest: 0.99, 0.72, and 0.47, respectively. Rao *et al.* (2011) using a Southern Appalachian mountain watershed catchment water balance approach determined Penman-Montelith AET/PET average ratios of 0.58 and 0.81 for coniferous (plantation) and deciduous (native hardwood) forests, respectively, using data from 1986 to 2007, and ratios of 0.67 and 0.75 for conifers using data just from the 2004 and 2005 years, respectively.

One method of estimating AET is to adjust the Priestley-Taylor coefficient α for soil moisture availability. Fisher *et al.* (2005) and Komatsu (2005) compiled soil-moisture adjusted Priestley-Taylor coefficients for a number of vegetative types and surface conditions (shown below). The ratios were normalized to the reference PET for comparative purposes. Grass that was not irrigated had a relative AET/PET of 0.87 compared to the reference condition. Coefficients for forest ecosystems ranged from 0.41 to 0.91, with an average of 0.64 for either deciduous or coniferous forest. Similar results were obtained with other models, in terms of AET/PET ratio, for forested ecosystems.

Priestly Taylor Coefficients Demonstrating Reductions in PET Relative to a Reference Crop

Surface Conditions	Priestley-Taylor Coefficient	Normalized Coefficient (Calculated AET /reference PET)	Reference
Grass (soil at field capacity) – reference	1.29 (reference)	1	Fisher et al 2005
Irrigated ryegrass	1.27	0.98	Fisher et al 2005
Saturated surface	1.26	0.98	Fisher et al 2005
Open-water surface	1.26	0.98	Fisher et al 2005
Wet meadow	1.26	0.98	Fisher et al 2005
Short grass	1.12	0.87	Fisher et al 2005
Bare soil surface	1.04	0.81	Fisher et al 2005
Wet Douglas-fir forest	1.18	**0.91**	Fisher et al 2005
Boreal broad-left deciduous	1.09	**0.84**	Komatsu (2005); n=1
Douglas-fir forest	1.05	**0.81**	Fisher et al 2005
Mixed reforestation (water limited)	0.9	**0.70**	Fisher et al 2005
Ponderosa pine (water limited, daytime)	0.87	**0.67**	Fisher et al 2005
Temperate broad-leaf deciduous	0.85	**0.66**	Komatsu (2005); n=9
Douglas-fir forest (unthinned)	0.84	**0.65**	Fisher et al 2005
Tropical broad-leaf evergreen	0.82	**0.64**	Komatsu (2005); n=7
Douglas-fir forest (thinned)	0.8	**0.62**	Fisher et al 2005
Douglas-fir forest (daytime)	0.73	**0.57**	Fisher et al 2005
Spruce forest (daytime)	0.72	**0.56**	Fisher et al 2005
Temperature coniferous evergreen	0.65	**0.50**	Komatsu (2005); n=35
Boreal coniferous evergreen	0.55	**0.43**	Komatsu (2005); n=38
Boreal coniferous deciduous	0.53	**0.41**	Komatsu (2005); n=2

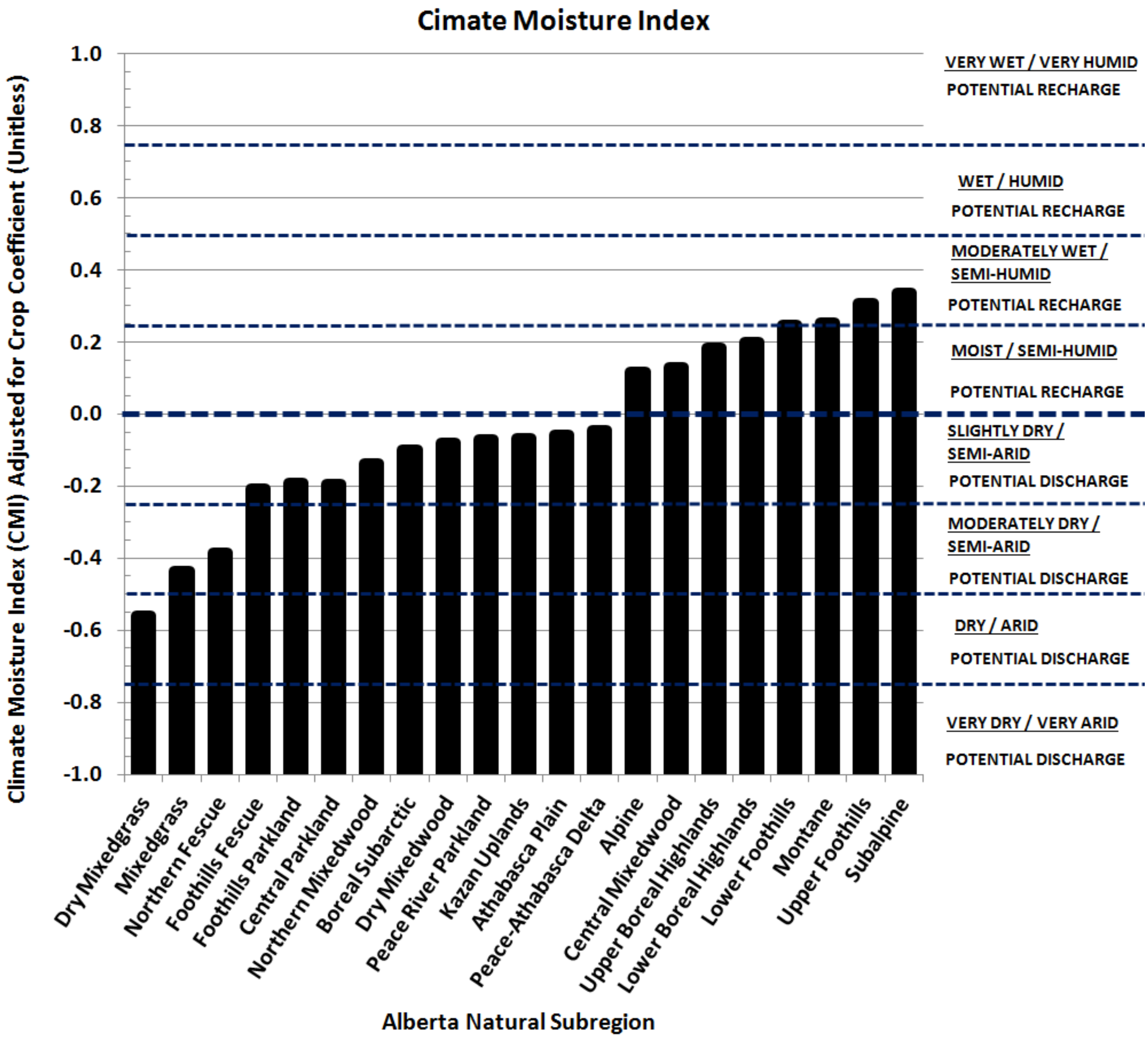
2.6.3 Climate and Annual Soil Moisture Surplus/Deficit

The information above was used to assist in determining whether a particular Alberta Subregion would have an annual average moisture surplus or deficit, and by default would be under potential recharge or discharge conditions, by incorporating reasonable adjustments to PET (*i.e.*, to generate AET values) for calculating Climate Moisture Index (CMI) values.

The Subregions were generally categorized in relative climate classifications of Very Humid, Humid, Sub-Humid, and Semi-Arid as considered by Thorpe *et al.* (2001), and their work at Saskatchewan Research Council. In addition, a similar generic classification scheme of Wet, Moist, Dry, and Very Dry provided by the Natural Regions Committee (2006), Government of Alberta, was used. Values for P and PET were obtained from the Alberta climate normals database for the years 1961 to 1990, sourced from Agriculture and Agri-Food Canada (AAFC, 1997). Data were extracted and processed as a function of Ecodistrict that make up the Alberta Natural Subregions as published in 2005. Precipitation data were available on a monthly and annual basis, including both snowfall and rainfall. AAFC (1997) estimated PET values using the Penman procedure in a manner similar to that used in the WOFOST Crop Simulation Model (van Diepen *et al.* 1988). The AAFC Penman calculations were made on a daily basis assuming a grass cover with an albedo of 0.25 when average mean daily air temperatures were above 0 ^{o}C and a value of 0.75 when temperatures were below freezing and the ground was covered in snow.

PET was adjusted to more closely approximate AET values by multiplying PET by an empirically derived crop coefficient parameter (K_c), as per Allen *et al.* (1998). A K_c value of 0.7 was used for the following Subregions of Alberta composed of extensive coniferous forest ecosystems associated with lower net potential evapotranspiration rates: Upper Foothills; Lower Foothills; Montane; Subalpine; Central Mixedwood; Lower Boreal Highlands; and, Upper Boreal Highlands. A K_c value of 0.8 was used for Subregions that sustain primarily mixtures of native grasslands and deciduous woodlands and/or have been extensively developed into agricultural land: Dry Mixedgrass; Foothills Fescue; Northern Fescue; Mixedgrass; Central Parkland; Peace River Parkland; Foothills Parkland; and, Dry Mixedwood. The value of 0.8 was also applied to Subregions composed of poorly drained soils, frozen organic soils, and/or stunted tree stands, which will be associated with a greater evapotranspiration potential compared to boreal forest ecosystems: Northern Mixedwood; Boreal Subarctic; Athabasca Plain; Kazan Uplands; and, Peace-Athabasca Delta. Sphagnum moss can have a relatively high transpiration rate (Brown, 2010).

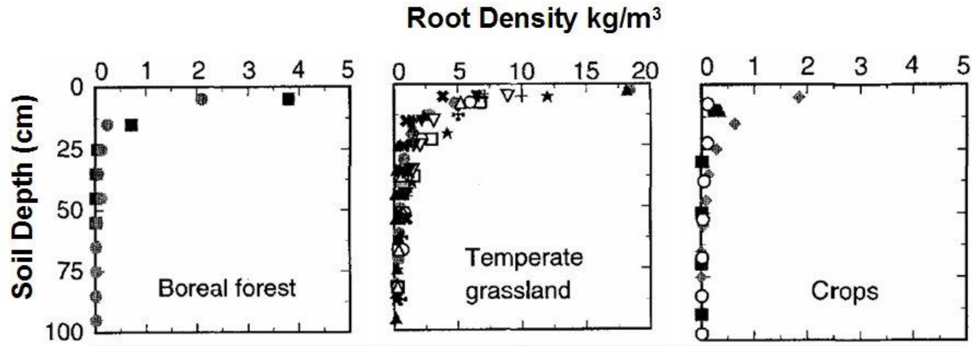
P and PET estimates are combined to calculate water balance. The results can be illustrated by calculating CMI values. CMI can be normalized to fall between 1 and -1 by calculating (P/PET)-1 when P<PET and 1-(PET/P) when P≥PET. A positive CMI is indicative of potential recharge and a negative value potential discharge. The results are shown below, using Alberta climate data and adjusting PET with K_c as described above. None of Alberta's Subregions were within the Very Dry/Very Arid, Wet/Humid, or Very Wet/Very Humid categories. Dry Mixedgrass was categorized as Dry/Arid - cactus are observed in this Subregion. All coniferous forest Subregions were within the Moderately Wet/Semi-Humid or Moist/Semi-Humid categories. Forests characterized by stunted trees and poorly drained soils (and/or frozen organic soils) as well as agricultural and deciduous forest parkland were categorized as Slightly Dry/Semi-Arid. Mixedgrass and Northern Fescue were categorized as Dry/Arid. It should be noted that runoff was not taken into consideration, and this can reduce the amount of precipitation available for infiltration. Runoff is affected by microclimate and topography. When Subregion-specific runoff estimates for Alberta (Hogg and Hurdle 1995; Hogg 1994) were considered, Subregions identified to be under potential recharge remained in that category.



Local variations in climate associated with micro-climates or distinct vegetation type are not accounted for in the SST program. Climate conditions are assumed to be uniform within each Natural Subregion. A more refined estimate of drainage conditions may be obtained by installing nested wells, and incorporating a measured vertical gradient into the SST.

2.6.4 Root Zone Depth and Reclaimed Soils

Vertical salt transport modeling and associated breakthrough curves for SRG calculations assumed that good post-reclamation plant growth has been achieved following the completion of remediation activities. Good growth is associated with typical root depths, as shown below. A root depth of 0 to 1.5 m was used in water balance model runs for the SST. As can be seen in the density graph below, the majority of root biomass (> 70%) is in the upper 0.3 m of soil although deeper roots extend to 1 m (and potentially deeper), which may be of importance during long periods between rainfall events where plant water uptake may be more dependent on deeper root biomass.



Cover Type	% Root Biomass in Upper 30 cm
Boreal Forest	83
Temperate Grassland	83
Crops	70

Source: Jackson et al., 1996.

2.6.5 Soil Lithology and Properties

Two generalized soil lithology groupings are used to categorize soil texture at sites across Alberta (coarse and fine) in a similar manner to Tier 1 guidelines provided by ESRD (2014a). For subsoil (> 1.5 m), the predominant texture is selected. The soil texture governing transport is selected for entry into the SST. For example, if soils are primarily fine soils with occasional sand lenses, and fine soils are primarily governing salinity transport, a fine texture is selected. However, if the coarse intervals are relatively extensive and continuous such that they could represent a significant transport pathway, the coarse texture would be selected. The definition of coarse and fine soils for calculating subsoil salinity guidelines with the SST is determined from reported clay percentage via analysis by hydrometer.

The SST program is not intended to be applied to peat or muskeg deposits, or gravels, although it may be applied to heavier clays (clay content >60%) as shown in the textural triangle figures. Guidelines calculated by the SST may be used in areas with muskeg/peat deposits, although the guidelines solely apply to mineral soils that may underlie an organic layer, but not the organic layer itself. In other words, if peat deposits extend to 2.5 m, the SST guidelines would apply to deeper depths (> 2.5 m) where mineral soils are present.

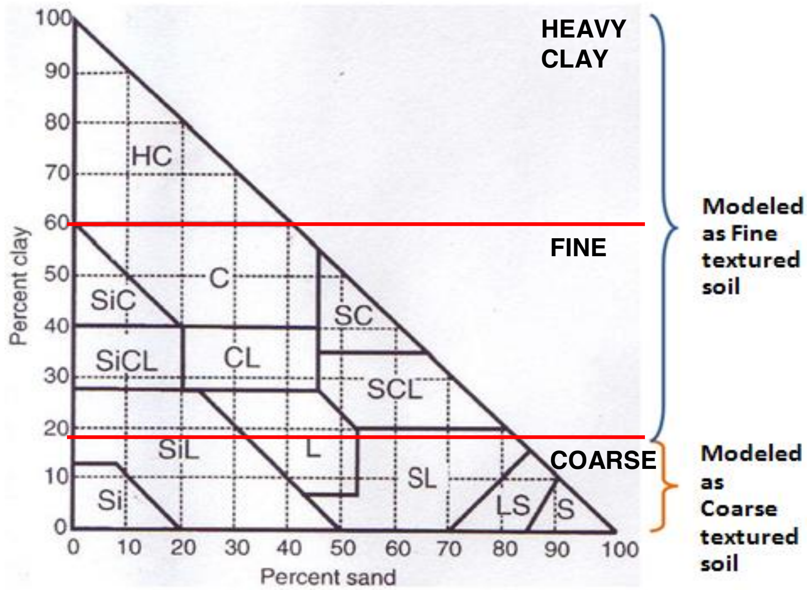
Subsoil lithology is modeled in the SST program based on the percent of clay content (as indicated below). Judgment is required by the proponent to adequately identify the thickness of soil layers based on field borehole logs and soil textural information.

1. Clay content > 60% (heavy clays):
   - Modeled as a fine soil texture; guideline is adjusted to account for differences in bulk density and porosity for a heavy clay; and,
   - There is a toggle in the SST program to allow for heavy clay.

2. Clay content 18 to 60% (includes clay, silty clay, silty loam):
   - Modeled as a fine soil texture.

3. Clay content < 18% (includes sandy loam, silt, loamy sand, sand):
   - Modeled as a coarse soil texture, however:
   - Special consideration must be given if the thickness of the sand unit is > 0.5 m since:
     - it may indicate the potential presence of a DUA, which requires a Tier 2B approach so that the unit can be tested for hydraulic conductivity and potentially yield; and,
     - it may indicate the potential for preferential lateral flow pathways through which subsoil salts could be transported towards a nearby aquatic life receptor and a Tier 2B analysis may be warranted.
   - If sand units are ≤ 0.5 m thick and there are no consecutive layers of sand, then it may not represent a DUA.

CANADIAN SYSTEM OF SOIL CLASSIFICATION



Agriculture and Agri-Food Canada. 2013. The Canadian System of Soil Classification. 3rd Edition. Soil Classification Working Group, Expert Committee on Soil Survey, Land Resource Research Centre. Ottawa. http://sis.agr.gc.ca/cansis/taxa/cssc3/chpt17.html

Statistics are calculated to determine the mean % clay content (calculated separately outside of the SST such as in Microsoft Excel, the SST does not perform this calculation) which can be used to select the appropriate soil lithology in the SST (*i.e.*, fine or coarse). Soils with a clay content of ≥ 18% (including heavy clays) are treated as fine texture soils and soils with < 18% clay content are treated as coarse texture soils. The value 18% is used for particle-size classes to differentiate between coarse and fine loam soils, and also reflects the change from non-plastic to plastic limits.

It is the responsibility of the proponent to represent the soil lithology of the site accurately. Parameters used in the SST for coarse soils (sand) and fine soils (clay) are summarized in the table below.

Parameters	**Fine Texture (Clay Content > 18%)**	**Coarse Texture (Clay Content < 18%)**
Bulk Density (g/cm^3)	1.620	1.685
Ksat (mm/d)	0.79	422
Dispersivity (mm)	100	100
Porosity	0.381	0.357
Campbell's Parameter **α**	2.66	0.658
Campbell's Parameter **β**	15.5	9.07
Moisture Retention 10kPa	0.361	0.297
Moisture Retention 30 kPa	0.342	0.269
Moisture Retention 1500 kPa	0.240	0.175

*Note: **α** and **β** are coefficients of moisture tension.*
For sites with predominant heavy clay (clay content > 60%) lithologies, a bulk density and porosity of 1.4 g/cm^3 and 0.47, respectively, is used by the SST.

2.6.6 Soil Drainage Rate

The site water balance and drainage rate are factors involved in determining whether a chloride impact will leach appreciably to groundwater or be drawn upward into the rooting zone. Significant leaching to groundwater can result in degradation of groundwater quality for livestock watering, subsequent lateral migration to an aquatic life receptor, as well as deep drainage to a DUA and human consumption. The key parameters considered during development of the SST program for establishing drainage rates are shown below.

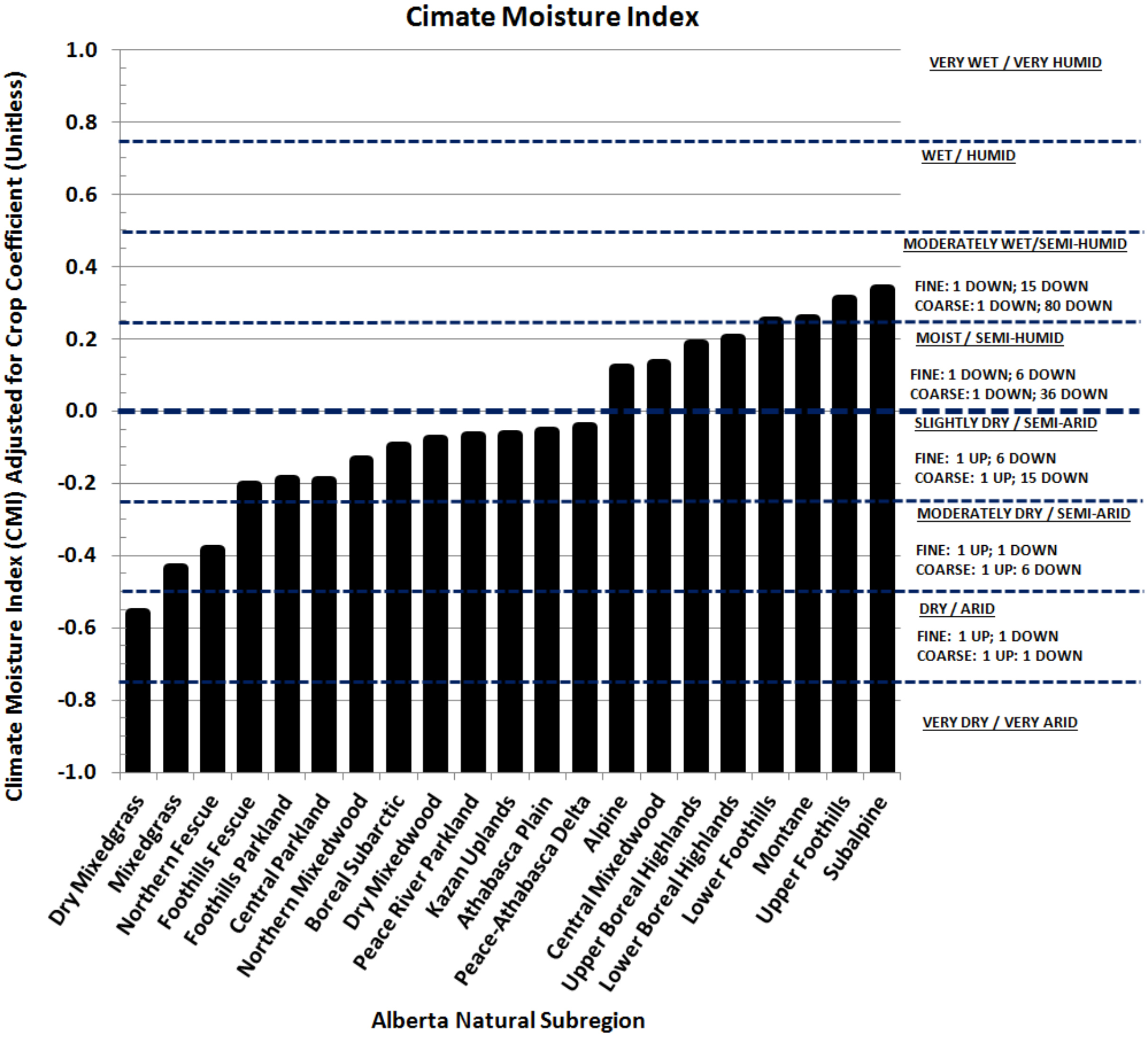
- ESRD default infiltration rates for coarse and fine soils as upper bound ranges;
- Climate Moisture Index (CMI) and general plant cover type;
- Soil lithology; and,
- Site-specific vertical gradient.

Drainage rates are also influenced by topography and deep geology. These factors were not directly considered in the estimation of drainage rates. Specific discharge and recharge categories were defined for calculating guidelines. A negative soil drainage rate indicates discharge conditions (net upward migration of water and salts). A positive drainage rate indicates recharge conditions (net downward migration of water and salts).

Maximum drainage rates for predicting downward leaching of salts were capped at values similar to the infiltration rates for Tier 1 guidelines for other chemicals in Alberta (such as petroleum hydrocarbons). ESRD (2014a) determined maximum drainage rates based on precipitation data from Edson (surrounded by the Lower Foothills Subregion, mean annual precipitation of approximately 560 mm/year) multiplied by 2% and 10% of the annual precipitation for fine and coarse soils, respectively. This is equivalent to drainage rates of 12 and 60 mm/year for fine and coarse soils, respectively. These values are within the range of recharge rates identified in areas with similar climates and soil textures (Scanlon *et al.*, 2006). In the SST, the maximum drainage rate for fine soils was set at 15 mm/year (approximately equivalent to the Tier 1 infiltration rate for fine soils of 12 mm/year). For coarse soils, the maximum rate was set at 80 mm/year, which is approximately 33% greater than the ESRD (2014a) Tier 1 infiltration rate for coarse soil of 60 mm/year. In general, the coarse soil in the SST for salt modeling is coarser than the ESRD definition of coarse soils for hydrocarbons. For areas with precipitation and evapotranspiration rates that differ from Edson, the SST calculates correspondingly lower drainage rates, resulting in different subsoil salinity SRGs. For example, in the Central Mixedwood that has approximately 100 mm less precipitation per year, the maximum downward drainage rates are set at 6 and 36 mm/year for fine and coarse textured soils, respectively, compared to 15 and 80 mm/year for the Lower Foothills.

For Subregions that were determined to have a potential net moisture surplus, or a positive CMI (*e.g.*, Upper Foothills, Lower Boreal Highlands), salts will transport downward in a manner associated with recharge conditions. Because of potential variable rates of downward drainage, a different drainage rate is used in the SST model for shallow groundwater than the DUA. A lower downward drainage rate is used to develop guidelines for receptors located in closer proximity to the soil surface (*e.g.*, root zone, shallow groundwater and aquatic life). A higher downward drainage rate is used to develop guidelines for deeper receptors, such as the DUA. For Subregions that have a potential net moisture deficit (*e.g.*, Mixedgrass), or a negative CMI, an upward drainage category is considered for shallower receptors (discharge condition). A downward drainage category is considered for deeper receptors such as the DUA. While this implies that salts are simultaneously moving upward and downward at the same time, the assumption is made to ensure that the modelled results protect against a change in plant conditions or land use that could turn a discharge area into a recharge area. For example, O'Connell *et al.* (2003) determined that land left in fallow for an extended period can increase deep drainage, a land management practice that may occur in agricultural areas of Alberta. Furthermore, land in Semi-Arid areas can shift from discharge to recharge conditions if native grassland and shrubland is converted to agricultural crops, due in part to a lower density of plant cover and greater bare soil exposure, as was observed in the High Plains (US) and Great Plains of North America (Scanlon *et al.*, 2005; van der Kamp *et al.*, 2003).

Drainage categories in the SST are shown below as a function of CMI and soil texture. The highest downward drainage rates were associated with Foothills and Rocky Mountain Natural Regions and the Subalpine Subregion, and default drainage rates are downwards for these Regions. Similarly, for Boreal Forest Subregions containing extensive stands of conifers (Central Mixedwood, Lower and Upper Boreal Highlands), default drainage rates were downward, although at slower rates compared to the Foothills and Rocky Mountain Regions. The lowest drainage rates were for the Grassland Natural Region, and both upward and downward drainage rates were used to protect against changes in land use (*e.g.*, native grassland versus agricultural crop). Similarly, for Parkland and certain Boreal Forest Subregions where the water balance is near neutral, an upward and downward drainage rate was used. The downward default drainage rate for these Subregions is higher that Subregions within the Grassland Natural Region, due to greater precipitation rates and lower potential evapotranspiration.



Measured Vertical Hydraulic Gradient

By default, drainage categories are determined in the SST based on site location and Subregion information. In addition, drainage categories may be determined from supplementary data such as a vertical hydraulic gradient from nested wells. Under Tier 2B, it is possible to use site-specific nested monitoring well data to modify the default drainage rate for calculating root zone, shallow groundwater, and DUA Tier 2 guidelines, by adjusting the vertical hydraulic gradient. There are specific requirements for installing the wells and for data collection, which are discussed under minimum investigation requirements. An adjustment based on nested wells is allowed for situations where the default drainage categories may not be appropriate for a particular site due to local conditions such as topography, micro-climate, *etc*. Drainage categories that are used by the SST based on a particular site-specific vertical hydraulic gradient are shown below. For a single site-specific vertical hydraulic gradient entered into the SST, there will be two drainage rates used to calculate guidelines - a lower and higher drainage rate. The lower (slower) drainage rate is used to develop SRGs for receptors in closer proximity to the soil surface (*e.g.*, root zone). The higher (faster) drainage rate is used to develop SRGs for receptors located at depth (*e.g.*, DUA). The use of two drainage rates was considered appropriate given variability in vertical hydraulic gradient field measurements.

Vertical saturated hydraulic conductivity cannot be adjusted under Tier 2A or 2B based on hydraulic conductivity measurements in monitoring wells (*e.g.*, slug tests) or from soil core (*e.g.*, Shelby tubes) leaching column laboratory work. Site-specific vertical hydraulic conductivity information can be incorporated as part of a Tier 2C assessment.

LOWER DRAINAGE RATE CATEGORIES BASED ON SITE-SPECIFIC VERTICAL HYDRAULIC GRADIENT (ROOT ZONE PROTECTION)		
Vertical Gradient	**Coarse**	**Fine**
< 0	-1 mm/yr	-1 mm/yr
0 to 0.01	1 mm/yr	1 mm/yr
≥ 0.01 to 0.099	6 mm/yr	1 mm/yr
≥ 0.1	15 mm/yr	6 mm/yr
HIGHER DRAINAGE RATE CATEGORIES BASED ON SITE-SPECIFIC VERTICAL HYDRAULIC GRADIENT (DUA PROTECTION)		
Vertical Gradient	**Coarse**	**Fine**
< 0	1 mm/yr	1 mm/yr
0 to 0.01	6 mm/yr	1 mm/yr
≥ 0.01 to 0.099	15 mm/yr	6 mm/yr
≥ 0.1	80 mm/yr	15 mm/yr

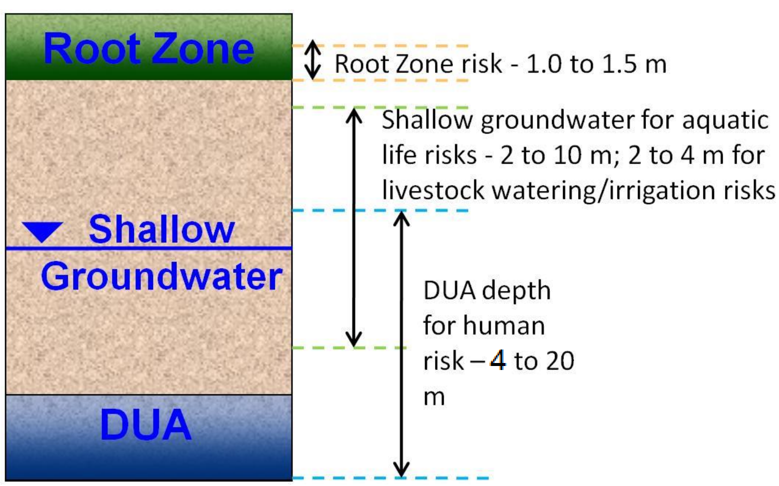
Negative convention means upward transport (discharge)
Positive convention means downward transport (recharge)

Although sands have limited capillary rise, coarse soils in Alberta may contain a significant silt content that has the capacity to induce capillary rise-related salt transport to the soil surface. As a result, the potential for upward transport is considered for coarse as well as fine soils.

2.6.7 Key Breakthrough Curve Depths

The Hydrus-1D model was used to estimate break through curves at specific vertical soil profile depths from which guidelines are calculated for receptors and pathways of concern:

1. root zone (1.0 to 1.5 m);
2. shallow groundwater depth for aquatic life risks (variable from 2 to 10 m);
3. 2 to 4 m depth for the dugout scenario and livestock watering/irrigation risks; and,
4. DUA depth for human risks from consumption of DUA water (variable from 4 to 20 m).



2.6.8 Shallow Groundwater Table Depth

The depth of shallow groundwater is an important input parameter. It is used to determine the following: 1) breakthrough depth for developing soil and groundwater guidelines protective of aquatic life receptors; 2) depth interval over which a chloride plume disperses in groundwater (saturated zone) prior to reaching a DUA; and, 3) whether the dugout scenario guidelines apply (*i.e.*, water table is within the range of $\leq$ 2 to 4 m). For a Tier 2A approach, the user can choose a depth range for the water table dropdown list in the SST program (*e.g.*. 2 to 4 m), to account for uncertainty in identifying the water table depths in borehole logs (absence of groundwater monitoring wells). For Tier 2B, measured groundwater elevations from monitoring wells are used.

2.6.9 Buffer Concept for the Root Zone

Guidelines for plant receptors in Natural, Agricultural and Residential/Parkland land uses are calculated based on preventing naturally occurring plus facility related salinity from exceeding a relevant site-specific upper bound of the ESRD (2014a) Tier 1 root zone salinity rating categories (*i.e.*, Good, Fair, Poor, Unsuitable) within the 1.0 to 1.5 m depth interval. Guidelines are similarly developed for Industrial/Commercial land use, with exception of the Good soil quality category where the CCME Industrial root zone guideline is used. A buffer is calculated using background information for determining the allowable contribution of chloride towards root zone salinity current day and in the future.

The approach for calculating the salinity buffer and protection of the root zone from excess salinization is to use the 95th percentile EC value from background locations at depths from 1.0 to 1.5 m below ground surface to determine the ESRD (2014a) soil quality rating category for the root zone as per Tier 1. For example, if the 95th percentile was 4.2 dS/m, this would be in the Fair category (3 to 5 dS/m). The upper bound of the category (5 dS/m for Fair soils) is selected as the root zone guideline (from 1.0 to 1.5 m) and used for calculating a buffer. The arithmetic average background root zone salinity (from 1 to 1.5 m) is also calculated. The size of the buffer is then determined from the difference in EC from the root zone guideline (upper boundary of the relevant Tier 1 category) and the arithmetic average. For example, if the arithmetic average is 2.7 dS/m, the buffer is equal to 2.3 dS/m (5 dS/m (upper bound of the Fair category) – 2.7 dS/m (arithmetic mean)). The SST does not address issues related to root zone salinity at depths shallower than 1.0 m – Tier 1 guidelines must be met for this depth interval in a manner that will lead to successful reclamation.

The EC buffer is calculated automatically in the SST based on the background statistics calculated by the SST. The EC buffer that is used to determine the acceptable contributions of chloride that will not lead to an exceedence of the ESRD soil quality category according to the following equation that is built into the SST:

$$EC_{BUF} = \mathrm{EC}_{\mathrm{TIER\ 1\ BACK}} - EC_{AVG\ BACK}$$

Where:

EC_{BUF}	=	EC buffer (dS/m) allocated to avoid an exceedence of Tier 1 across the deeper portion of the root zone due to upward transport of subsoils impacted by chloride (1.0 to 1.5 m)
$EC_{TIER\ 1\ BACK}$	=	EC Tier 1 guideline for the root zone in background soils (upper boundary of the appropriate subsoil (1.0 to 1.5 m) Tier 1 category)
$EC_{AVG\ BACK}$	=	average background EC (dS/m) for the site

For the Unsuitable soil quality category, the EC buffer is calculated from the 95th percentile EC value and the average background EC value for the site because no upper bound exist for the Unsuitable category (*i.e.*, Unsuitable EC is > 10 dS/m). The following equation is built into the SST:

$$EC_{BUF} = \mathrm{EC}_{95\mathrm{th}\ \%\mathrm{ile}} - EC_{AVG\ BACK}$$

Where:

EC_{BUF}	=	EC buffer (dS/m) allocated to avoid an exceedence of Tier 1 across the deeper portion of the root zone due to upward transport of subsoils impacted by chloride (1.0 to 1.5 m)
$EC_{95th\ \%ile}$	=	EC Tier 1 guideline for the root zone (upper boundary of the appropriate subsoil (1.0 to 1.5 m) Tier 1 Tier 1 category)
$EC_{AVG\ BACK}$	=	average background EC (dS/m) value for the site

It should be noted that if two samples are available from the same borehole within the 1 to 1.5 m depth interval, their data should be averaged and considered as a single data point for calculating the EC guideline and buffer.

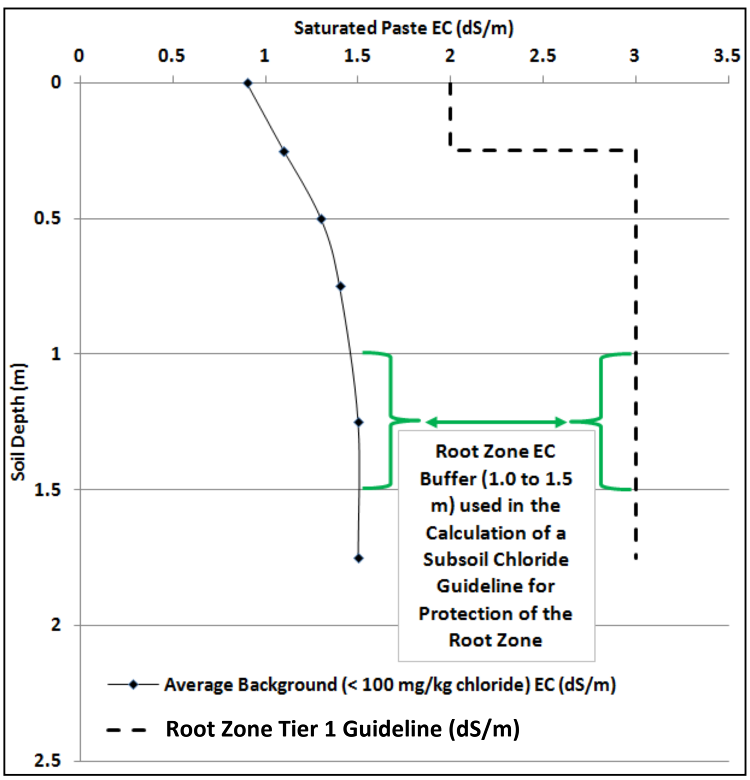
Examples of root zone EC guideline and buffer calculations that determine the subsoil chloride guideline for protection of the root zone are provided below.

Example #1: Root Zone Guideline/Buffer for Good Soils			
Borehole	Depth Interval (m)	Saturated Paste EC	Chloride (mg/kg)
BH10-1	1.25	1.1	80
BH10-2	1	0.6	22
BH10-4	1.5	1.3	64
BH10-8	1.25	2.2	100
n		4	
Arithmetic Average		1.3	
Standard Deviation		0.7	
95th Percentile		2.1	
Root Zone (1 to 1.5 m) Guideline (based on SCARG and the 95th Percentile)		3	
Root Zone EC Buffer (Guideline - Average)		1.7	

Example #2: Root Zone Guideline/Buffer for Poor Soils			
Borehole	Depth Interval (m)	Saturated Paste EC	Chloride (mg/kg)
BH10-1	1	4.4	22
BH10-2	1	6.6	22
BH10-4	1.5	8.2	64
BH10-8	1.25	9.1	100
BH10-9	1.5	3.3	18
BH10-11	1	4.8	91
BH10-14	1.25	5.1	33
n		7	
Arithmetic Average		5.9	
Standard Deviation		2.1	
95th Percentile		8.8	
Root Zone (1 to 1.5 m) Guideline (based on SCARG and the 95th Percentile)		10	
Root Zone EC Buffer (Guideline - Average)		4.1	

Example #3: Root Zone Guideline/Buffer for Unsuitable Soils			
Borehole	Depth Interval (m)	Saturated Paste EC	Chloride (mg/kg)
BH10-1	1	4.4	22
BH10-2	1	4.1	22
BH10-4	1.5	13	64
BH10-8	1.25	11	100
BH10-9	1.5	10.6	18
BH10-11	1	5.8	91
BH10-11	1	4.1	91
BH10-16	1	4	29
n		8	
Arithmetic Average		7.1	
Standard Deviation		3.8	
95th Percentile		12.3	
Root Zone (1 to 1.5 m) Guideline (based on SCARG and the 95th Percentile)		12.3	
Root Zone EC Buffer (Guideline - Average)		5.2	

Note for Good soils, four background samples from four different boreholes (total of four or more samples) are required as a minimum collected over the depth interval of 1.0 to 1.5 m (maximum of 25 background samples can be entered); for Fair, Poor, and Unsuitable soils, an minimum of six samples is required from six different boreholes (total of six or more samples) over the depth interval of 1.0 to 1.5 m (maximum of 25 samples). The SST is run separately for each sub-area if more than one background environment is defined. It is recommended that more than 6 background boreholes be drilled (e.g., n=8), samples can be stored, and analyzed at a later date in the event that one or more of the intended background boreholes are impacted.



Outliers can contribute to the misrepresentation of data for guideline calculation purposes. An outlier analysis is required prior to the data being entered in the SST (identifies values which are greater than 2 x Standard Deviation + Arithmetic Mean). Values greater than the outlier should result in one of the following actions:

1. The data point is removed from the data set so no outliers are used (maximum of two iterations); or,
2. More background investigations are conducted to determine whether there are two distinct background environments or whether a larger dataset is required to better reflect the variability in background salinity.

An example of an outlier analysis is provided below, using information from background boreholes. The initial dataset contained 8 background boreholes with chloride concentrations less than 100 mg/kg. After the first outlier analysis was conducted, the data for BH10-1 was identified as an outlier, and removed from the dataset. The last (second) outlier iteration was conducted and BH10-14 was identified as an outlier, and removed from the dataset. This dataset suggests there are areas of relatively high natural salinity, which may or may not be widespread in nature. The locations of background boreholes should be re-examined to ensure there is proper spatial weighting and that the distribution of background borehole locations is representative of the distribution of background areas of high, moderate, and low salinity.

Initial Background Dataset - Outlier Iteration #1			
Borehole	Depth Interval (m)	Saturated Paste EC	Chloride (mg/kg)
BH10-1	1.25	14	80
BH10-2	1	2	22
BH10-4	1.5	2	64
BH10-8	1.25	2.5	100
BH10-9	1.5	3.8	18
BH10-11	1	3.3	91
BH10-14	1.25	8.8	33
BH10-16	1	4	29
n		8	
Arithmetic Average		5.1	
Standard Deviation		4.2	
95th Percentile		12.2	
Root Zone (1 to 1.5 m) Guideline (based on SCARG and the 95th Percentile)		12.18	
2x Standard Deviation		8.5	
Outlier Threshold (2x Standard Deviation + Mean)		13.5	
Outliers (n)?		Yes (1; BH10-1)	

Initial Background Dataset - Outlier Iteration #2			
Borehole	Depth Interval (m)	Saturated Paste EC	Chloride (mg/kg)
BH10-1	1.25	14	80
BH10-2	1	2	22
BH10-4	1.5	2	64
BH10-8	1.25	2.5	100
BH10-9	1.5	3.8	18
BH10-11	1	3.3	91
BH10-14	1.25	8.8	33
BH10-16	1	4	29
n		7	
Arithmetic Average		3.8	
Standard Deviation		2.4	
95th Percentile		7.4	
Root Zone (1 to 1.5 m) Guideline (based on SCARG and the 95th Percentile)		10	
2x Standard Deviation		4.7	
Outlier Threshold (2x Standard Deviation + Mean)		8.5	
Outliers (n)?		Yes (1; BH10-14)	

Final Background Dataset - Post Outlier Analysis			
Borehole	Depth Interval (m)	Saturated Paste EC	Chloride (mg/kg)
BH10-1	1.25	14	80
BH10-2	1	2	22
BH10-4	1.5	2	64
BH10-8	1.25	2.5	100
BH10-9	1.5	3.8	18
BH10-11	1	3.3	91
BH10-14	1.25	8.8	33
BH10-16	1	4	29
n		6	
Arithmetic Average		2.9	
Standard Deviation		0.9	
95th Percentile		4.0	
Root Zone (1 to 1.5 m) Guideline (based on SCARG and the 95th Percentile)		5	
2x Standard Deviation		1.8	
Outlier Threshold (2x Standard Deviation + Mean)		4.7	
Outliers (n)?		No	

Clear documentation of outlier analysis work and values excluded from the background dataset must be provided.

2.6.10 Importing Data from Excel

Data for background soil salinity can be imported into SST program from MS Excel. Data can be imported column by column into the tool (or the entire dataset as a block) and completing a copy/paste – do not highlight the header rows in the SST when pasting data. Saturation percentage values must be entered as non-decimal numbers (*e.g.*, 45 instead of 0.45 for a 45% saturation percentage). Note that soil depth intervals must be entered as a single value (*e.g.*, 1.25 m) rather than a range (*e.g.*, 1.1 – 1.25 m).

2.7 Root Zone Scenarios

There are three root zone scenarios that can be run in the SST:

1. Unimpacted root zone;
2. Impacted root zone; and,
3. Excavation and backfill of root zone.

Each scenario can result in a different subsoil chloride SRG for protection of the deep root zone (1.0 to 1.5 m). Multiple scenarios can be considered for a single site, depending on the spatial distribution of chloride impacts.

2.7.1 Unimpacted Root Zone

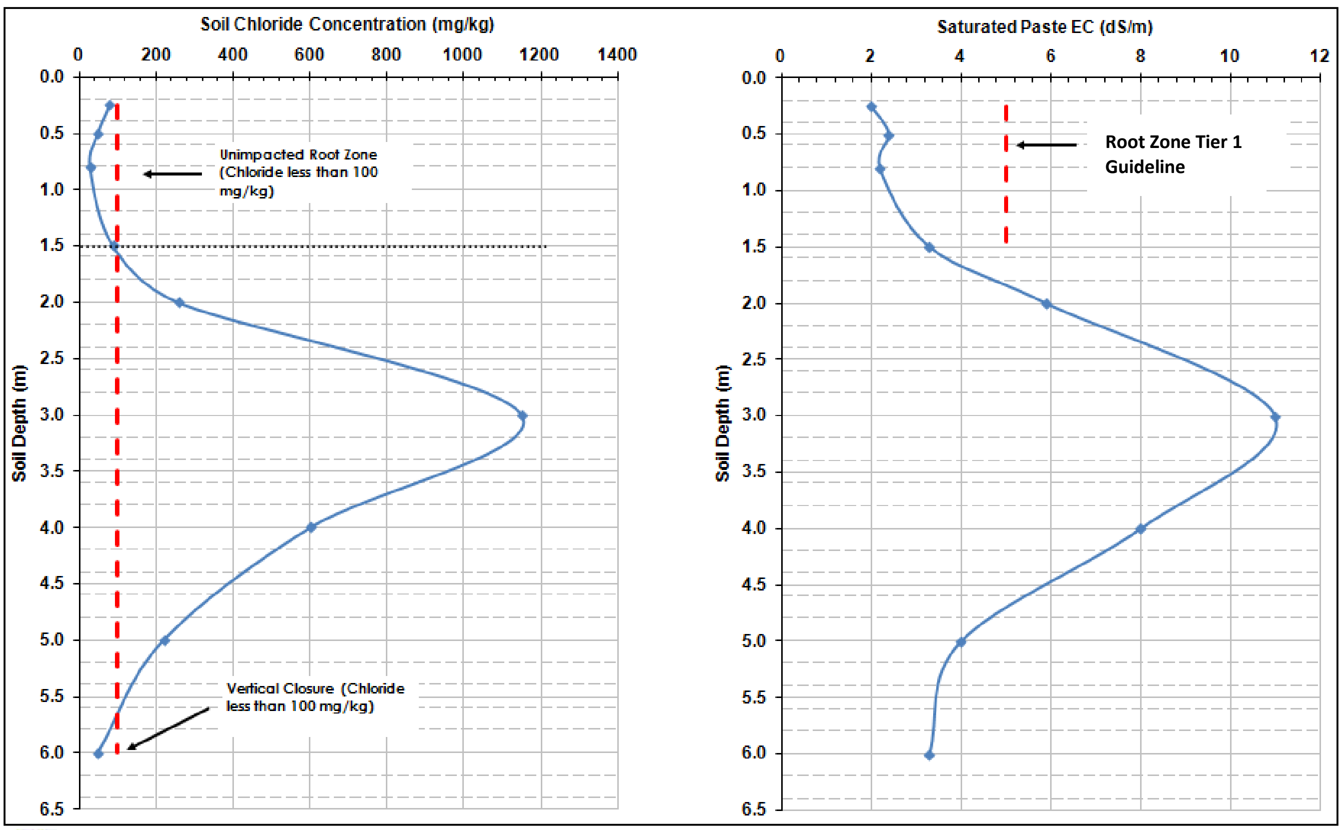
An unimpacted root zone is defined as soils from 1.0 to 1.5 m with chloride concentrations less than 100 mg/kg and with EC values lower than the applicable Tier 1 guideline for the site. The SST will calculate automatically a subsoil chloride SRG based on background root zone EC statistics, the relevant Tier 1 EC guideline for the root zone, and the future contribution of subsoil chloride discharge into the root zone resulting in increased root zone EC. Essentially, the EC_{BUF} parameter described previously is equal to the $EC_{FUTURE\ Cl}$ parameter described below. In other words, the buffer represents the amount of subsoil chloride that can be transported into the root zone in the future, without resulting in average EC values exceeding the Tier 1 guideline determined from background soil chemistry data. The following equation is used to express an unimpacted root zone scenario:

$$EC_{AVG\ BACK} + \mathrm{EC}_{\mathrm{FUTURE\ Cl}} \leq= EC_{Tier\ 1}$$

Where,

$EC_{AVG\ BACK}$	=	average background EC (dS/m) from 1.0 to 1.5 m based on background borehole data
$EC_{FUTURE\ Cl}$	=	increase in EC due to subsoil (> 1.5 m) chloride discharge into the deeper root zone (1.0 to 1.5 m) within the impacted area
$EC_{Tier\ 1}$	=	upper bound of the root zone Tier 1 category determined from the 95th percentile of background data (for the deeper root zone receptor in the SST (1.0 to 1.5 m))

For an unimpacted root zone scenario, the root zone chloride concentrations will be less than 100 mg/kg and the root zone EC will be below the Tier 1 guideline. An example of an unimpacted root zone is shown below.



Vertical graphical profiles of chloride and EC data should be included in guideline calculation supporting documentation to facilitate the regulatory review process.

2.7.2 Impacted Root Zone

The impacted root zone analysis is applied when there are chloride impacts (> 100 mg/kg) in the rooting zone (1.0 to 1.5 m), but the root zone EC does not exceed the Tier 1 SCARG salinity guideline, and some buffer remains for the future contribution from subsoil chloride (below 1.5 m) discharging into the root zone. The SST will calculate automatically a subsoil chloride SRG based on background root zone EC statistics and the calculated (outside of the SST) 95th percentile EC due to the presence of chloride impacts in the root zone. An impacted root zone chloride concentration is entered into the SST, which is automatically converted to an equivalent EC. The SRG is also based on the future contribution to root zone EC due to upward transport (discharge) of subsoil (> 1.5 m) chloride. The following equation is used to express an impacted root zone scenario:

$$EC_{Avg\ Back} + \mathrm{EC}_{\mathrm{Current\ Cl}} + \mathrm{EC}_{\mathrm{Future\ Cl}} \leq EC_{Tier\ 1}$$

Where,

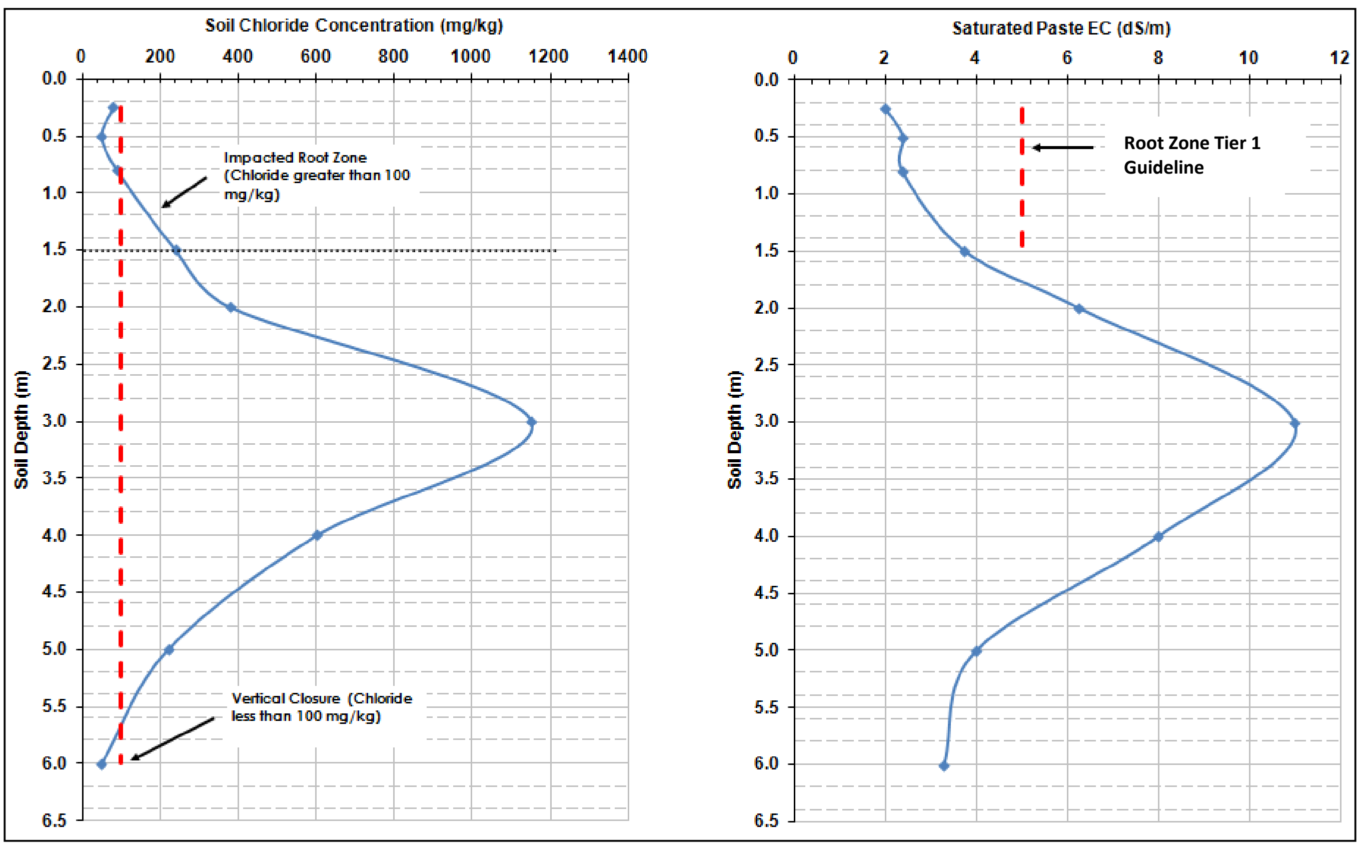
$EC_{AVG\ BACK}$ = average background EC from 1.0 to 1.5 m based on background borehole data

$EC_{CURRENT\ CI}$ = EC due to current chloride impacts (> 100 mg/kg) in the root zone from 1.0 to 1.5 m

$EC_{FUTURE\ CI}$ = increase in EC due to subsoil (> 1.5 m) chloride discharge into the deeper root zone (1.0 to 1.5 m) within the impacted area

$EC_{Tier\ 1}$ = upper bound of the root zone Tier 1 category determined from the 95th percentile of background data (for the deeper root zone receptor in the SST (1.0 to 1.5 m))

For an impacted root zone scenario, the root zone chloride concentrations will be greater than 100 mg/kg, and the root zone EC will be below the Tier 1 SCARG guideline. An example of an impacted root zone is shown below.



2.7.3 Excavation and Backfill of Root Zone

The excavation and backfill scenario is used for situations where chloride impacts in the root zone are sufficiently elevated that they lead to an exceedence of the root zone SCARG guideline (from 1.0 to 1.5 m), indicating there is no remaining buffer for future EC contribution due to subsoil chloride discharging into the root zone, in which case a subsoil root zone chloride SRG cannot be calculated. The EC of backfill material will influence the subsoil chloride SRG produced by the SST for protection of the root zone, where a lower backfill EC results in a greater subsoil chloride SRG due to a greater EC buffer within the root zone. The SST will calculate automatically a subsoil chloride SRG using the average EC of the backfill material in the root zone, as input into the SST. The following equation is used to express an excavation and backfill of the root zone scenario:

$$EC_{AVG\ FILL} + \mathrm{EC}_{\mathrm{FUTURE\ Cl}} \leq EC_{Tier\ 1}$$

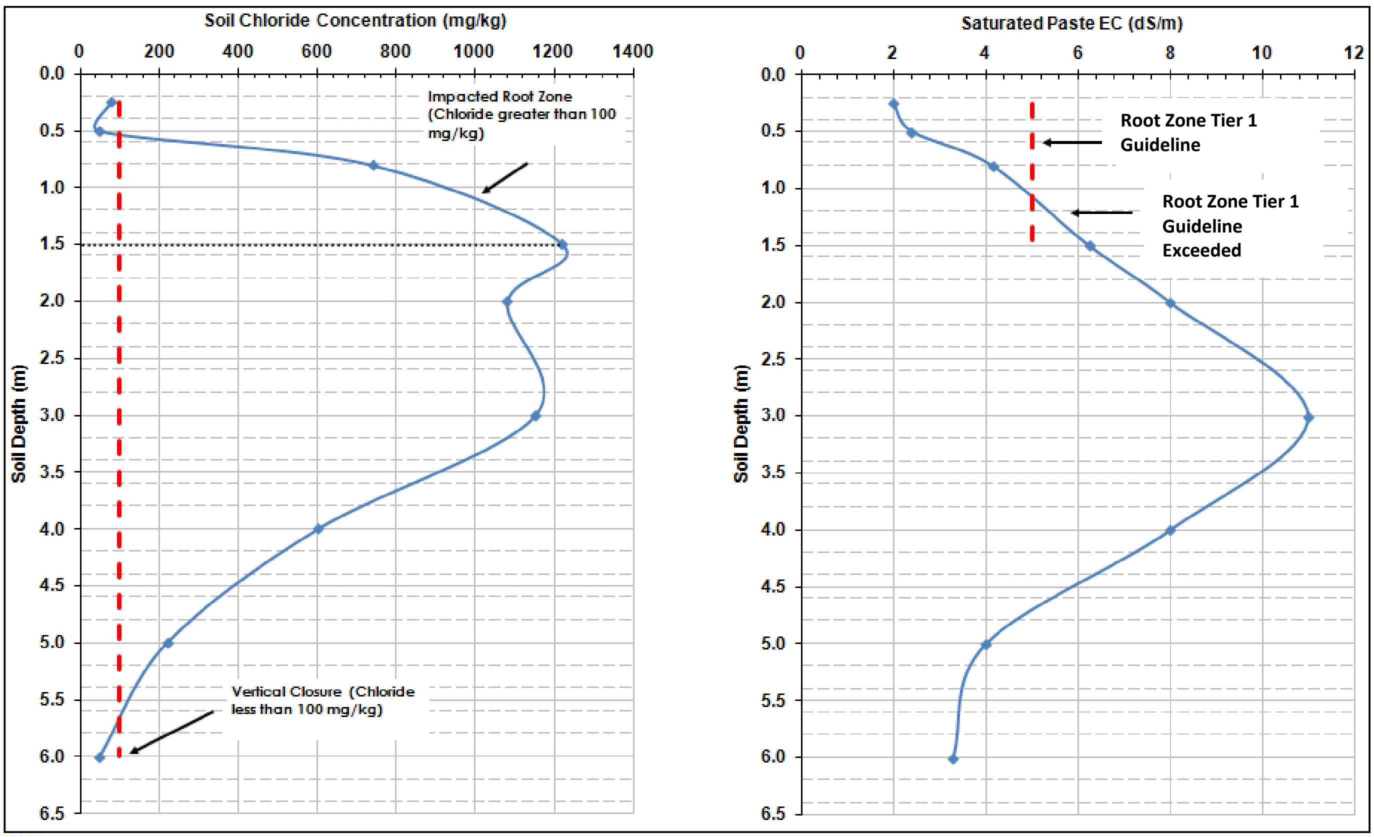
Where,

$EC_{AVG\ FILL}$ = average backfill material EC placed from 1.0 to 1.5 m based on backfill chemistry sampling

$EC_{FUTURE\ Cl}$ = increase in EC due to subsoil (> 1.5 m) chloride discharge into the deeper root zone (1.0 to 1.5 m) within the impacted area

$EC_{Tier\ 1}$ = upper bound of the root zone Tier 1 category determined from the 95th percentile of background data (for the deeper root zone receptor in the SST (1.0 to 1.5 m))

For the excavation and backfill scenario, the root zone EC is determined from chemistry data produced from the analysis of backfill material soils for salinity parameters. An example of an excavation and backfill scenario is provided below. The charts show root zone EC exceedences above the Tier 1 guideline due to elevated chloride from 1.0 to 1.5 m, triggering the need for excavation in order to meet Tier 1 guidelines for the root zone and to allow for a buffer for future contribution of chloride transported upward from subsoil.



Samples must be collected from backfill material and analyzed for salinity and texture parameters. Backfill chemistry and texture must be documented. The texture and chemistry of the backfill should be similar to native background material at an equivalent depth. For example, if the average background clay content of site is less than 18% from 1.0 to 1.5 m, then use backfill material of the same texture. This will allow for consistent predictions using the SST and the two default soil categories (fine and coarse). Where possible, backfill chemistry on average should be similar to background, and SRGs guidelines should be calculated using measured backfill EC. Contact ESRD or review appropriate ESRD guidance regarding reclamation requirements for the 0 to 1.5 m depth interval.

2.7.4 Contribution from Subsoil Sulphate toward Future Root Zone Salinity

The SST provides a subsoil chloride guideline and does not consider the future transport of subsoil sulphate, carbonate, and bicarbonate (naturally occurring anionic species) into the 1.0 to 1.5 m depth interval, from subsoil (> 1.5 m) for guideline calculation. There are three distinct root zone scenarios where this could have implications: 1) unimpacted root zone; 2) impacted root zone; and, 3) excavation and backfill.

For the unimpacted and impacted root zone scenarios, the influence of subsurface naturally occurring ion concentrations on subsoil chloride guidelines will be negligible. Background root zone EC levels are based on background concentrations of naturally occurring ions and are considered reflective of historical trends of ion movement in soil and groundwater. If significant migration of subsurface ions into the deeper root zone interval occurs in the future, it will be in both impacted and background locations and EC would similarly increase in the impacted and surrounding area. The potential exists that elevated sodium and chloride concentrations in the impacted area has resulted in an increased solubilization of precipitated naturally occurring ions, and some additional increase (above background) in root zone EC could be expected.

For the excavation and backfill scenario, if the backfill material is of lower EC than background, the possibility exists that there may be an additional contribution towards root zone EC at 1.0 to 1.5 m from the upward migration (discharge) of naturally occurring salt ions. This additional contribution is not taken into consideration in the SST due to several factors:

1. Sulphate and carbonate ions are expected to migrate at a slower rate than chloride under conditions where calcium concentrations are elevated because precipitation with calcium is likely to occur. However, in soils where calcium concentrations are low, minimal precipitate formation is expected to occur, and in these situations, the average backfill EC should be similar to the average background EC;

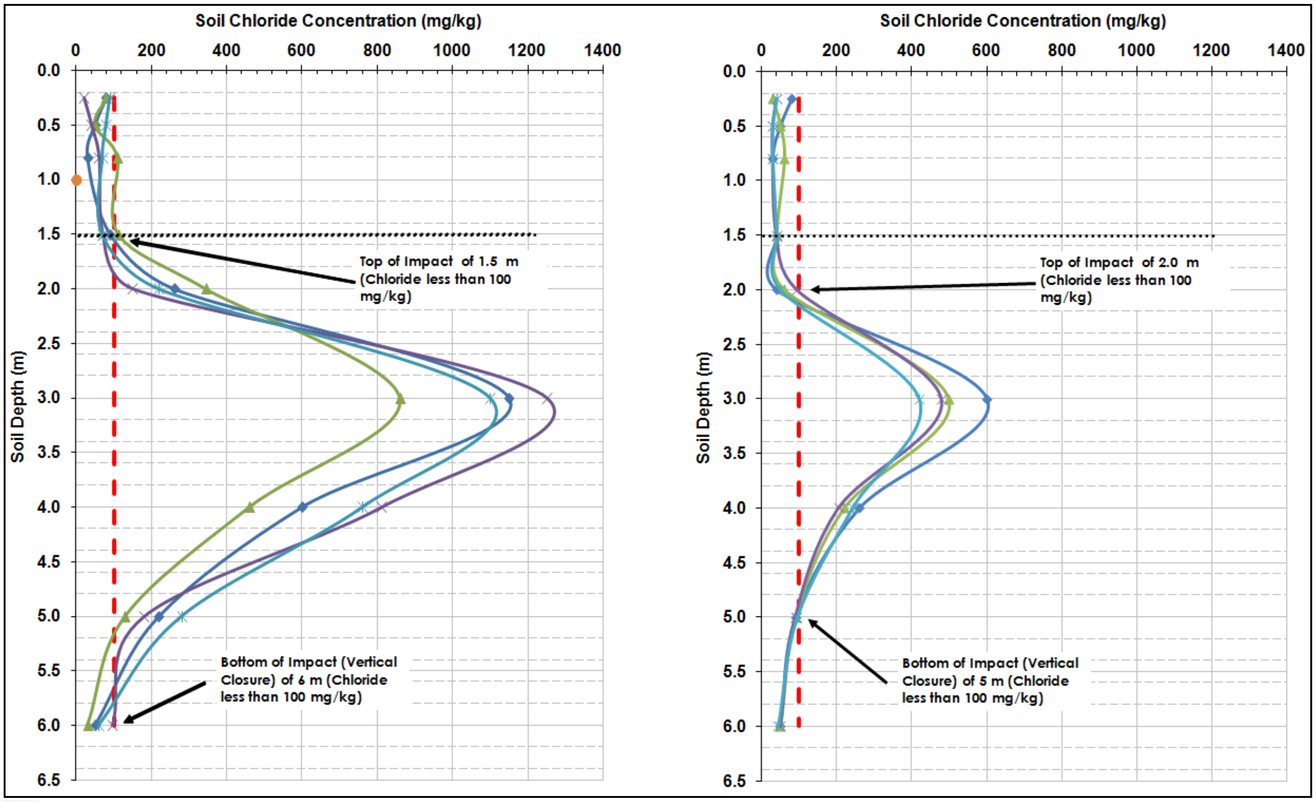
2. The root zone guidelines are based on contribution towards salinity at the deeper portion of the root zone (1.0 to 1.5 m) – providing the site is properly reclaimed, the presence of healthy plant growth is expected to minimize migration into shallower rooting depths; and,

3. In situations where the water table is relatively deep (*e.g.*, 6 m or greater), and/or the site is in a recharge area (due to Natural Subregion (*e.g.* foothills) or a nested well(s) demonstrates a downward vertical gradient), the risk is expected to be relatively low.

In situations with a shallow water table and discharge conditions where background salinity levels are relatively high, good plant growth will be required regardless to maintain low root zone concentrations, and equivalent land use is expected to consistent with the planting of salt tolerant species found in the background areas.

2.8 Vertical Chloride Impact Thickness (Top and Bottom of Impact)

Subsoil chloride guidelines calculated by the SST, for all receptors of concern, are based in part on the vertical mass (or concentration distribution by depth) of salinity impacts for a given site, or site area. An example of vertical subsoil chloride profiles is provided below. To ensure the mass of salt is estimated with acceptable accuracy, sampling intervals must be chosen to indentify changes in salt concentration with depth and the vertical extent must be delineated. Chloride concentrations less than 100 mg/kg are considered indicative of vertical closure, from which the top and bottom of impact can be defined. Vertical chloride profiles are typically grouped based on common top and bottom of impact values, magnitude of impact, and root zone scenario (discussed previously). In some cases, a data point with a slight exceedence of 100 mg/kg chloride can be used to define closure. Professional judgment is required when incorporating data points with chloride greater than 100 mg/kg as an indication of closure.



These charts provide suitable examples for the documentation of chloride chemistry in soil, highlighting vertical closure, grouped by unique areas of impact.

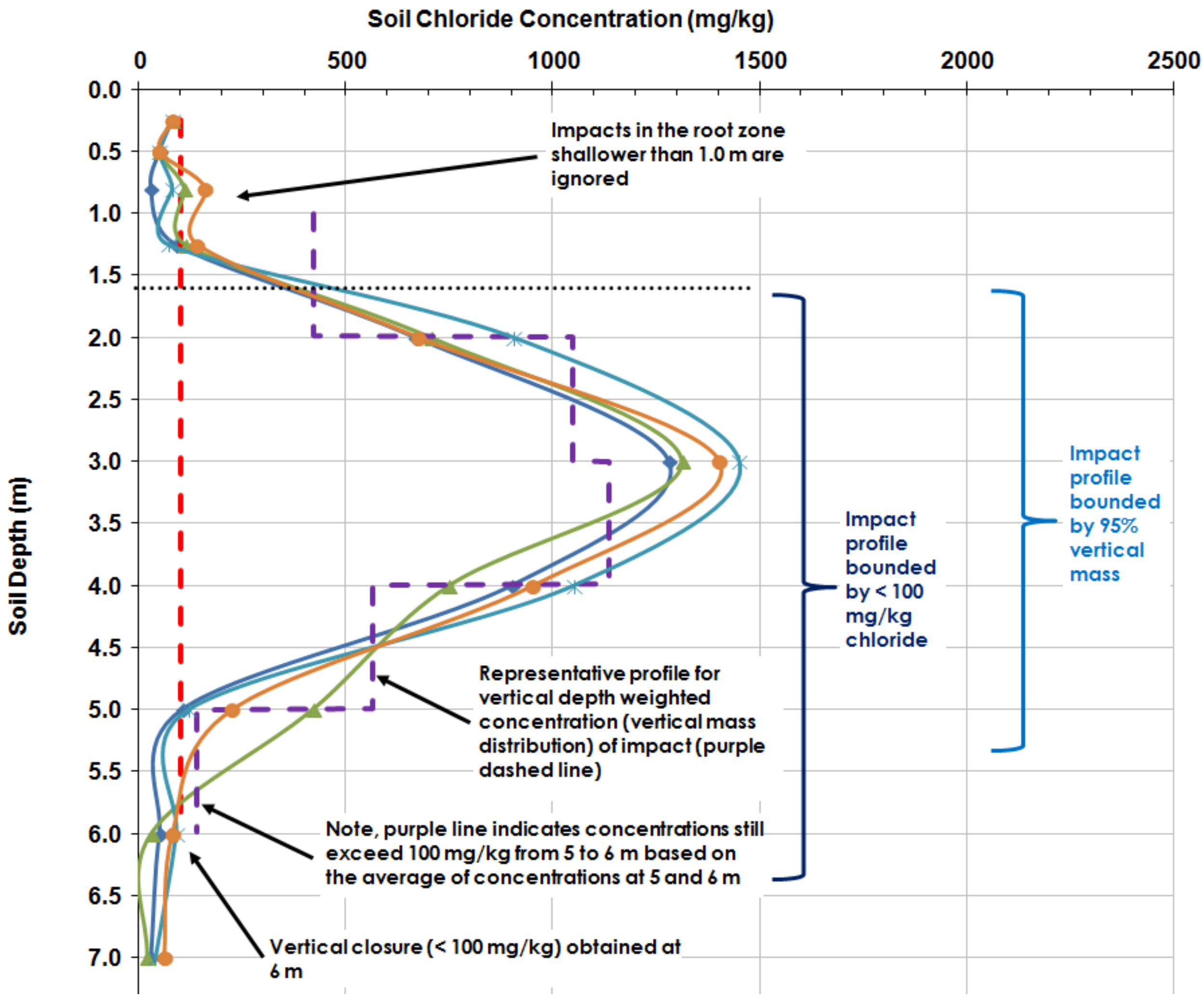
Scientific rationale should be provided and documented for review, explaining if and why any values greater than 100 mg/kg were used as an indication of chloride closure.

Calculation of Top or Bottom of Impact using 95% Vertical Mass Calculation

The top and bottom of impact can be refined by determining 95% of the vertical mass, per SubArea, or for a site if one SubArea is considered. *A 95% lateral mass calculation can not be conducted with Versions 2.5.3 of the SST.* A greater number of boreholes is required to define the 95% vertical mass. This is considered an advanced calculation required outside of the SST – the calculation must be provided if the top and bottom of impact are based on 95% of vertical mass rather than chloride concentrations < 100 mg/kg. Four boreholes are required per SubArea when a 95% vertical mass calculation is to be conducted. An example calculation with supporting data is provided below. Four chloride profiles (boreholes) are shown for a SubArea, with chloride concentrations ranging up to 1,450 mg/kg. Chemistry data is averaged across the four boreholes in a depth-wise manner, and also between sample depths for each borehole. The top of subsoil impact was 1.5 m and the bottom of impact was 6.0 m (closure obtained at 6 m with chloride < 100 mg/kg for all boreholes/profiles). It is assumed that subsoil samples (>1.5 m) have been taken from 2 m, 3 m, 4 m, 5 m, 6 m, and 7 m. Data is included from the base of the root zone (*e.g.*, 1.0 to 1.5 m) and combined with data from 2.0 m. Data at 6 m is included because it represents the depth at which closure was empirically obtained. While this may appear counterintuitive, there is an absence of data between 5.0 and 6.0 m and it must be assumed that chloride concentrations exceed 100 mg/kg to a depth of 5.9 m (just above the sample depth indicating closure). The average concentration from 5.0 to 6.0 m is determined from the average of data from 5.0 m and 6.0 m. Data is not included for the 0 to 1.0 m and 7 m and deeper depths (data not included in the calculation is shown as grey text in the table below – data used is shown in black text).

A graphically representation of this concept is provided in the diagram below by the dashed purple line, and supporting information is tabulated. Average concentrations are calculated for the following intervals: 1.0 to 2.0 m; 2.0 to 3.0 m; 3.0 to 4.0 m; 4.0 to 5.0 m; 5.0 to 6.0 m. The 4.0 to 5.0 m concentration would be the average of borehole data for this SubArea from 4.0 m and 5.0 m (in the example below, this is the average of 913 and 218 mg/kg, or 565 mg/kg). The purple line represents these average concentrations for each sample depth interval, averaged across the four boreholes (*e.g.*, 1 to 2 m – 421 mg/kg; 3 to 4 m – 1137 mg/kg; 4.0 to 5.0 m – 565 mg/kg; *etc.*). Using the 95% mass concept, the

5.0 to 6.0 m depth interval was found to represent 4.2% of the vertical mass, which is less than 5%. As a result, the bottom of impact can be entered into the SST as 5.0 m, providing sufficient documentation is submitted (the example tables and diagram below would be considered sufficient).



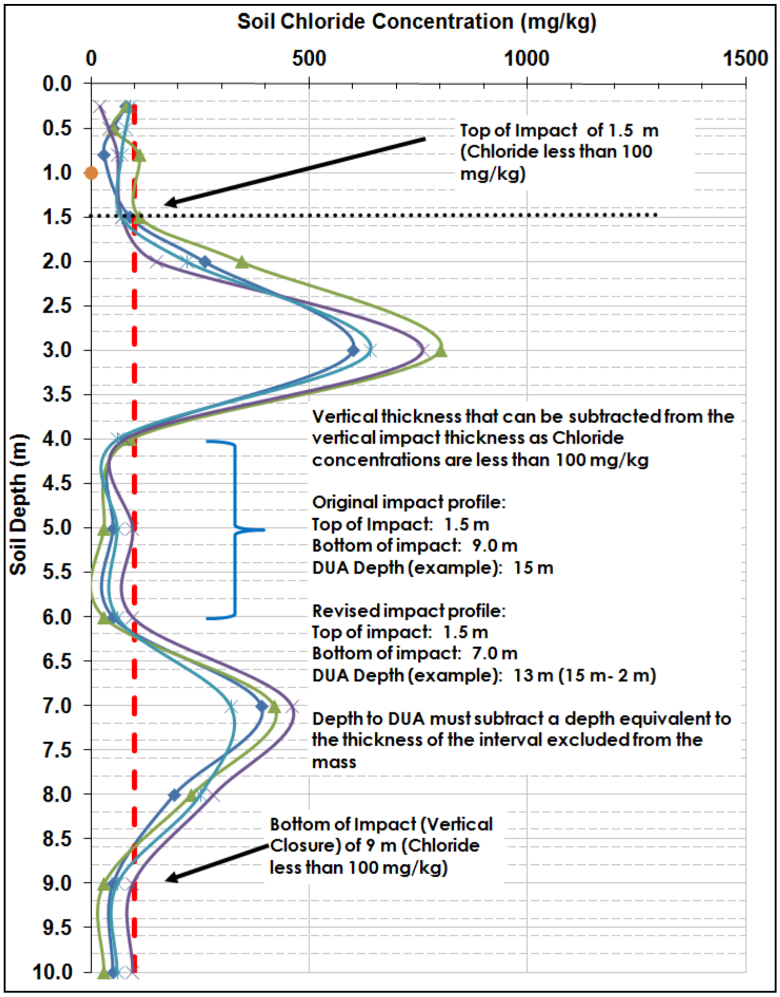
95% Vertical Mass Calculation

	BH-01	BH-02	BH-03	BH-04	Average			
Sample Depth (m)	Chloride (mg/kg)	Chloride (mg/kg)	Chloride (mg/kg)	Chloride (mg/kg)	Chloride (mg/kg)	Sample Depth Interval (m)	Average for Depth Interval (mg/kg)	Depth Weighted Vertical Mass for Each Interval (%)
0.25	80	80	80	80				
0.5	50	50	50	50				
0.8	30	110	80	160				
1.0 to 1.5	90	112	70	140	103	1 to 2 m	421	**12.7%**
2.0	669	705	905	675	739	2 to 3 m	1050	**31.7%**
3.0	1280	1312	1450	1402	1361	3 to 4 m	1137	**34.3%**
4.0	900	750	1050	952	913	4 to 5 m	565	**17.1%**
5.0	105	420	120	225	218	5 to 6 m	140	**4.2%**
6.0	50	30	90	80	63			
7.0	30	20	40	60				
	SUM (Impacts from 1.0 to 6 m)				**3396**		**3313**	**100%**

For 95% vertical mass calculations, tables and diagrams such as those provided above are required to provide sufficient documentation for review purposes.

<u>Subsoil Depth Intervals with Minimal Impacts</u>

In situations where a subsoil depth interval has chloride concentrations less than 100 mg/kg, but is bounded by impacted soils above and below, this interval can be excluded from the vertical mass and a shallower bottom of impact can be input into the SST. An example is provided below. Chloride concentrations from 4.0 to 6.0 m are less than 100 mg/kg. This situation may occur if one area with shallow impacts overlies a deeper groundwater plume of chloride. The top of impact is 1.5 m and the bottom of impact is 9.0 m. The bottom of impact input parameter can be revised to 7.0 m by subtracting the unimpacted zone from 4.0 to 6.0 m (2.0 m) from the previous bottom of impact of 9.0 m. However, in order for guidelines to remain conservative for the DUA, a similar value (2.0 m) must be subtracted from the DUA depth (*e.g.,* if the depth to a DUA has been determined to be ≥ 15 m, the DUA depth should be entered into the SST as 13 m (15 m – 2.0 m) to ensure the appropriate buffer thickness is still incorporated.



2.9 Lateral Groundwater Transport

Lateral salt transport is governed by advective flow in groundwater. Dispersion of the salinity plume occurs as groundwater spreads in x, y, and z directions. Groundwater flows down a hydraulic gradient or from areas of high to low hydraulic head, or from high groundwater elevation to low groundwater elevation. The velocity of groundwater flow is proportional to the hydraulic conductivity of the medium through which it is flowing (*e.g.,* clay or sand) and the hydraulic gradient, and is inversely proportional to effective porosity. The hydraulic conductivity of soils and rock varies over orders of magnitude (*e.g.,* 10^{-11} m/s (clay) to 10^{-2} m/s (gravel; Fetter, 2001). Groundwater velocities typically range from <0.1 m/yr to over 10's of m/year. Both hydraulic gradient and conductivity can vary across a site and are site-specific parameters.

2.9.1 Lateral Groundwater Bearing Zones and Parameters

Three water bearing zones are incorporated into the SST: shallow groundwater; deeper groundwater; and the DUA. Typically, distinct monitoring well networks are installed for shallow and deep groundwater, as well as the DUA (if it is characterized and default parameters are not used). In some instances, one monitoring well network may represent parameters for two of the water bearing zones considered in the SST. A summary of SST input parameters for The DUA, shallow groundwater, and deep groundwater bearing zones, are summarized below:

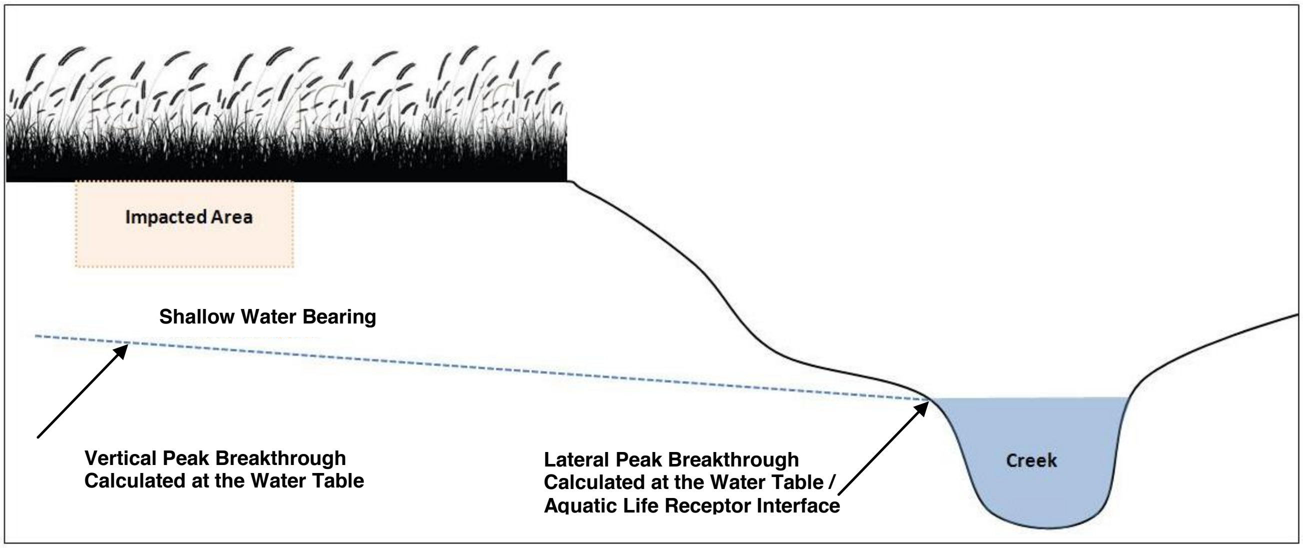
Parameter	Shallow Groundwater Input	Deep Groundwater Input	DUA Input

Depth of Water Bearing Zone	**Tier 2A: estimated from soil lithology; Tier 2B - measured from monitoring well data (3 or more wells)**	**Tier 2A: Default; Tier 2B - Default or use measured data from monitoring wells (3 or more wells)**	**Tier 2A/B: Coarse saturated interval ≥ 0.5 m thick identified during drilling or maximum depth of drilling; or, Tier 2B - measured from monitoring well data screening across potential DUA unit**
Hydraulic Conductivity	**Tier 2A defaults: 2E-07 m/s fine soils, 2E-06 m/s coarse soils; Tier 2B - default or maximum of measured values if 3 wells, or arithmetic mean of measured values if ≥ 4 wells (aquatic life risk)**	**Tier 2A defaults: 5E-09 m/s for fine soils, 5E-08 m/s for coarse soils; Tier 2B - default or arithmetic average of measurements from ≥ 3 deep groundwater wells (DUA risk)**	**Tier 2A default: 1E-06 m/s; Tier 2B - default or arithmetic average of ≥ 3 wells screened across the DUA**
Hydraulic Gradient	**Tier 2A default: 0.028 m/m; Tier 2B - default or average of measured values from ≥ 3 wells on two or more distinct sampling events (e.g., July, November)**	**Tier 2A default: 0.028 m/m; Tier 2B - default or average of measured values from ≥ 3 wells on two or more distinct sampling events (e.g. July, November)**	**Tier 2A default: 0.028 m/m; Tier 2B - default or average of measured values from ≥ 3 wells on two or more distinct sampling events (e.g., July, November)**
SubArea Source Dimensions	**15x15, 25x25, 50x50, 75x75, 100x100 m**		
Lateral Distance to Aquatic Life	**100 to 1,000 m for 75 x 75 m and 100 x 100 m source dimensions**		
	50 to 1,000 for 15 x 15, 25 x 25, and 50 x 50 m source dimensions	**NA**	**NA**
Lateral Distance to Dugout	**0 m; > 0 m for residential, industrial, or commerical land use adjacent to agricultural land use**	**NA**	**NA**
Lateral Distance to a DUA	**NA**	**NA**	**0 m**
Background Chloride Concentration	**Tier 2A/B: Default of 30 mg/L, or average measured at the groundwater discharge point into the aquatic life receptor**	**NA**	**Tier 2A/B: Default of 30 mg/L, or arithmetic average measured in a DUA if characterized**
TDS Concentration	**Tier 2A: estimated based on soils data; Tier 2B: arithmetic average of measured well data excluding elevated chloride and/or estimated from soils data; > 1,280 - irrigation pathway eliminated; > 7,000 - livestock watering pathway eliminated**	**NA**	**If > 4,000 mg/L, pathway is eliminated**
Vertical Gradient	**Tier 2A: default; Tier 2B: default or average of measured data from ≥ 3 wells, minimum of two distinct sampling events (e.g., July, November)**		**NA**

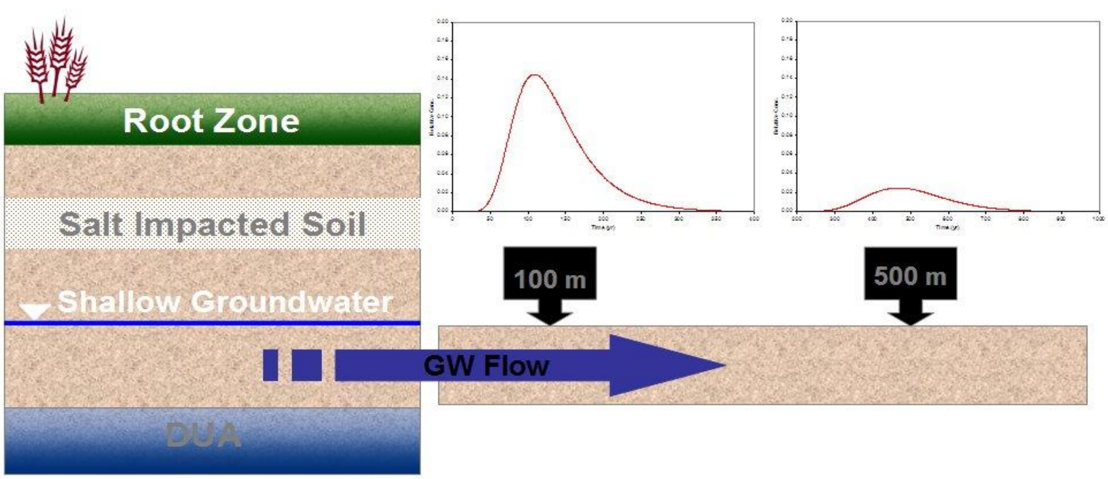
It should be noted that a lateral distance (i.e., non-zero) to receptor for shallow groundwater and the dugout scenario should be considered if commercial/industrial/residential land is adjacent to agricultural land

2.9.2 Shallow Groundwater Model (Aquatic Life Risk)

Shallow groundwater represents the water bearing zone involved with the transport of salt ions towards an aquatic life receptor (potentially a highly permeable layer such as sand lenses, or the shallowest encountered water bearing zone). Lateral salt transport in shallow groundwater in the SST is used to develop subsoil chloride guidelines for the protection of nearby surface water bodies that have functional aquatic ecosystems (referred to as Freshwater Aquatic Life (FAL) receptors). This excludes dugouts and canals, but may not exclude constructed wetlands or dugouts that are used as fish farms. The subsoil chloride guideline is a function of groundwater flow velocity and distance to aquatic life receptor, where velocity is the product of hydraulic gradient and conductivity divided by effective porosity. If the groundwater velocity is relatively slow and the distance to receptor is relatively long, dispersion processes will have more time to reduce peak chloride concentrations in the groundwater plume before reaching the aquatic life receptor, in which case concentrations may decrease to acceptable levels that will not result in an exceedence of aquatic life guidelines. Conversely, if the groundwater velocity is fast and the distance to receptor is relatively short, there will be limited time for dispersion and lower subsoil chloride guidelines may be required to prevent an unacceptable risk of adverse effect for the aquatic life receptor. Risks to aquatic life are determined based on the peak vertical breakthrough concentration of chloride at the shallow groundwater table, which subsequently could be transported laterally towards a surface water receptor where a second peak breakthrough will occur at the receptor location. An example is provided below.



- The SST considers diffusion and dispersion in three dimensions (capped or limited in the Z-direction) as a chloride plume is transported laterally towards an aquatic life receptor via shallow groundwater flow; and,
- The 3DADE model was used to simulate peak chloride concentrations at a potential aquatic life receptor located some lateral distance from the site (*e.g.*, 125 m, 1000 m, *etc.*). As chloride impacted groundwater is transported from the site, peak concentrations decrease as a function of groundwater velocity and distance to receptor, as shown graphically below for the same groundwater velocity, but with two distinct receptor distances. At 500 m, the peak breakthrough concentration is several fold lower than the peak breakthrough at 100 m.

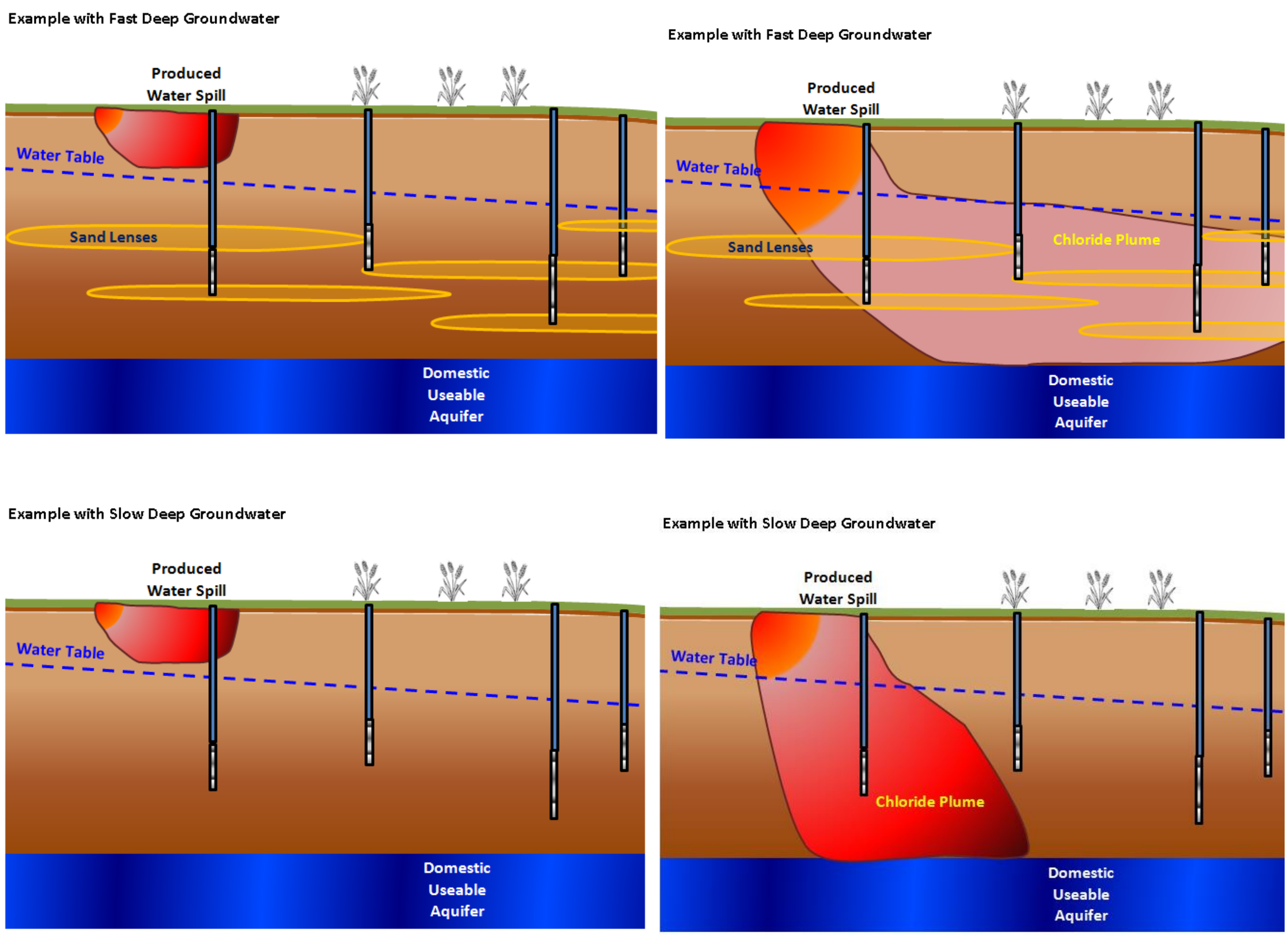


For the calculation of risk to aquatic life, the following processes/parameters are incorporated into modeling and the calculation of guidelines:

- Lateral attenuation (x, y, z directions);
- Hydraulic conductivity, gradient, and direction of flow in shallow groundwater;
- Tier 2A – distance to the closest aquatic life receptor in any direction;
- Tier 2B – distance to the closest aquatic life receptor in the direction of groundwater flow (a 60 degree sweep, 30 degrees on either side of the relevant groundwater flow vector);
- Aquatic life guideline at the point of groundwater discharge into the aquatic life receptor (120 mg/L chloride); and,
- No dilution of chloride due to mixing of groundwater with surface water within the aquatic life receptor water column.

2.9.3 Deep Groundwater Model (DUA Risk)

Deep groundwater represents the saturated soil lithology through which salts will spread laterally as they are leached downward towards a DUA. Lateral salt transport in deep groundwater in the SST is used to assess the extent to which peak chloride concentrations are attenuated due to lateral spreading of the plume as it leaches downward towards a DUA. If deep groundwater is relatively fast (higher hydraulic conductivity and steeper hydraulic gradient) and the DUA is relatively deep, the plume will spread out and peak concentrations will reduce by the time the chloride impact reaches the DUA. If deep groundwater is relatively slow and the DUA is relatively shallow, then there will be limited lateral spreading and reduction of peak concentrations before the chloride impact reaches a DUA. This is conceptually demonstrated in the graphic below.



- The SST considers diffusion and dispersion in three dimensions (capped in the Z-direction) as a chloride plume leaches downward towards a DUA; and,

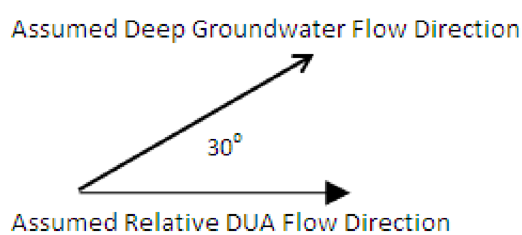
- 3DADE is used to simulate the reduction in peak breakthrough concentrations at a potential DUA depth caused by lateral groundwater flow and plume spreading as the plume leaches downward through deeper till and groundwater towards a DUA – deep groundwater parameters may differ from shallow groundwater parameters:

For the calculation of a rate of plume spreading during leaching towards a DUA through deep groundwater, and associated attenuation and DUA guideline calculation, the following parameters are considered:

- Hydraulic conductivity and gradient of deep groundwater;
- Drainage rate;
- Lateral attenuation in deep groundwater above the DUA (x, y, z directions); and,
- Flow vector offset for deep groundwater relative to the DUA (automatic).

2.9.3.1 Deep Groundwater – DUA Water Flow Vector Offset

The flow direction of shallow groundwater is less likely to be correlated with the flow direction of DUA water in a bedrock unit. However, the flow direction of sands and gravels that may meet the definition of a DUA, may be more likely correlated with the direction of groundwater flow in overlying till units. As a result, the calculated source length at the till/DUA interface was adjusted based on an assumed offset between the deep groundwater flow direction and flow direction of the DUA by 30 degrees. Alternate offsets are not available as an input parameter in the SST.



2.9.4 Domestic Use Aquifer (DUA)

For the DUA pathway, no lateral attenuation is considered within the DUA. In other words, the lateral offset distance to a nearby water well is not taken into consideration and it is assumed a water well could be installed anywhere onsite. The depth of the DUA is used to define the DUA buffer thickness. Situations where TDS concentrations exceed 4,000 mg/L in a DUA indicate that this pathway may be excluded. Under Tier 2B, it is possible to characterize the properties of a DUA with monitoring wells screened across the DUA, and accordingly adjust guidelines using non-default parameters.

The definition of a Domestic Use Aquifer (DUA) as per ESRD (2014a) is a geologic unit having one or more of the following criteria:

- a bulk hydraulic conductivity of >10^{-6} m/s or greater and sufficient thickness (> 0.5 m) to support a sustained yield of 0.76L/min or greater; or
- is currently being used for domestic purposes; or,
- any aquifer determined by Alberta Environment to be a DUA.

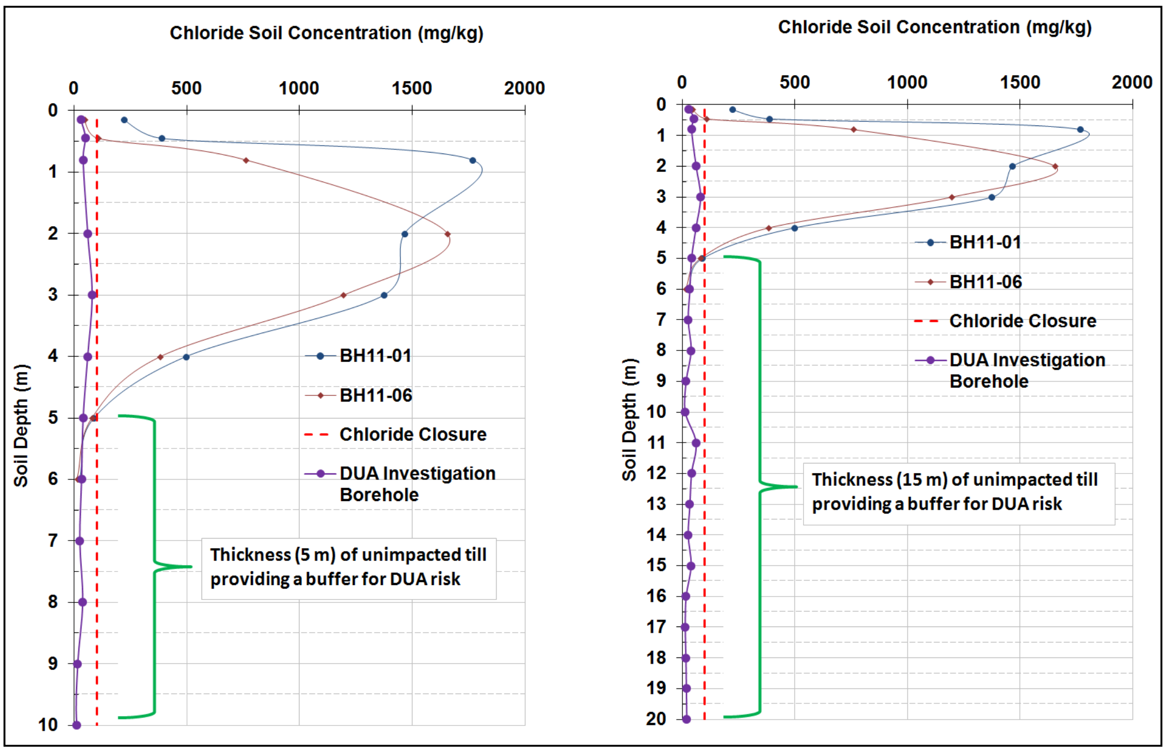
⚠ ***The SST does not have an input parameter for DUA TDS and it is up to the professional to interpret the SST output guidelines correctly for this receptor if the pathway is eliminated.***

2.9.4.1 Hydraulic Conductivity and Gradient

Hydraulic conductivity and hydraulic gradient values for a DUA are used in calculations of dilution for chloride entering the DUA from overlying till pore water. The higher the hydraulic conductivity or gradient of the DUA, the higher the estimated groundwater velocity in the DUA and the greater is the estimated dilution. Default parameters are assumed in alignment with ESRD (2014a) Tier 1 guidelines. The user may enter site-specific data providing a minimum of three monitoring wells are screened within a DUA. A minimum of three slug test results are required. Water elevations should be taken from all three wells during two different monitoring events in order to calculate a gradient. When DUA investigations are to be conducted, once data has been generated, both arithmetic and geometric mean hydraulic conductivity values are calculated. If the arithmetic mean is greater than or equal to 10^{-6} m/s, the unit is considered a DUA for evaluation in the SST. If the arithmetic mean conductivity is less than 10^{-6} m/s, it is not considered a DUA for evaluation in the SST. Essentially, the arithmetic mean hydraulic conductivity value is used to screen whether the unit should be assessed as a DUA in the SST. If the unit has been confirmed as a DUA for assessment, the arithmetic mean hydraulic conductivity is not entered into the SST. Instead, the geometric mean is entered to provide an additional measure of conservatism. The use of site-specific parameters will result in a change in the dilution factor parameter DF3.

2.9.4.2 Depth of DUA and Vertical Transport Buffer Calculation

As salts leach downward towards the DUA, attenuation of the peak concentration is incorporated based in part on the thickness of unimpacted till (buffer) between the base of impact and the DUA. The diagram below illustrates the effect of deeper drilling beneath the base of impact on the buffer thickness. If no DUA is encountered during drilling, the DUA depth will default to the maximum drilling depth. For the diagram on the left, the buffer beneath the maximum impact depth (5 m based on 100 mg/kg chloride) and above the DUA (assumed from the maximum depth of drilling, 10 m) is 5 m. In comparison, for the diagram on the right where deeper drilling has occurred, the buffer between the maximum impact depth (5 m) and the DUA is 15 m, based on a 20 m maximum depth of drilling. This results in a greater vertical buffer thickness and a less constrained SRG for the DUA pathway.



2.9.4.3 DUA Chemistry Buffer Based on Background Chloride Concentrations

Background concentrations of chloride in a DUA are expected to vary across the province. The sum of background plus site-related contributions towards DUA water quality should not lead to an exceedence of the 250 mg/L ESRD (2014a) water quality guideline. A default chloride concentration of 30 mg/L is assumed for a DUA in the SST. In areas where elevated chloride concentrations may be present in a DUA, a lower buffer (in mg/L of chloride) is determined in terms of allowable contribution from the site. The buffer is calculated as the difference between the background DUA chloride concentration and the applicable drinking water chloride guideline of 250 mg/L (Refer to the following equation):

$$DUA_{Cl\,BUF} = DWQG_{Cl\,DUA} - \mathrm{BWC}_{\mathrm{Cl\,DUA}}$$

Where,

$DUA_{Cl\,BUF}$ = Chemistry Buffer (mg/L) for chloride in the DUA – used to calculated a SRG for chloride protective of the DUA pathway

$DWQG_{Cl\ DUA}$ = Drinking Water Quality Guideline for chloride in a DUA (250 mg/L; ESRD 2014a)

$BWC_{Cl\ DUA}$ = Background Water Concentration for chloride in a DUA (30 mg/L default, or determined from site-specific measurements)

Note, if the background chloride concentration measured in the DUA is within approximately 20% of the 250 mg/L guideline (*i.e.* $\geq$ 210 mg/L), or is greater than the guideline, the user must default to a Tier 2C approach since a minimal residual buffer is present.

2.9.4.4 DUA Dilution Factor

The dilution of salt laden pore water as it leaches into DUA water from the overlying till is calculated based on the following equation in the SST program, derived from ESRD (2014a):

$$DF3 = 1 + \frac{Z \times v}{I \times X}$$

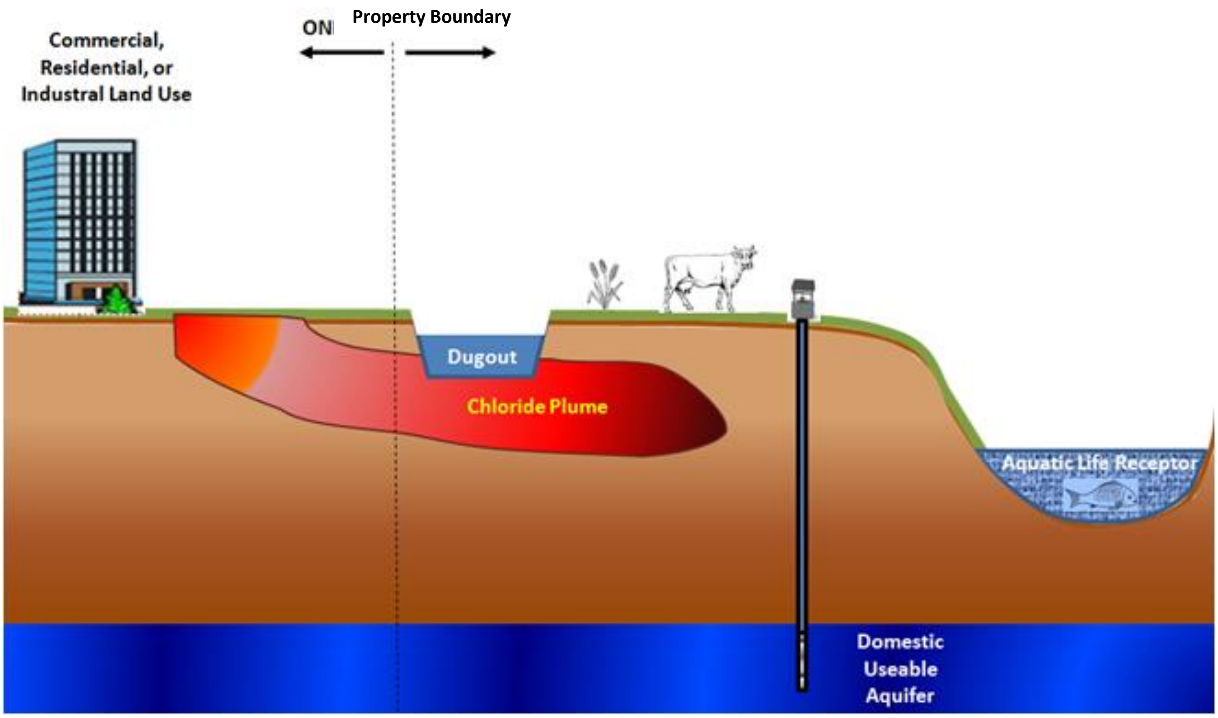
Z = mixing depth
v = Darcy velocity of groundwater
I = infiltration rate
X = source length

- Mixing depth typically taken to be 2 m;
- Darcy velocity of the DUA = HC (K) x i; hydraulic conductivity multiplied by the hydraulic gradient;
- Source length (m; largest lateral dimension of impacted soils); and,
- Infiltration (or drainage) rate.

2.10 Dugouts

Dugouts may be recharged via surface runoff and/or groundwater discharge. Dugouts are designed to collect surface water and connectivity with groundwater should be avoided, although for guideline calculation it was assumed that groundwater could discharge into a future dugout constructed onsite. Dugouts were assumed to be used for livestock watering and plant irrigation purposes. This is in alignment with ESRD (2014a) Tier 1 guidelines where shallow groundwater is considered for potential livestock watering and irrigation uses for Agricultural land use. The use of dugouts for livestock watering is also considered for Natural land use where livestock grazing activities occur and dugout construction is required to supply potable water sources. The pathway is considered for Industrial, Commercial, Natural, or Residential land uses that are situated immediately adjacent of Agricultural land. For Tier 2B, this applies to Agricultural land downgradient of groundwater flow, and for Tier 2A this applies to Agricultural land in any direction from the site.

For Agricultural land and Natural land used for livestock grazing where dugout construction is required, it is assumed a dugout can be placed anywhere onsite, and no dilution is considered for lateral transport and attenuation. However, for chloride impacts on Industrial, Commercial, Natural, or Residential land use areas that are situated immediately adjacent of Agricultural land, the reduction in peak chloride concentration during lateral transport (in a manner identical to the approach for aquatic life) is considered over the lateral buffer transport distance determined from the edge of the chloride impacted area to the property boundary where a dugout could be constructed (a graphical example is provided below).



This pathway also applies to Natural lands adjacent to Agricultural lands

Documentation of surrounding land use is required for sites that are in Commercial, Residential, Industrial, or Natural areas where Agricultural land may be immediately adjacent

2.10.1 Dugout Pathways Elimination

A maximum dugout depth is assumed to be 4 m. Situations where the seasonal average groundwater table is greater than 4 m, results in elimination of the dugout pathway for both livestock watering and irrigation water. There are also upper bound salinity (TDS) limits that result in pathway elimination, when background TDS is sufficiently elevated that groundwater would be a poor resource for livestock watering (>7,000 mg/L) or irrigation (>1,280 mg/L).

2.10.2 Dugout Adjustment Factor Calculation

An adjustment factor was developed to account for the reduced contribution of groundwater towards dugout water chemistry, given contribution of dugout water volume from sources of lower salinity water such as precipitation and runoff. Default adjustment factors of 3-fold (1/3rd) and 10-fold (1/10th) were adopted for coarse textured and fine textured soils, respectively.

The following variables were considered in the estimation of adjustment factors for the dilution of groundwater discharging into a dugout, due to runoff and precipitation for determining guidelines relevant to livestock watering and plant irrigation:

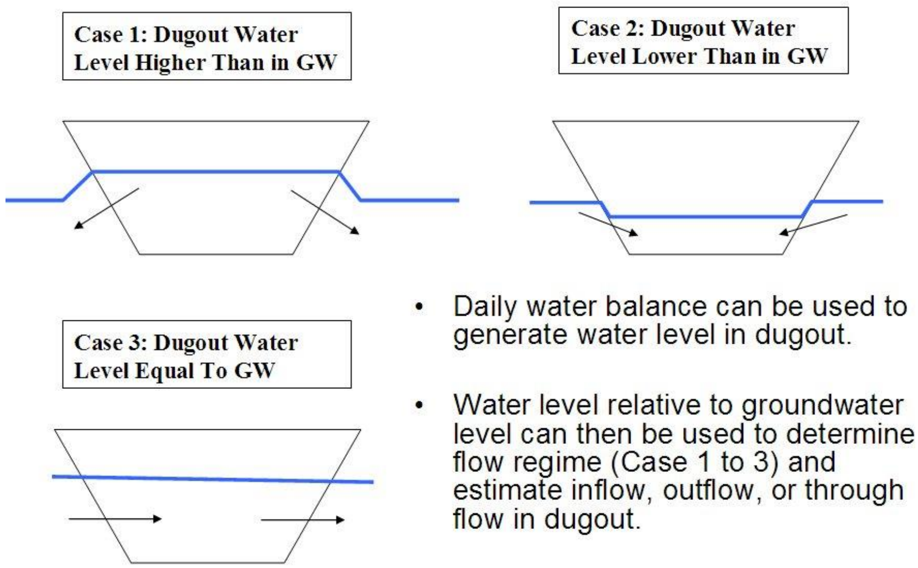
1. Evaluation of water and chloride balances under varying conditions;
2. Climate input of rainfall and snowmelt, with a runoff fraction collected by the dugout;
3. Climate input of potential evaporation;4. Pumping from the dugout for irrigation, livestock watering and domestic use (calibrated to a dynamically stable dugout volume);
5. Soil texture and influence on hydraulic conductivity for groundwater discharge into the dugout; and,
6. Groundwater inflows (hydraulic gradient) calculated as a function of the dugout water level under varying conditions.

Other additional parameters/methods considered, include:

- Typical dugout volume, dimensions, catchment areas and runoff coefficients from PFRA document "Quality Farm Dugouts"; and,

- Dugout evaporation methodology from "Gross Evaporation for the 30-year period 1971-2000 in the Canadian Prairies" by PFRA.

Several cases are shown below to highlight the influence of the dugout water level, relative to the shallow groundwater elevation, in terms of the net flow of water into and out of the dugout beneath the soil surface.

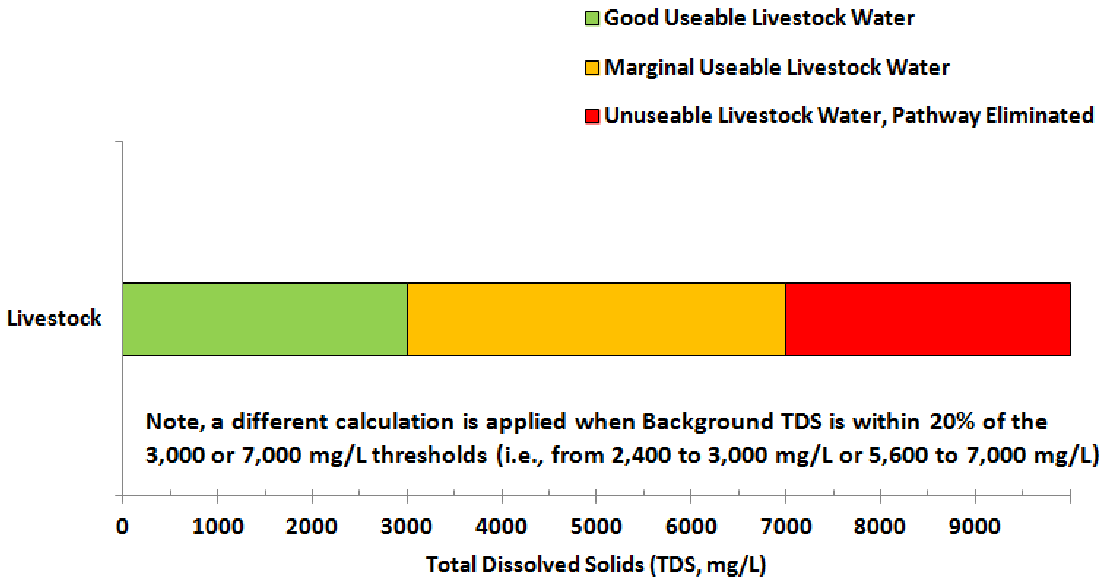


Adjustment factors of 3-fold and 10-fold were developed for coarse textured and fine textured soils, respectively, based on the texture selected for soils at depths greater than 1.5 m in the SST.

2.10.3 Livestock Water Buffer

SRGs are calculated for the protection of livestock watering via a dugout scenario by determining the future contribution of chloride (and associated cation to maintain charge balance) towards the dugout water total dissolved solid (TDS) concentration. The SRGs are based on preventing an exceedence of ESRD (2014a) Tier 1 guidelines for TDS, when future chloride related impacts are added to background groundwater TDS values.

The following equations are used by SST to calculate the livestock watering buffer automatically. Two key livestock watering guidelines were used in the buffer calculation: 3,000 mg/L and 7,000 mg/L. TDS concentrations below 3,000 mg/L are considered good sources of water for livestock, the use of which are not expected to be associated with an unacceptable risk of potential adverse effects. In periods where low TDS water is unavailable, livestock may consume water up to 7,000 mg/L, although an increased risk may be present for potential mild adverse effects (*e.g.*, laxative effect). At concentrations greater than 7,000 mg/L, there is an elevated probability for the occurrence of potentially serious and more deleterious adverse effects, and groundwater is considered unsuitable for livestock watering purposes and the pathway is eliminated. The buffer is used by the SST program to calculate a suitable SRG based on the contribution of chloride (and sodium) to TDS in a dugout. Because a infinitesimally small guideline can be produced as background approaches the guideline thresholds of 3,000 or 7,000 mg/L, an additional set of equations was added to prevent this from occurring when the arithmetic average TDS concentration is more than 80% of the threshold value, or within 20% of the guideline value. When the background TDS is within this range, a 20% exceedence over background is used to determine the livestock watering buffer rather than the difference between the guideline value of 3,000 or 7,000 mg/L and background TDS. The algorithms used to calculate the TDS buffer for livestock watering are shown below.



When background TDS < 2,400 mg/L (*i.e.,* <80% of 3,000 mg/L)

$$DUG_{TDS\ BUF\ Livestock} = LWQG_{TDS} - \mathrm{BWC}_{\mathrm{TDS}}$$

Where,

$DUG_{TDS\ BUF\ Livestock}$ = Buffer (mg/L) for TDS in the dugout – used to calculated a SRG for chloride for the livestock watering pathway

$LWQG_{TDS}$ = Livestock Water Quality Guideline for TDS in a dugout (lower threshold of 3,000 mg/L; ESRD 2014a)

BWC_{TDS} = Background Water Concentration (mg/L) for TDS in a dugout (calculated from site-specific data, no default)

When background TDS > 2,400 and < 3,000 mg/L (*i.e.,* > 80% and < 100% of 3,000 mg/L)

$$DUG_{TDS\ BUF\ Livestock} = \mathrm{BWC}_{\mathrm{TDS}} \times 20\%$$

Where,

$DUG_{TDS\ BUF\ Livestock}$ = Buffer (mg/L) for TDS in the dugout – used to calculated a SRG for chloride for the livestock watering pathway

BWC_{TDS} = Background Water Concentration (mg/L) for TDS in a dugout (calculated from site-specific data, no default)

20% = Allowable exceedence over background when background TDS is in close proximity to the guideline value

When background TDS > 3,000 and < 5,600 mg/L (*i.e.,* > 3,000 mg/L and <80% of 7,000 mg/L)

$$DUG_{TDS\ BUF\ Livestock} = LWQG_{TDS} - \mathrm{BWC}_{\mathrm{TDS}}$$

Where,

$DUG_{TDS\ BUFLivestock}$ = Buffer (mg/L) for TDS in the dugout – used to calculated a SRG for chloride for the livestock watering pathway

$LWQG_{TDS}$ = Livestock Water Quality Guideline for TDS in a dugout (higher threshold of 7,000 mg/L)

BWC_{TDS} = Background Water Concentration (mg/L) for TDS in a dugout (calculated from site-specific data, no default)

When background TDS > 5,600 and < 7,000 mg/L (*i.e.,* > 80% and < 100% of 7,000 mg/L)

$$DUG_{TDS\ BUF\ Livestock} = \mathrm{BWC_{TDS}} \times 20\%$$

Where,

$DUG_{TDS\ BUF\ Livestock}$	=	Buffer (mg/L) for TDS in the dugout – used to calculated a SRG for chloride for the livestock watering pathway
BWC_{TDS}	=	Background Water Concentration (mg/L) for TDS in a dugout (calculated from site-specific data, no default)
20%	=	Allowable exceedence over background when background TDS is in close proximity to the guideline value

When background TDS > 7,000 mg/L

Pathway Eliminated

2.10.4 Irrigation Water Buffer

SRGs are calculated for the protection of irrigation water via a dugout scenario by determining the future contribution of chloride (and associated cation to maintain charge balance) towards the dugout water TDS concentration. The SRGs are based on preventing an exceedence of Alberta Agriculture and Rural Development guidelines for TDS, when future chloride related impacts are added to background groundwater TDS values.

The following equations are used by SST to calculate the irrigation water buffer automatically. The buffer is used by the SST program to calculate suitable subsoil chloride guideline based on the contribution of chloride (and sodium) to TDS in a dugout. Tier 1 guidelines are available for irrigation water EC. EC in water can be converted to TDS based on the following equation:

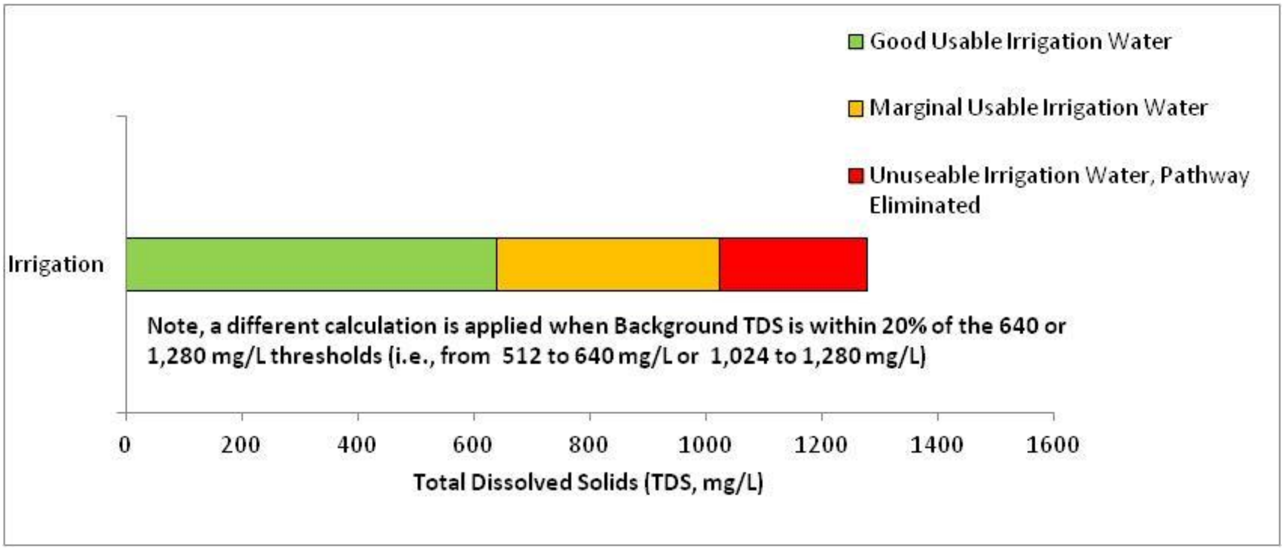
TDS (mg/L) = 640 X EC (dS/m)

Source: Tanji, 1990

Irrigation water that has an EC value of <1.0 dS/m (TDS of 640 mg/L) is considered to be of good quality. Irrigation water that is of marginal quality but is still considered useable will have an EC between 1.0 dS/m and 2.0 dS/m (TDS between 640 and 1,280 mg/L). Irrigation water with an EC of greater than 2.0 dS/m is considered un-useable, and the pathway is eliminated. The following are equations used by SST to calculate the irrigation water buffer **automatically**. The buffer is then used by the SST program to calculate the SRG for chloride based on the contribution of chloride (and sodium) to TDS.

As with the livestock watering buffer calculation, because a infinitesimally small guideline can be produced as background approaches the guideline thresholds of 640 or 1,280 mg/L, an additional set of equations was added to prevent this from occurring when the arithmetic average TDS concentration is more than 80% of the threshold value, or within 20% of the guideline value. When the background TDS is within this range, a 20% exceedence over background is used to determine the irrigation watering buffer rather than the difference between the guideline value of 640 or 1,280 mg/L and background TDS. The algorithms used to calculate the TDS buffer for irrigation water are shown below.

###TK



When background TDS < 512 mg/L (*i.e.,* <80% of 640 mg/L)

$$DUG_{TDS\ BUF\ Irrigation} = IWQG_{TDS} - \mathrm{BWC_{TDS}}$$

Where,

$DUG_{TDS\ BUFIrrigation}$	=	Buffer (mg/L) for TDS in the dugout – used to calculated a SRG for chloride for the irrigation water pathway
$IWQG_{TDS}$	=	Irrigation Water Quality Guideline for TDS in a dugout (lower threshold of 640 mg/L)
BWC_{TDS}	=	Background Water Concentration (mg/L) for TDS in a dugout (calculated from site-specific data, no default)

When background TDS > 512 and < 640 mg/L (*i.e.,* > 80% and < 100% of 640 mg/L)

$$DUG_{TDS\ BUF\ Irrigation} = \mathrm{BWC_{TDS}} \times 20\%$$

Where,

$DUG_{TDS\ BUF\ Irrigation}$	=	Buffer (mg/L) for TDS in the dugout – used to calculated a SRG for chloride for the irrigation water pathway
BWC_{TDS}	=	Background Water Concentration (mg/L) for TDS in a dugout (calculated from site-specific data, no default)
20%	=	Allowable exceedence over background when background TDS is in close proximity to the guideline value

When background TDS > 640 and < 1,024 mg/L (*i.e.,* > 640 mg/L and <80% of 1,280 mg/L)

$$DUG_{TDS\ BUF\ Irrigation} = IWQG_{TDS} - \mathrm{BWC_{TDS}}$$

Where,

$DUG_{TDS\ BUF\ Irrigation}$	=	Buffer (mg/L) for TDS in the dugout – used to calculated a SRG for chloride for the irrigation water pathway
$LWQG_{TDS}$	=	Irrigation Water Quality Guideline for TDS in a dugout (higher threshold of 1,280 mg/L)
$BWC_{Cl\ DUA}$	=	Background Water Concentration (mg/L) for TDS in a dugout (calculated from site-specific data, no default)

When background TDS > 1,024 and < 1,280 mg/L (*i.e.,* > 80% and < 100% of 1,280 mg/L)

$$DUG_{TDS\ BUF\ Irrigation} = \mathrm{BWC_{TDS}} \times 20\%$$

Where,

$DUG_{TDS\ BUF\ Livestock}$	=	Buffer (mg/L) for TDS in the dugout – used to calculated a SRG for chloride for the irrigation water pathway
BWC_{TDS}	=	Background Water Concentration (mg/L) for TDS in a dugout (calculated from site-specific data, no default)
20%	=	Allowable exceedence over background when background TDS is in close proximity to the guideline value

When background TDS > 1,280 mg/L

Pathway Eliminated

2.11 SubAreas Options

There are several options available for developing SubAreas that can be run through the SST to produce more refined SRGs. There options include:

1. Root Zone and Dugout Pathway with SubAreas
2. FAL and DUA Pathways with No SubAreas and Run as a Single Site
3. FAL and DUA Pathways with SubAreas and Using Buffer Allocation Factors

All three approaches are acceptable for developing Tier 2A/2B guidelines. The root zone and dugout pathways have been separated from the FAL and DUA pathways as SRGs for the former two are not dependent on source dimensions.

2.12 Root Zone and Dugout Pathways with SubAreas

Tier 2A and Tier 2B SRGs can be calculated for root zone and dugout (irrigation and livestock watering) pathways using SubAreas. For sites with simple salinity contaminant scenarios, where the distribution of impacts is generally similar and the magnitude (as well as depth of impact) is relatively small (shallow), a single scenario can be run. For sites with more complicated distributions of salinity impacts and multiple root zone scenarios (*i.e.*, unimpacted, impacted, excavate and backfill), SubAreas can provide more refined SRGs for the root zone and dugout pathways. The development of SubAreas for these pathways can be considered in situations where:

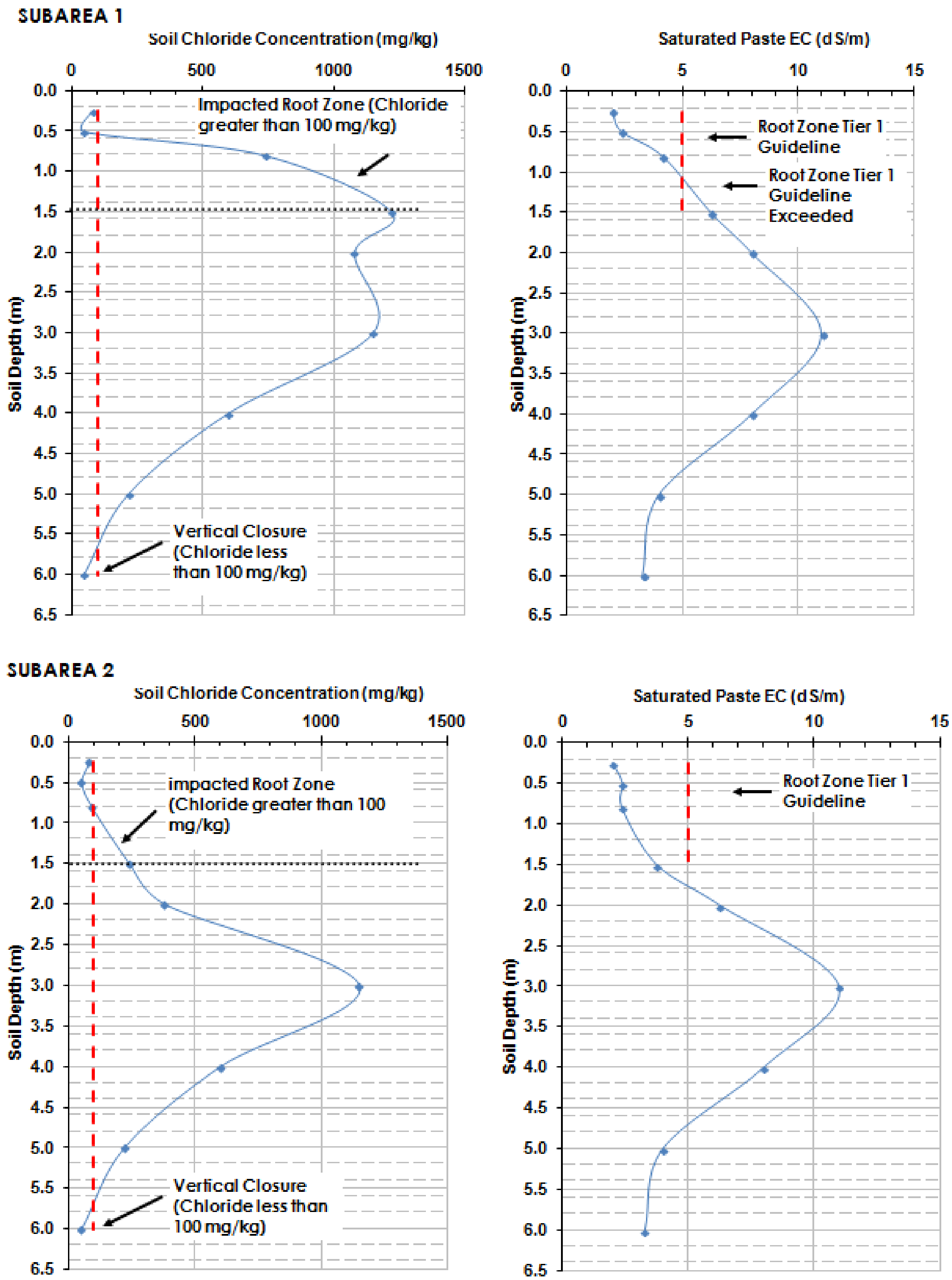
- Variability in the magnitude and vertical distribution of chloride impacts;
- Variable excavation depths laterally across the site;
- Root zone scenario variability (unimpacted, impacted, excavate and backfill);
- Need to avoid excavation in certain areas due to infrastructure such as high pressure sour pipelines or on an unstable slope*, etc.*;
- Variable groundwater depths;
- Variable soil lithology (*e.g.*, half the site is coarse, half the site is fine); and/or,
- Relatively large variability in background soil root zone salinity

For example, there is a two category 'jump' between the category where the mean background root zone EC occurs and the category where the 95th percentile EC occurs for a particular background chemistry dataset (*e.g.*, mean EC of 2.8 dS/m = Good, 95th %ile EC of 6.9 = Poor, representing a two category 'jump' (neither statistical parameter was within the Fair category)). One option available for this situation is to divide the site laterally into distinct SubAreas for root zone analysis, with two different background environments.

A second example would be for a Tier 2B assessment where groundwater information is present, and one half of the site has a water table depth of 2 m whereas the other half has a water table of 5.5 m. The dugout irrigation water and livestock watering guidelines would be applicable for the half of the site with a water table shallower than 4 m.

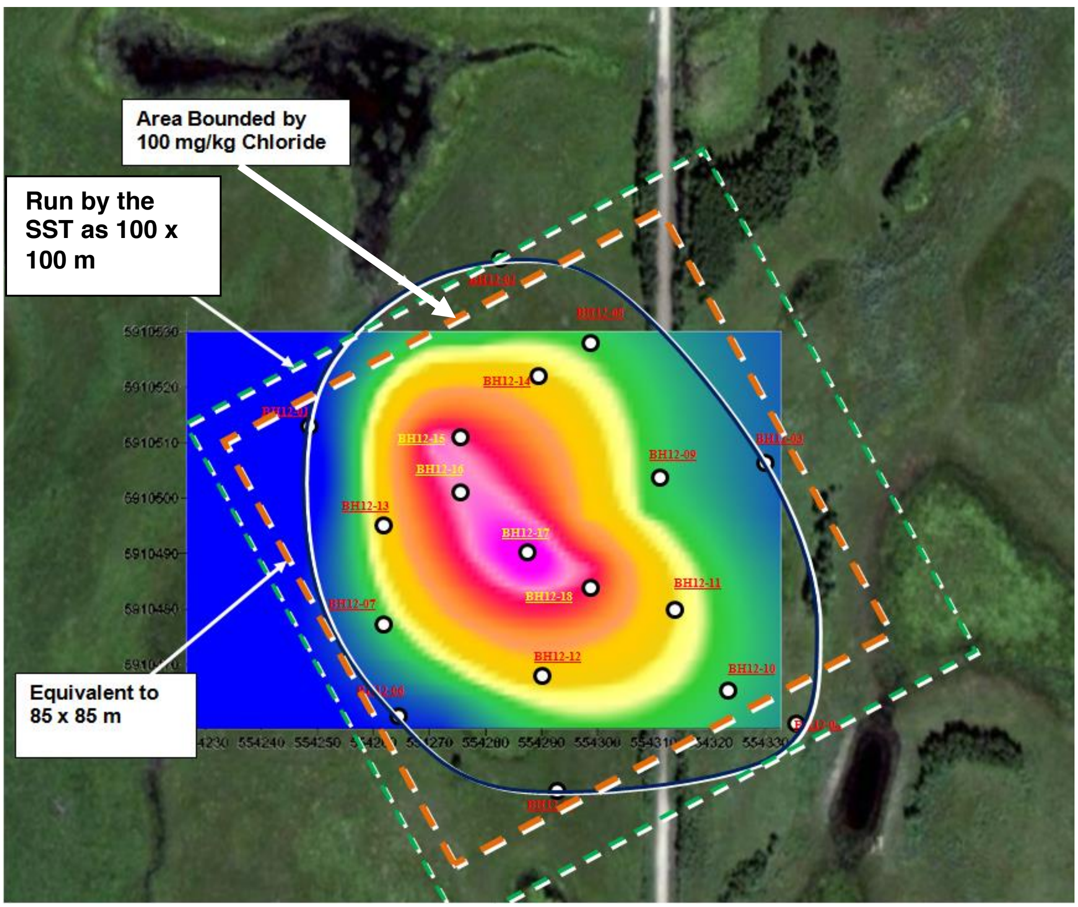
An anticipated common application of SubAreas will be varying excavation depths in areas with variable magnitude and depth of salinity impact. Certain sites may also have multiple sources of impact with separation distance (*e.g.*, wellhead on one side of the site, flare pit on the other side), and different excavation depths can be developed for distinct sources.

The process of developing SubAreas involves grouping areas of salinity impact together and defining them as a distinct SubArea, an example of which is shown below. Two representative chloride and EC vertical profiles have been shown for a site divided into two SubAreas (SubArea 1 and SubArea 2). The profiles in SubArea 1 clearly show that the root zone EC guideline of 5 dS/m has been exceeded, automatically triggering an Excavate and Backfill scenario. However, SubArea 2 can be run as an Impacted Root Zone and if the calculated subsoil Tier 2(A or B) chloride SRG is greater than 1,200 mg/kg, then no excavation would be required for SubArea 2 and the only area to be excavated would be the root zone for SubArea 1. However, comparison against dugout, FAL, and DUA SRGs would be required to determine the final assessment of SubAreas requiring excavation.



2.13 FAL and DUA Pathways with No SubAreas and Run as Single Site

The SST has default initial square source dimensions (area) of 15 x 15 m, 25 x 25 m, 50 x 50 m, 75 x 75 m, and 100 x 100 m. These source dimensions can be used for sites with dimensions that fit within these categories, and where applicable, only a single source dimension can be run for the DUA and FAL pathways. A greater source dimension is associated with less attenuation of the peak concentration prior to reaching the receptor, and lower SRGs. The source area parameter is used for calculating the extent of chloride dispersion during lateral transport towards a FAL receptor or lateral dispersion during downward leaching of chloride impacts towards a DUA. The same source dimension (*e.g.*, 50 x 50 m) is defined for both the aquatic life and DUA receptors. Sites that fall within a source dimension range (*e.g.*, between 25 x 25 m to 50 x 50 m) will be run in the SST using the largest dimension of that range or 50 x 50 m. In the example below, the site has an impact area that is equivalent to 85 x 85 m bounded by lateral chloride concentrations of less than 100 mg/kg. It would be run by the SST as a 100 x 100 m source. The source area should be entered into the SST as 85 (85 x 85 m square) and not 100 x 100 m since some calculations used to determine the DUA guidelines are directly related to source area regardless of the final square size used by the SST in fate and transport modeling.



If a greater source dimension is required for defining the lateral extent of impacts at a site (*e.g.*, > 100 x 100 m), then multiple SubAreas must be developed, which is discussed in the following section. Furthermore, providing investigation requirements are met, sites with dimensions less than 100 x 100 m can also be divided into multiple SubAreas (*e.g.*, 25 x 25 m and 35 x 30 m; discussed in the following section). SubAreas may result in more relaxed (higher) SRGs and distinct SRGs are calculated for each SubArea using Buffer Allocation Factors.

Under a Tier 2A scenario, in the absence of groundwater information, SRGs must take into consideration potential cumulative salt loading at a receptor of concern, by determining the most conservative source length/dimension across the site, in any cardinal direction. This is of relevance for multiple impact areas, such as a well centre impact and a flare pit impact. If the well centre impact was characterized by a dimension of 15 x 15 m and the flare pit by 25 x 20 m, when run in the SST as a single area for the DUA and FAL pathways, a source dimension of 50 x 50 m would be entered. This is due to an absence of knowledge regarding the direction of groundwater flow.

There are situations where different impact areas are separate and can be run independently in the SST, under Tier 2B but not Tier 2A. Under a Tier 2B scenario with sufficient groundwater information, calculations of SRGs will still consider the potential for cumulative salt loading at a receptor, although there may be instances different impact areas may not summate because of groundwater flow direction. This is discussed further in the following section.

Borehole data is required for confirmation of concentrations in different areas of a salinity impact as well as for lateral closure (defined by chloride of ≤ 100 mg/kg). The first step in determining source area is to identify the area bounded by 100 mg/kg chloride. In the example above, the following boreholes had chloride concentrations < 100 mg/kg at all depth intervals (*e.g.*, from surface to 6 m): BH12-01 to BH12-06 and an area bounded by 100 mg/kg is highlighted with a blue/white line. Various software programs (Adobe Standard, Surfer, *etc.*) are available, or more conventional methods may be used, to calculate the area bounded by this line. In the example below, it represents an area of approximately 85 x 85 m. This would be entered into the SST, which would then place this dimension into the next highest default category of 100 x 100 m (green/white dashed square) for guideline calculations for FAL and the DUA, although aspects of the smaller dimension of 85 x 85 m are still considered for the DUA. This (85 x 85 m) would be the source length (dimensions) entered into the SST under a Tier 2A or 2B approach, with a single area of impact and no consideration of SubAreas.

2.14 FAL and DUA Pathways Run with SubAreas and Using Buffer Allocation Factors

Under Tier 2A and 2B levels of assessment, sites may be divided into SubAreas for the development of separate FAL and DUA SRGs, which are applicable to each SubArea. Buffer Allocation Factors (BAFs) are assigned to each SubArea. The total BAF can never exceed 1.0, and as a result it provides the same level of protection as an SST run with a single area. This level of assessment should be considered in situations where:

- Impact dimensions that do not match well with the default SST source dimension (e.g., 50 x 50 m source dimensions for a 50 x 25 m plume)
- Variability in the magnitude and vertical distribution of chloride impacts in different areas of the site;
- Variable excavation depths in different areas;
- Relatively complex contaminant plume geometry;
- Need to avoid excavation in certain areas due to infrastructure such as high pressure sour pipelines or on an unstable slope*, etc.*;
- Variable groundwater depths or flow directions; and/or,
- Variable soil lithology (*e.g.*, half the site is coarse, half the site is fine).

An anticipated common application of SubAreas will be varying excavation depths in areas with variable magnitude and depth of salinity impact. Certain sites may also have distinct impact areas due to distinct sources with a considerable separation distance (*e.g.*, wellhead on one side of the site, flare pit on the other side). SubAreas can be added up to a total source dimension of 200 x 150 m, however, the resulting SRGs for the DUA and aquatic life pathways will become very low and constrained for large source dimensions.

Example 1

A site has a 25 x 25 m flare pit impact and a 10 x 10 m wellhead impact and groundwater could be contaminated with salinity from both impact areas (one area is downgradient of flow from the second area under Tier 2B or it is a Tier 2A assessment). The potential exists for a summative impact for the DUA and FAL receptors (SRGs are dependent on source area for these two receptors). Two options are available for developing SRGs for this example site: 1) use a square source dimension of 35 x 35 m encompassing both source dimensions; or, 2) develop SubAreas with dimensions of 25 x 25 m and 10 x 10 m, and assess independently with the SST in a manner that includes the potential for cumulative risk and application of BAFs. The magnitude of the BAF assigned to each SubArea can be tested in an iterative manner to produce the most applicable SRGs for the site. Examples of possible BAFs for two SubAreas include:

	BAF Trial 1	BAF Trial 2	BAF Trial 3	BAF Trial 4
Flare Pit	90%	10%	44%	97%
Wellhead	10%	90%	66%	3%
Total	**100%**	**100%**	**100%**	**100%**

The selection of option 1 above and using a square source dimension of 35 x 35 m will over-represent the extent of chloride impact (35 x 35 m = 1,225 m^2 versus 25 x 25 m (625 m^2) + 10 x 10 m (100 m^2) = 725 m^2). However, if measured chloride concentrations at the site in both areas (flare pit and wellhead) are lower than the SRGs calculated using option 1, then there is no need to pursue a more detailed approach to guideline development. However, should exceedences be anticipated, option 2 can be selected, SubAreas developed, and BAFs tested to produce optimized SRGs. The flare pit impact and wellhead impact would have separate guidelines developed for both the DUA and FAL receptors, and cumulative risks would be considered via BAFs.

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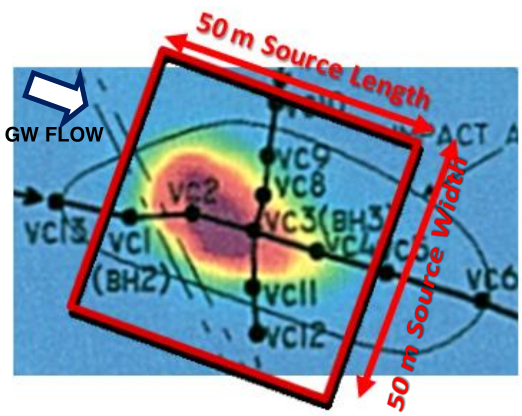
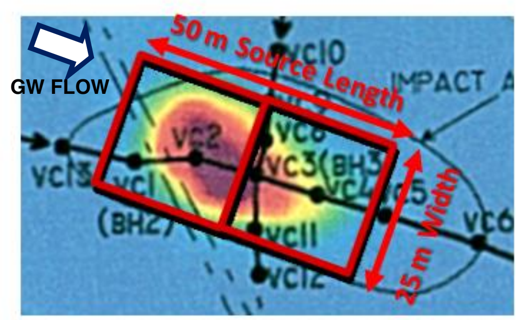
Example 2

There are also situations where an impact due to a single source may be subdivided into SubAreas to avoid an overrepresentation of chloride mass, under Tier 2A or 2B. A graphic example is provided below that would be applicable under Tier 2A or under Tier 2B when groundwater is flowing in a Southeast direction. On the left is a representation of the source dimensions based on a default SST 50 x 50 m impact given that the source length was determined to be 50 m. However, if the source width is less, the 50 x 50 m assumption will over represent the chloride mass. Alternately, two 25 x 25 m SubAreas can be modeled in tandem (rightmost scenario in the diagram below), and BAFs apportioned between each SubArea for the DUA and FAL pathways (*e.g.*, factors of 50% and 50%, or 35% and 65%, to each Subarea; the total must never exceed 100%). Regardless of the number of SubAreas developed, because no more than 100% of the DUA or FAL chemistry buffer is allotted, the resulting estimated subsoil chloride SRGs will not exceed Tier 1 guidelines at receptor locations.



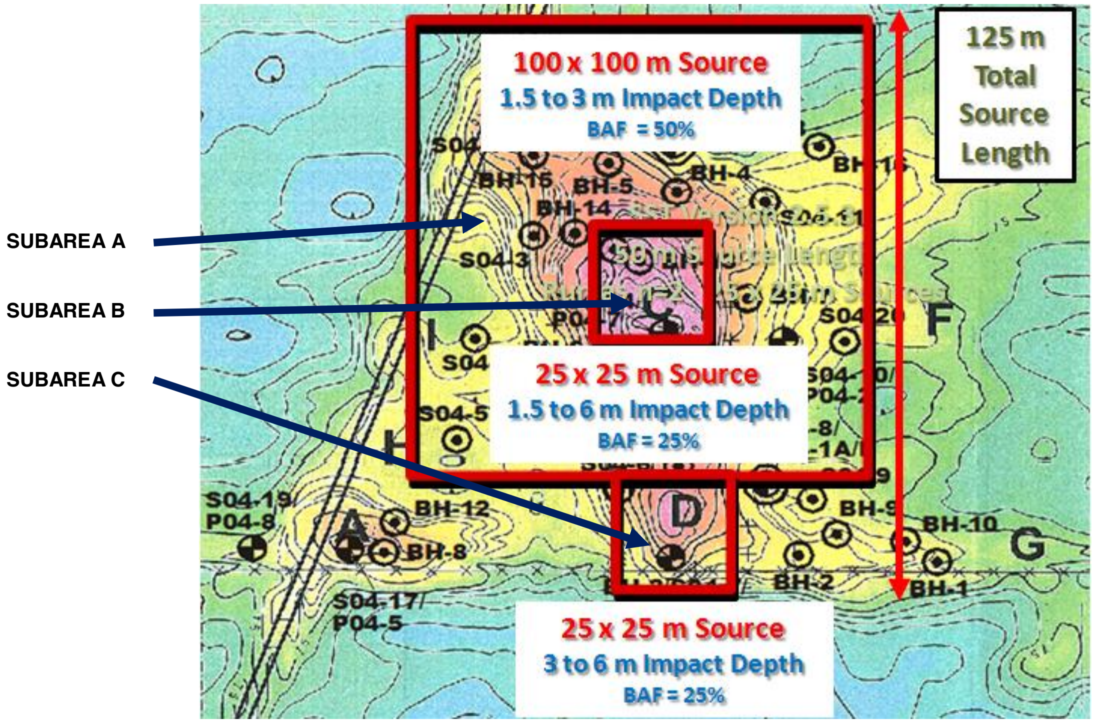


Example 3

A third example is provided below where there may be value in developing SubAreas and distinct SubArea-specific SRGs for the DUA and FAL receptors. The example site has been subdivided into three impacted SubAreas:

- SubArea A) 100 x 100 m source dimension with a 1.5 to 3.0 m impact depth (less SubArea B);
- SubArea B) 25 x 25 m source dimension with a 1.5 to 6.0 m impact depth; and,
- SubArea C) 25 x 25 m source dimension with a 3.0 to 6.0 m impact depth.

A different BAF is allocated to each SubArea (the total must not exceed 100%), entered into the SST, and SRGs are calculated for each SubArea. This approach allows for the development of guidelines flexible for alternate remediation strategies. For example, consider a situation where impact C (3.0 to 6.0 m, 25 x 25 m) is located offlease and permission cannot be obtained for remediation. Providing there are no risks in terms of the root zone and livestock watering/irrigation water via a dugout scenario, a larger BAF can be applied to this area when calculating risk to the DUA and FAL receptors producing less constrained SRGs, which may lead to a no dig scenario for SubArea C. Alternately, there may be triggers for a greater extent of remediation in SubArea B, in which case a smaller BAF can be assigned under the assumption that the majority of the impacts will be remediated (*e.g.*, excavation to 5 m leaving a relatively thin impact layer from 5 to 6 m), and a greater portion of the BAF can be applied to SubArea A and C resulting in less constraining guidelines for SubAreas A and C. A third example of guideline flexibility would be a smaller BAF applied to SubAreas B and C, resulting in deeper excavation, but a less constrained guideline for the larger SubArea A. It is at the proponent's discretion to assign BAF factors, and regardless of how they are assigned, the sum must not exceed 100% so that model predictions do not lead to an exceedence of ESRD (2014a) Tier 1 guidelines at receptor locations. More detailed guidance on how to develop SubAreas is discussed later in this help manual.



2.14.1 Impact Areas that are Cumulative for Risk and Guideline Calculations

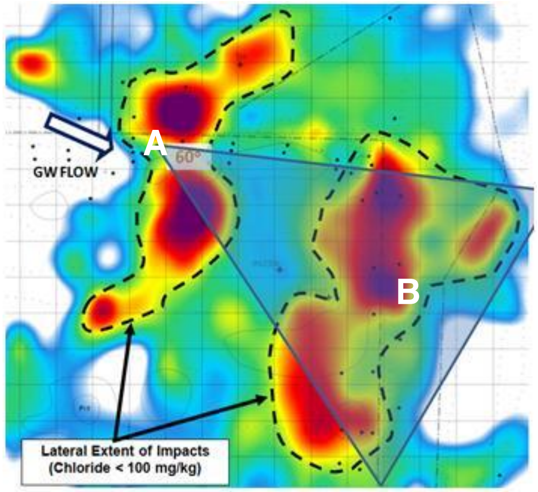
Under Tier 2A where the groundwater flow direction is unknown, impacts from two or more separate SubAreas in all instances would be assumed to be cumulative in terms of salinity contribution at receptor locations, even if the SubAreas are separated by unimpacted till. For Tier 2B where the groundwater flow is known, there are three general cases for determining whether cumulative risks need to be considered for laterally adjacent SubAreas for the DUA and FAL pathways (where BAF factors could be developed).

Case 1. SubAreas where one groundwater plume will migrate into another SubArea area are considered to have the potential for cumulative risk. A 60^{o} arc (30^{o} either side of the seasonal average groundwater flow direction) is considered for assessing plume overlap, given uncertainty and variability in groundwater flow direction.

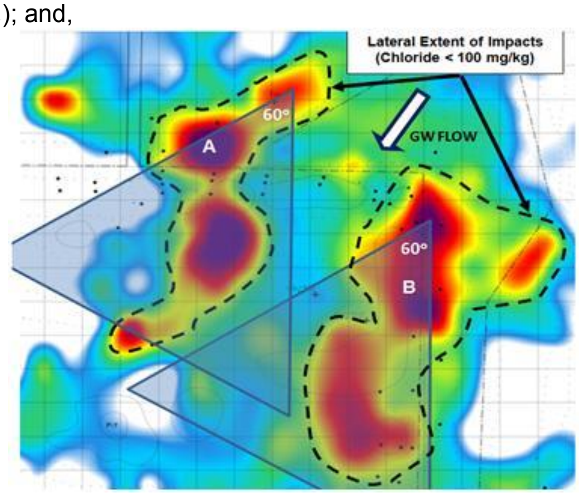
Case 2. SubAreas that are located side by side, perpendicular to the direction of groundwater flow, and are not ‘touching’ (due to the presence of unimpacted soils with < 100 mg/kg chloride at relevant depth intervals and multiple borehole locations between the two SubAreas) are considered to have a low relative risk for cumulative impacts since lateral dispersion of chloride in groundwater is approximately 1/10th of longitudinal dispersion. The potential for overlap increases with greater travel distances and slower groundwater velocities, however, these scenarios are associated with a lower relative risk for the DUA and FAL receptors since a greater extent of dispersion will occur prior to impacts reaching receptors.

Case 3. SubAreas that are located side by side, perpendicular to the direction of groundwater flow, and are ‘touching’ (due to the absence of soils with < 100 mg/kg chloride at relevant depth intervals and multiple borehole locations between the two SubAreas) are considered to have the potential for cumulative impacts and risk.

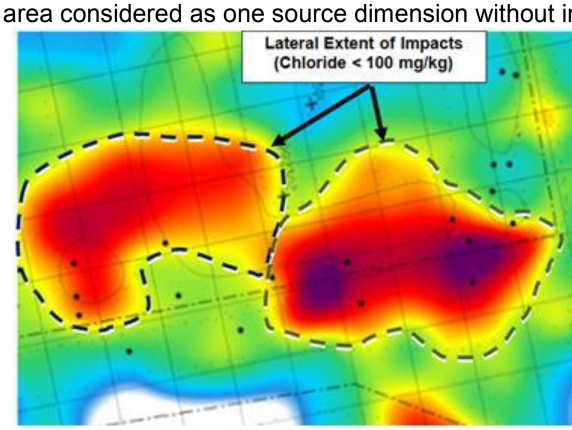
Case 1: SubAreas (A&B) situated in series – a 60^{o} arc at the centre of the most upgradient SubArea overlaps with a downgradient SubArea– risks are considered to be cumulative and BAF factors must be developed;



- **<u>Case 2</u>**: SubAreas (A&B) situated in parallel (laterally adjacent) and separated by soils with < 100 mg/kg chloride (*i.e.*, not 'touching') - where a 60° arc at the centre of the most upgradient SubArea does not overlap with an adjacent SubArea – risks are non-cumulative, and BAF factors for each SubArea are not required. The SubAreas would be run as two independent scenarios without cumulative impacts. However, SubAreas could be established for each independent scenario - *i.e.*, SubArea (or scenario) A could be subsequently divided into SubAreas A.1 and A.2 *etc.*); and,



- **<u>Case 3</u>**: SubAreas situated in parallel (laterally adjacent) but are <u>not</u> separated by soils with < 100 mg/kg chloride (*i.e.*, touching) – risks are cumulative, and BAF factors must be assigned (separate source dimensions for each area), or the entire impact area considered as one source dimension without implementing BAF factors.



If an immediately upgradient salinity impact due to another facility is know where a buffer (soils with < 100 mg/kg chloride) is absent and the two impacts are essentially 'connected' or 'touching', it is necessary to reduce the allowable buffer (BAF) for DUA and FAL receptor subsoil SRGs in the SST to account for potential cumulative risks.

2.15 Buffer Allocation Factor Calculation

SRGs can be first developed based on the root zone and dugout receptors since the corresponding guidelines are solely based on vertical salt transport and are not dependent on source area. Once completed, SRGs can subsequently be developed for the FAL and DUA pathways, which are based on source dimensions and require an analysis of cumulative risk from adjacent SubAreas for subsoil SRG development. For certain scenarios, guidelines for a particular pathway may exceed Management Limits (7,000 mg/kg). Closure can not be obtained if chloride concentrations exceed Management Limits. Risk management/exposure control can be conducted when Management limits are exceeded.

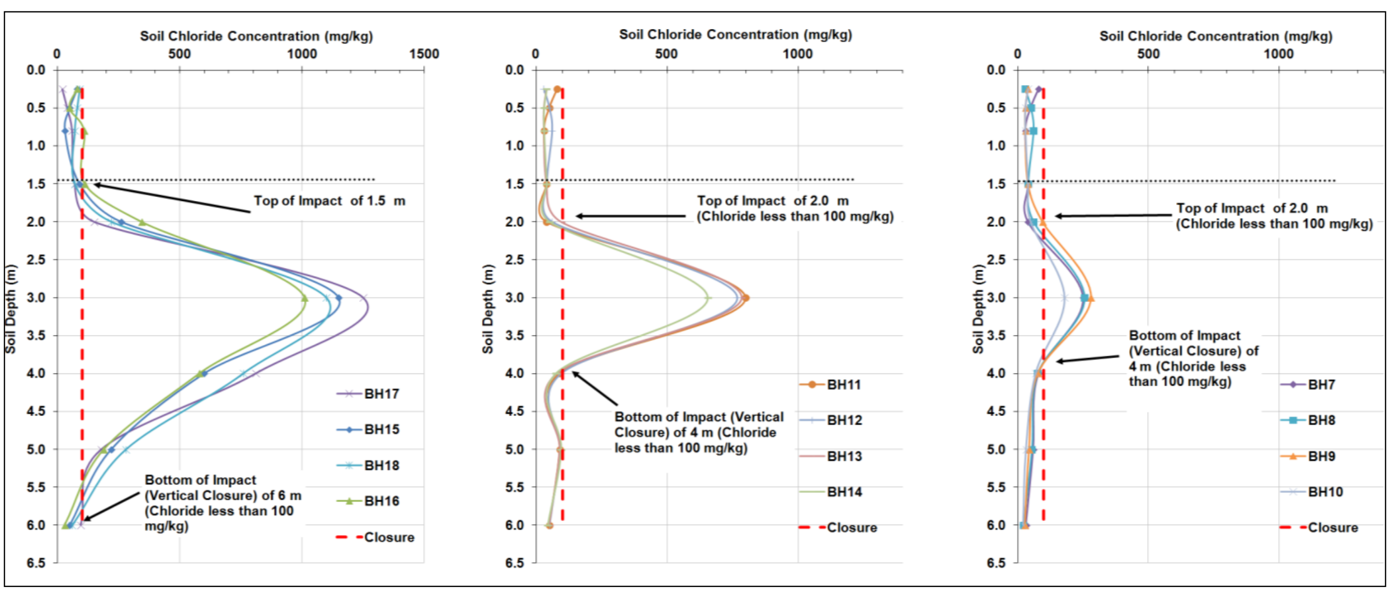
The tables below (including Section 2.16) show SST input parameters for an example site that was divided into four SubAreas (1A, 1B, 2, and 3). Source dimensions and vertical profiles are shown in figures below. Entering these data into the SST for SubAreas 1A&B results in NGR (No Guideline Required) for the irrigation water pathway as the background TDS is > 1,280 mg/L. The livestock water pathway SRG is 2,000 mg/kg. The root zone subsoil chloride SRG is 1,280 mg/kg. For SubAreas 2 and 3, the irrigation water pathway SRG is similarly NGR. The livestock pathway is 2,500 mg/kg and the root zone SRG is 2,900 mg/kg. Based on these results, remediation is not required for the root zone or dugout pathways by comparing SRGs for these pathways with the vertical chemistry profiles shown below.

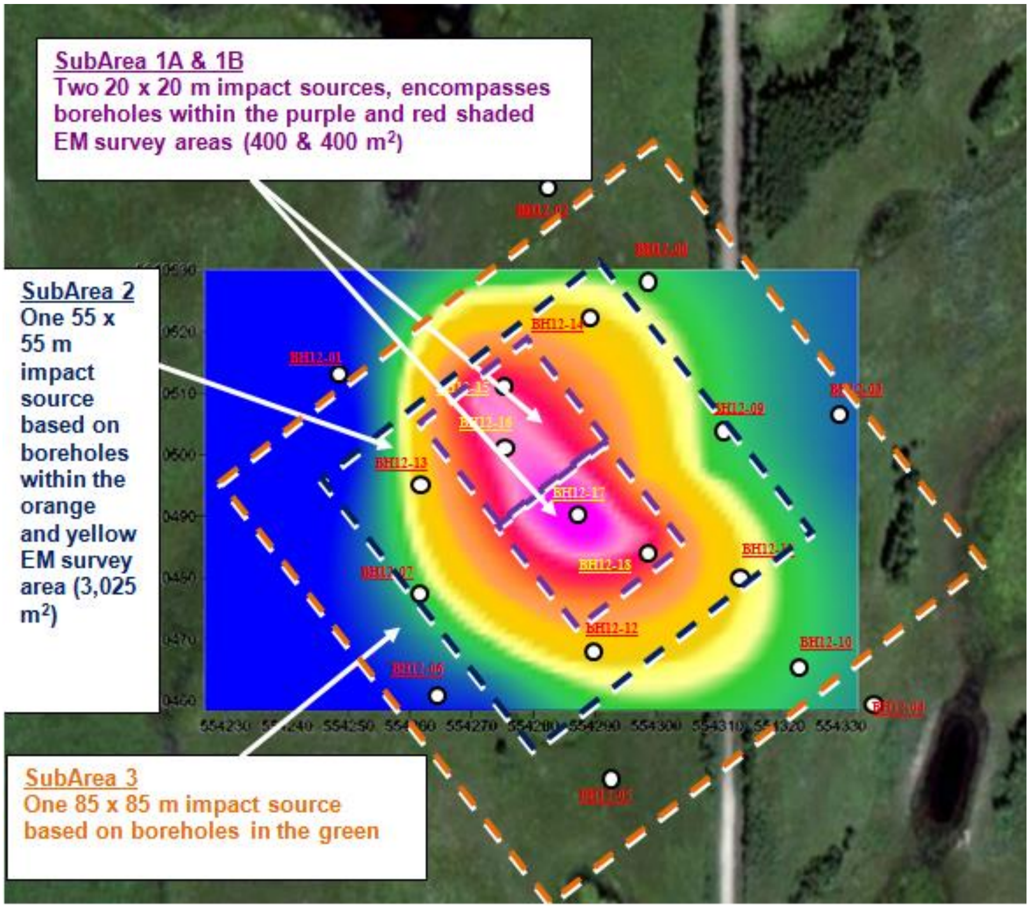
SRGs are subsequently calculated for the DUA and FAL pathways based on source dimensions for each SubArea. The SRGs require that the increase in chloride concentrations in the DUA and at the FAL do not result in an exceedence of Tier 1 guidelines for these two pathways (250 mg/L and 120 mg/L chloride, respectively) when all the SubAreas are considered in terms of cumulative risk. The consequence of not dividing the site into SubAreas would be the development of SRGs under a single scenario characterized by the maximum lateral impact dimension (85 x 85 m) and the maximum vertical impact dimension (1.5 to 6.0 m). This would overestimate the mass of chloride and therefore the chloride risk associated with the larger lateral dimensions of SubAreas 2 and 3, which have thinner vertical impact depth profiles (*i.e.*, impacts from 2.0 to 4.0 m rather than 1.5 to 6.0 m). However, if all measured concentrations are below SRGs calculated for this more conservative scenario, then additional effort to refine guidelines using SubAreas and BAFs is of minimal benefit.

Preferentially, each SubArea would have a minimum of 4 boreholes, although this may not be feasible in all cases. The advantage of having more boreholes per SubArea is that the probability of identifying the most heavily impacted soils per SubArea is improved. This can facilitate remediation efforts and avoid complications where greater soil concentrations of chloride are measured in confirmatory samples, which may imply deeper than anticipated remediation may be required or that an alternate scenario/SubArea should have been developed.

Vertical Chloride Profiles Broken down by SubArea

SubArea 1A&B (20x20 & 20x20m) **SubArea 2 (47x47m)** **SubArea 3 (65x65m)**





The lateral source dimensions for each SubArea are shown in the table below. Source dimensions can be adjusted for SubAreas that overlap smaller SubAreas to avoid double counting mass. For SubArea 2, the unadjusted source dimension is 55 x 55 m (3,025 m^2). The area representing the encompassed SubAreas 1A&B (400 m^2 + 400 m^2) can be subtracted from this area, resulting in an adjusted source dimension for SubArea 2 of 47 x 47 m (2,225 m^2). The value of 47 m is entered into the SST for source dimension. A similar calculation is completed for SubArea 3 (85 x 85 m, 7,225 m^2) where the unadjusted area from SubArea 2 (55 x 55 m, 3,025 m^2) is subtracted resulting in an adjusted SubArea 3 source dimension of 65 x 65 m (4,200 m^2). The source dimension of 65 m is entered into the SST for SubArea 3.

Unadjusted and Adjusted Source Dimensions

Area	Source Dimension (Unadjusted) (m)	Source Length (Un-adjusted) (m)	Adjusted Source Dimension Excluding Inner SubAreas
SubArea 1a	20 x 20 (400 m.2)	20	20 x 20 (400 m.2)
SubArea 1b	20 x 20 (400 m.2)	20	20 x 20 (400 m.2)
Subarea 2	55 x 55 (3,025 m.2)	55	47.2 x 47.2 (2,225 m.2 = 3,025 - 400 - 400)
Subarea 3	85 x 85 (7,225 m.2)	85	64.8 x 64.8 (4,200 m.2 = 7,225 - 3,025)

Entering these source dimensions and the other input parameters into the SST results in the following SRGs:

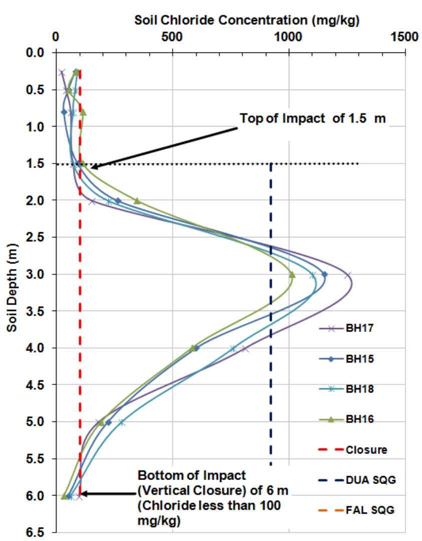
SubArea		Aquatic Life		DUA		Livestock	Irrigation	Root Zone
		SQG	Final BAF	SQG	Final BAF	SQG	SQG	SQG (mg/kg)
Area 1A		3500	0.35	920	0.29	2000	NGR	1600
Area 1B		3500	0.35	920	0.29	2000	NGR	1600
Area 2		1000	0.17	900	0.29	2500	NGR	2900
Area 3		380	0.13	300	0.13	2500	NGR	2900
SUM			1.00		1.00	NA	NA	NA

Different BAF values can either be tested with the SST or in Microsoft Excel or other similar software platform before running final SST runs where BAF factors are included for final reporting. The BAFs can be pre-assessed because the SRGs are linear in relationship to the size of the chloride buffer for the DUA and FAL pathways.

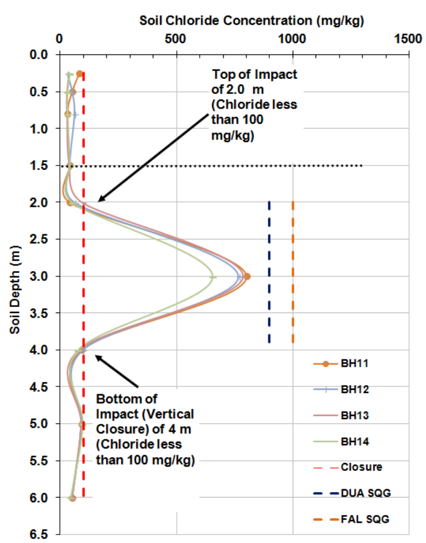
The subsoil chloride SRGs summarized above can be compared with measured vertical chloride concentrations as shown below. For the FAL and DUA pathways, no remediation would be required for SubAreas 2 and 3 as measured concentrations were below SRGs throughout the impacted depth profile. For SubAreas 1A and 1B, chloride concentrations exceed the DUA SRG, indicating remediation is required in order to achieve closure. An excavation depth of 3 m resulted in a DUA SRG for these two SubAreas of 1,300 mg/kg. Comparing with the measured concentrations shown in the vertical profiles below, no further subsoil remediation would be required for this example site. Soils from 0 to 1.5 m with chloride less than 100 mg/kg could be salvaged and re-used as backfill. Root Zone EC and SAR values would still require an assessment to ensure they meet ESRD (2014a) Tier 1 SRGs.

Vertical Chloride Profiles by SubArea with DUA and FAL Subsoil SRGs

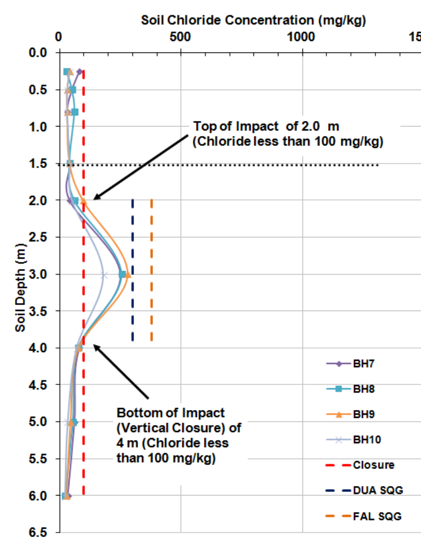
SubArea 1A&B (20x20 & 20x20m)



SubArea 2 (47x47m)



SubArea 3 (65x65m)



2.16 Example of SST Input Parameters Table

An example summary table of SST input parameters is shown below. Similar tables should be provided in SST submissions to ESRD.

TABLE OF SST INPUT PARAMETERS FOR EXAMPLE SITE

SST Input Parameter	Value	Units	Notes
Tier of Guideline	2A	- -	
Land Use	Agricultural	- -	See Report Figure x.
Subregion and Climate Moisture Index Category	Central Parkland, Dry	- -	Based on site LSD
Nearby Dugout used as a fish farm?	No	- -	See Report Section x.
Water Table Depth	2 to 4 (3)	m	Transition depth from brown to grey saturated fine soils at approximately 3 m – see Report Appendix x and Table x.
Sulphate in soil	1,425	mg/kg	Based on arithmetic mean of six background boreholes with sample depths from 1.0 to 5.0 m (2 m above/below estimated water table depth) – see Report Table x.
Carbonate in soil	0	mg/kg	Not measured
Bicarbonate in soil	0	mg/kg	Not measured
Saturation % for TDS in shallow groundwater calculation	55	%	Arithmetic mean of data used to calculated background sulphate in soil – see Report Table x.
Calculated TDS in Groundwater	5,913	mg/L	Calculated with the SST
Heavy clay in subsoil (2 to 4 m)	No	- -	Saturation less than 80%, textural analysis indicated clay content from 26 to 41%, average of 35% – see Report Table x.
DUA depth or max. drill depth	18	M	Deepest drill depth and no DUA found – see Report Table x.
Source Length	20 x 20 20 x 20 47 x 47 65 x 65	m m m m	Area 1A – see Report Figure x Area 1B Area 2 (unadjusted = 55 x 55 m, adjusted = 47 x 47 m) Area 3 (unadjusted = 85 x 85 m)
Distance to surface waterbody that is an aquatic life receptor	502	m	Closest distance in any direction from the site from the edge of the impact to the high water mark edge – see Report Figure x.
Average Root Zone background saturation % (1.0 to 1.5 m)	49.82	%	Calculated, see Report Table x.
Average Root Zone background EC (1.0 to 1.5 m)	5.1	dS/m	Calculated, see Report Table x.
95th Percentile Root Zone background EC (1.0 to 1.5 m)	8.2	dS/m	Calculated, see Report Table x. Note: no outliers. See Table x for outlier analysis. Label / Depth / Sat% / EC (dS/m) / Chloride (mg/kg) BH1 / 1.25 / 48 / 3.8 / 55.2 BH2 / 1.25 / 49.2 / 6.5 / 22.3 BH3 / 1.25 / 50 / 3.9 / 16.5 BH4 / 1.25 / 51 / 8.8 / 94.6 BH5 / 1.25 / 50.2 / 3.2 / 12.6 BH6 / 1.25 / 50.5 / 4.6 / 66.3
Root Zone SCARG Guideline (1.0 to 1.5 m)	10	dS/m	Poor soil quality category based on the 95th percentile, no outliers, no two category jump
Top of Impact	1.5 1.5 2 2	m	Area 1A – see Report Figure x and Table x Area 1B Area 2 Area 3
Bottom of Impact	6 6 4 4	m	Area 1A – see Report Figure x and Table x Area 1B Area 2 Area 3
Soil Lithology	fine	‘- -	Based on laboratory soil textural analysis, borehole logs, and saturation percentage data from unimpacted boreholes

SST Input Parameter	Value	Units	Notes
Final Buffer Allocation Factor	FAL DUA 35 29 35 29 17 29 13 13	%	Note: FAL and DUA buffers each add to 100%: Area 1A – see Report Figure x and Table x Area 1B Area 2 Area 3
Type of Root Zone Analysis	Unimpacted Unimpacted Unimpacted Unimpacted	- -	Area 1A – see Report Figure x and Table x Area 1B Area 2 Area 3
Measured vertical gradient	N/A	m/m	Not applicable – Tier 2A
Lateral hydraulic gradient for Shallow Groundwater	0.028	m/m	Default for Tier 2A
Lateral hydraulic conductivity for Shallow Groundwater	2E-07	m/s	Default for Tier 2A – fine soils
Lateral hydraulic gradient for Deep Groundwater	0.028	m/m	Default for Tier 2A
Lateral hydraulic conductivity for Deep Groundwater	5E-09	m/s	Default for Tier 2A – fine soils
Background groundwater chloride at aquatic life receptor	30	mg/L	Default for Tier 2A
Background chloride in the DUA	30	mg/L	Default for Tier 2A
Lateral gradient for the DUA	0.028	m/m	Default for Tier 2A
Lateral conductivity for the DUA	1E-06	m/s	Default for Tier 2A

A similar type of table must be submitted with SST SRGs showing details on input parameter calculations

3 SITE INFORMATION REQUIREMENTS

Basic site information must be collected for the calculation of Tier 2A and Tier 2B guidelines:

1. Tier selection;
2. Land use;
3. Natural Subregion;
4. Dugout as fish farm; and,
5. User information
    - Location LSD;
    - Site Name;
    - Nearest centre to the site (information for scenario tracking).

3.1 Tier Selection

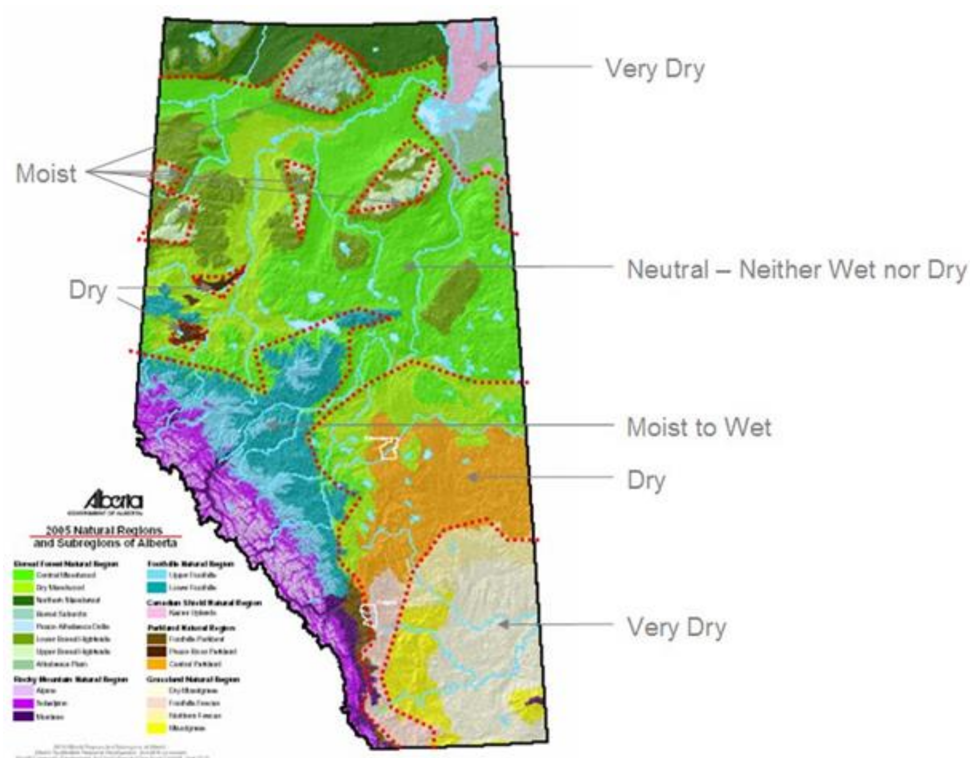
The selection of Tier 2A or Tier 2B guidelines is based on site-specific information and site characteristics. The tiered paradigm does not require that simple sites automatically default to a Tier 2A approach, which is associated with a greater number of conservative assumptions. The primary purpose of the Tier 2A approach is to provide a rapid screening method for developing guidelines in the absence of installed monitoring wells and measured groundwater data, and consequently more conservative assumptions are made to account for the lack of site specific data.

3.2 Land Use

Land use selection will determine relevant receptors and pathways of exposure applicable for the development of SRGs. The land uses defined by ESRD (2014a) are Agricultural, Natural areas, Residential/Parkland, Commercial and Industrial. If a SST assessment is being conducted for a commercial, industrial, or residential property that is adjacent to agricultural lands, a toggle must be selected in the SST and the distance from the edge of the chloride impacted area to the agricultural lands must be estimated and entered into the SST.

3.3 Natural Subregion and Climate Moisture Index Category

The SST software program will determine the natural Subregion applicable for a site based on the township designation (Alberta Township System) entered by the user. The natural Subregion will determine the Climate Moisture Index (CMI) category for a site and associated drainage rates. If the township falls within 2 CMI zones, the selection can be made using professional judgment and observations of native vegetation in the vicinity of the site, compared against reported vegetation types that occur within different Subregions.



Vertical recharge/discharge rates, determined in part by the selected Subregion and associated CMI, can be overridden by the application of a site-specific vertical gradient, calculated from seasonal average nested well elevation data under a Tier 2B approach.

3.4 Nearby Dugout Used as a Fish Farm

The potential exists in Alberta for dugouts to be used as fish farms. If a dugout exists near the site area (within 500 m any direction from the site under Tier 2A, or 500 m downgradient of groundwater flow under Tier 2B) that has in the past been used, or is currently being used as a fish farm, the aquatic life chloride guideline of 120 mg/L is applied. This can be determined based on field observation and landowner discussions. In situations where a nearby dugout is a fish farm, the distance to the dugout is entered into the SST as the distance to aquatic life receptor, providing that distance is shorter than the distance to a natural water body that meets the definition of an aquatic life receptor.

Blue Arrow – groundwater flow direction for a Tier 2B assessment

3.5 Soil Lithology

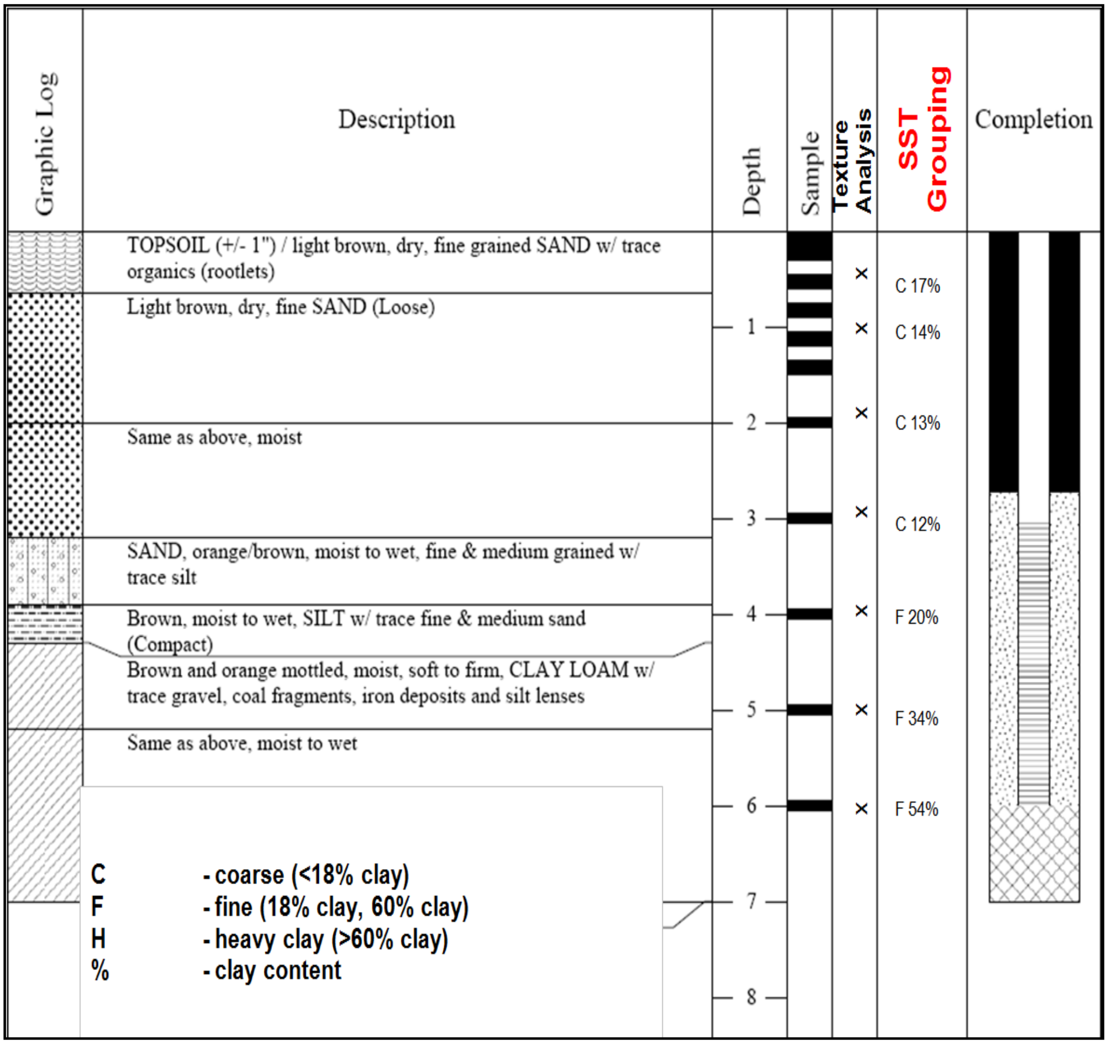
An understanding of soil lithology is a requirement for the development of subsoil SRGs. Laboratory data for soil texture are required to develop borehole logs of soil lithology that are less influenced by field investigator judgment, since judgments vary between practitioners and educational backgrounds. (*e.g.*, one practitioners silty clay may be another practitioners sandy loam). Soil texture (% sand, %silt, %clay) data are required for:

1. boreholes located within the salt impacted area;
2. background boreholes within the deeper portion of the root zone (1.0 to 1.5 m soil depth for the SST, although it is recommended that data be collected for a typical topsoil depth (0 to 0.3 m) and the shallower root zone (0.3 to 1.0 m)); and,
3. material intended to be used as backfill.

For selected boreholes in the salt impacted area, a minimum of three textural analyses are required for each unique and significant soil lithology unit identified in the field, for integration into the development of borehole log interpretations. A minimum of three textural analyses are required for the root zone over the 1.0 to 1.5 m depth interval for background locations, and it is recommended that a minimum of three samples be collected at shallower soil depths. For backfill material, a minimum of three textural analyses are required. The % sand, % silt and % clay should be noted from laboratory results and soils classified into the following general categories for use within the SST:

1. Heavy Clay Soil: clay content > 60%;
2. Fine Soil: clay content 18 to 60% (includes clay, silty clay, silty loam); and,
3. Coarse Soil: clay content < 18% (includes sandy loam, silt, loamy sand, sand).

Soil textural information can be recorded in tables or on borehole logs for site-specific SST guideline documents submitted to ESRD. An example of a borehole log that includes a recording of depth intervals where textural analyses are collected as well as the SST equivalent textural category is provided below.



This is an example of reporting requirements. Soil texture profiles must be reported, but do not necessarily have to be incorporated into borehole logs, and can be provided in tabular or graphical form.

Thick sand/gravel deposits that meet the definition of a DUA are not considered to be soil lithologies through which salinity is modeled for vertical or lateral transport in the SST. These deposits would be considered receptors of concern. A Tier 2C assessment would be required because the impacts are already within a DUA. The SST models salinity transport to receptors of concern, not within receptors of concern.

Muskeg or peat layers have not been incorporated into the SST. The SST can be used to develop guidelines for mineral soils beneath peat layers. ***Guidelines produced by the SST are not applicable to depths intervals of muskeg/peat***. Consult ESRD for assistance with determining appropriate salinity guidelines for muskeg/peat layers.

3.5.1 Use of Soil Saturation Percentage Data to Assist with Determining Soil Texture

As a means to further evaluate soil texture, laboratory saturation percentage can be examined. Saturation percentage is the ratio of water to soil in a saturated paste, multiplied by 100 (United States Salinity Laboratory Staff, 1954). As reported by Stiven & Khan (1966), saturation percentages are generally based on clay content of soils. Generally soils with low clay content have a lower saturation percentage and soils with a higher saturation percentage have a higher clay content, excluding organic soils. Due to relatively large concentrations of organic constituents in organic soils, a greater amount of water is required to create a saturated paste and thus high saturation percentages are also indicative of organic soils. As a rough approximation, soils can be generally classified into textural groupings based on the following soil saturation percentages:

- Low clay concentrations (*i.e.* <18% clay) 20% - 45%
- Medium clay concentrations (*i.e.* 18% - 60% clay) 45% - 70%
- High clay concentrations (*i.e.* >60% clay) 70% - 120%
- Organic soils 90% - 130%

Additional Alberta-specific analyses have been conducted under contract to PTAC examining relationships between saturation percentage and soil texture, which may be of use to proponents conducting SST assessments (Equilibrium, 2014). Soil saturation percentage data from boreholes/monitoring wells located within areas with sodium chloride impacts should not be included in this analysis, since elevated SAR values combined with lower EC values can lead to clay swelling and dispersion, which in turn can influence saturation percentage. Preferentially, data is used from background boreholes providing soil texture in the surrounding background is similar to the impacted area. Ultimately, the choice of soil lithology entered into the SST is based on laboratory textural analysis. Saturated paste information is considered supplementary for selecting soil lithology input parameter selection.

3.5.2 Selection of Soil Lithology

The arithmetic average % clay content is calculated outside of the SST (the SST does not perform this calculation) for soils at various depths across the site. This information is combined with borehole logs to select an appropriate soil lithology. A single lithology is selected for the SST Version 2.5.3 in comparison to Version 2.5.2 where lithology was segregated into depth intervals shallower and deeper than 1.5 m.

Lithology selection in Version 2.5.3 is primarily based on determining the texture that governs the fate and transport of salinity impacts at a site. For example, a site that is predominantly fine textured with limited thickness coarse continuous layers can be run as fine (as opposed to coarse). However, consideration must be given to preferential transport for relevant receptors of concern. One regularly occurring scenario where components of fine and coarse textured transport require additional consideration is the presence of a continuous saturated coarse interval that ‘connects’ the source of salinity impact with a receptor of concern. For example, a 0.4 m thick and continuous sand unit is encountered within the saturated zone and within the depth interval of salinity impact. This unit is continuous between the salinity impact and the nearest downgradient aquatic life receptor into which salinity from the site may discharge. A toggle has been added to the SST to address this scenario to ensure that as a minimum, groundwater properties for a coarse soil are selected to develop appropriate SRGs for the FAL receptor where there is a continuous coarse interval between the salinity impact area and relevant FAL receptor.

Sites can be divided into SubAreas as a function of soil texture. If half of the site (laterally) is continuously fine and half is continuously coarse, two different scenarios must be run through the SST. If there is unresolved uncertainty regarding the appropriate texture for selection, practitioners can determine the most sensitive texture that produces the lowest subsoil SRGs for protection of receptors of concern and apply these SRGs to the entire site. The generation of site-specific texture-relevant SRGs are however preferred.

The final selection of soil lithology requires professional judgment and an understanding of fate and transport as well as pathways of exposure for receptors of concern. Several examples are provided below to assist with the site-specific selection of appropriate lithology in the SST.

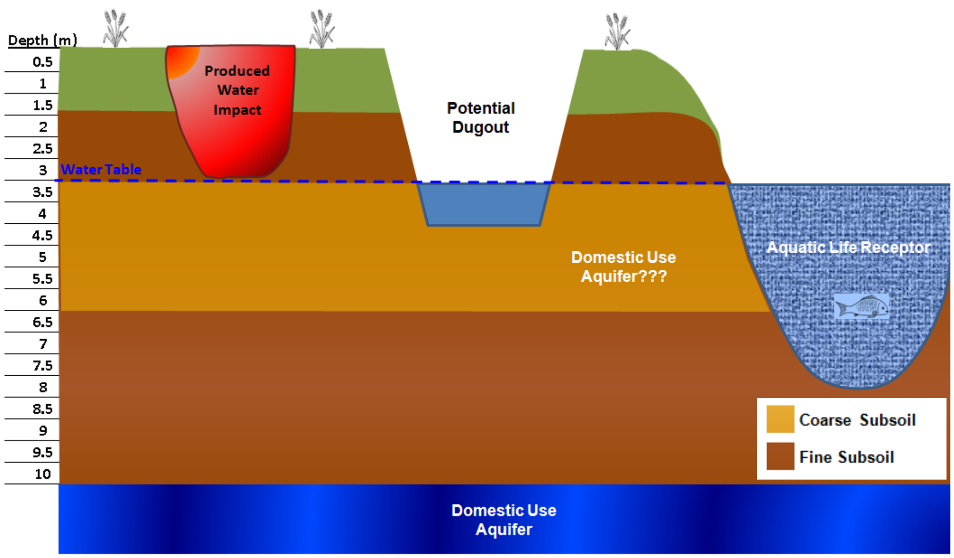
Example #1

The first example has a salinity impact within the vadose zone at depths shallower than 3 m (see Figure below). The water table is similarly shallow (3 m) and the root zone is impacted. The top to bottom of impact is 1.5 to 3.0 m. Soils are fine to a depth of 3 m, coarse from 3 to 6 m, and fine from 6 to 10 m.

Tier 2A

A fine soil texture would be entered into the SST for this example. The impacts are located within fine soils. Because a saturated thick coarse interval was identified from 3 to 6 m, due to a lack of monitoring well data at a Tier 2A level of assessment, the DUA would be assumed to be located at 3 m. If elevated chloride concentrations were identified within the coarse interval, a Tier 2B assessment would be required as the possibility would exist that a DUA has been impacted. If chloride closure (<100 mg/kg) is obtained shallower than the coarse interval, then a Tier 2A assessment is acceptable.

For the dugout pathway, although part of the key depth interval of 2 to 4 m is located within coarse soils, the salinity impacts within fine soils must leach downward at fine textured governed rates prior to entering the dugout. As a result, a fine texture selection is appropriate for the dugout scenario. This similarly applies to the DUA pathway. For the root zone, impacts must be transported within the fine till. For the FAL receptor, a fine texture would be applicable. However, a continuous saturated coarse interval is present, which may connect the salinity impact with a FAL receptor. Version 2.5.3 has a toggle where default coarse parameters are used for shallow groundwater (*i.e.*, hydraulic conductivity of $2x10^{-6}$ m/s and hydraulic gradient of 0.028) to ensure the derived SRGs are appropriate for the site where continuous coarse intervals are encountered in predominantly fine till.



Tier 2B

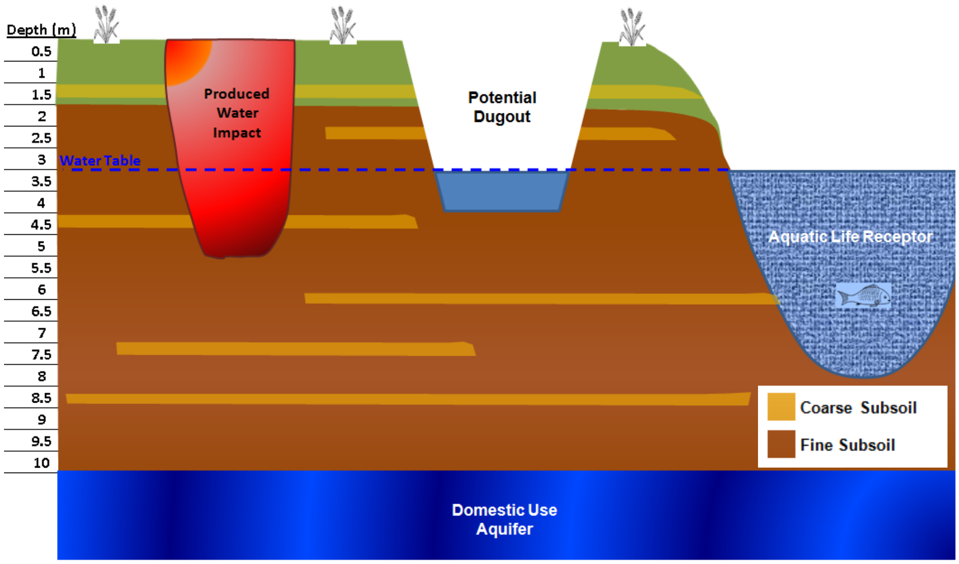
For a Tier 2B assessment, a fine lithology would be selected (as per Tier 2A) for calculating SRGs. For the FAL receptor, fine lithology would be appropriate for the same reasons as Tier 2A, with the exception that monitoring wells would be screened within the coarse interval and site-specific values for the hydraulic gradient and conductivity of shallow groundwater would be determined. The conductivity of wells within the coarse interval could be used to determine whether this unit is a DUA. Similarly, a pump test could be completed on the wells for a similar determination.

Given a water table of 3 m, fine textured subsoil from 1.5 to 3 m, coarse saturated subsoil from 3 to 6 m, if a site-specific vertical gradient is to be determined, it will be necessary for the installation of multiple wells nests. A nest within the coarse interval could be utilized to develop SRGs for the root zone, FAL, and dugout receptors. Nested well data from the underlying fine textured soil (from 6 to 10 m) would be required for the DUA receptor, providing the shallower coarse interval was not identified as a DUA. The installation of vertical nested wells for this type of lithology scenario is discussed in greater detail in a subsequent section of this manual.

Example #2

A second example involves a scenario with a water table at 3 m, an impacted root zone, and a top to bottom of impact of 1.5 to 5 m (see Figure below). Soil lithology is characterized by predominantly fine textured soil, with discontinuous relatively thin bands (< 0.5 m) of coarse soil at multiple depth intervals. The maximum depth of drilling was 10 m, which was assumed to be the depth to a DUA since a > 0.5 m thick coarse interval was not identified at a shallower depth.

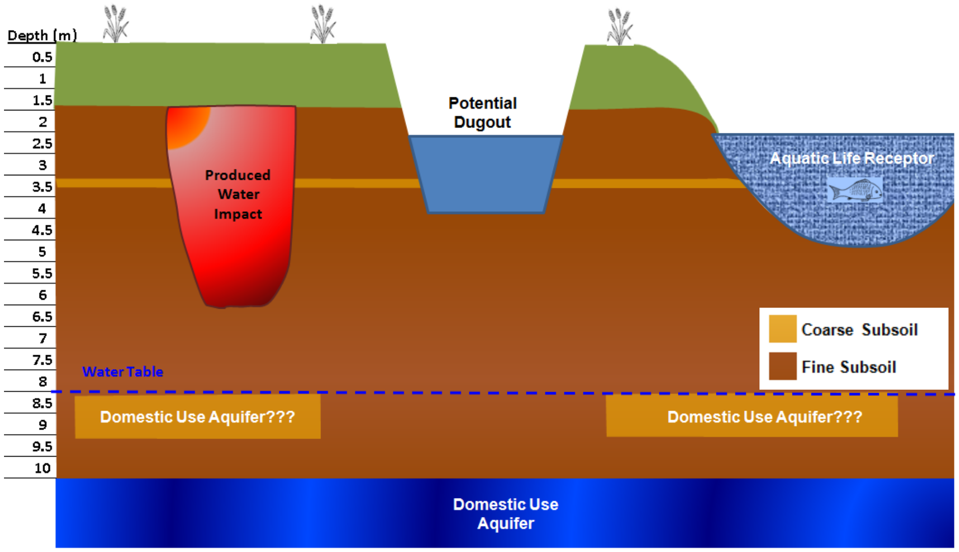
Tier 2A
Under Tier 2A, a fine soil lithology would be selected. Vertical transport for this lithology scenario will be governed by fine textured soils since discontinuous coarse intervals from 5 to 10 m will have a limited effect on net vertical water movement. For the FAL receptor, sufficient conservatism has been built into the SST so that relatively thin or laterally discontinuous coarse intervals, in close proximity to the water table depth, will have a minimal effect on the SRG for predominantly fine textured subsoil with frequent but discontinuous coarse intervals. None of the coarse intervals had a thickness greater than 0.5 m, and the DUA depth is set at the maximum depth of drilling (10 m).



Tier 2B
Under Tier 2B, a fine textured soil would similarly be selected. Shallow groundwater wells would be required with screen intervals installed near the water table surface. Deep groundwater wells may be installed as an option to provide conductivity and gradient information for soils from 5 to 10 m, which would be used in the SST to determine the rate of lateral plume attenuation as it leaches vertically towards the DUA. A vertical nest could also be installed to determine a site-specific vertical gradient. The wells should be installed within the fine till and without a coarse interval between the nested well screens.

Example #3

A third example involves a scenario with a water table at 8 m, an unimpacted root zone, and a top to bottom of impact of 1.5 to 6 m (see Figure below). Soil lithology is characterized by fine textured soil, with a continuous and relatively thin interval (< 0.5 m) of coarse soil at 3.25 m and a relatively thicker, laterally discontinuous, coarse interval from 8 to 9 m.

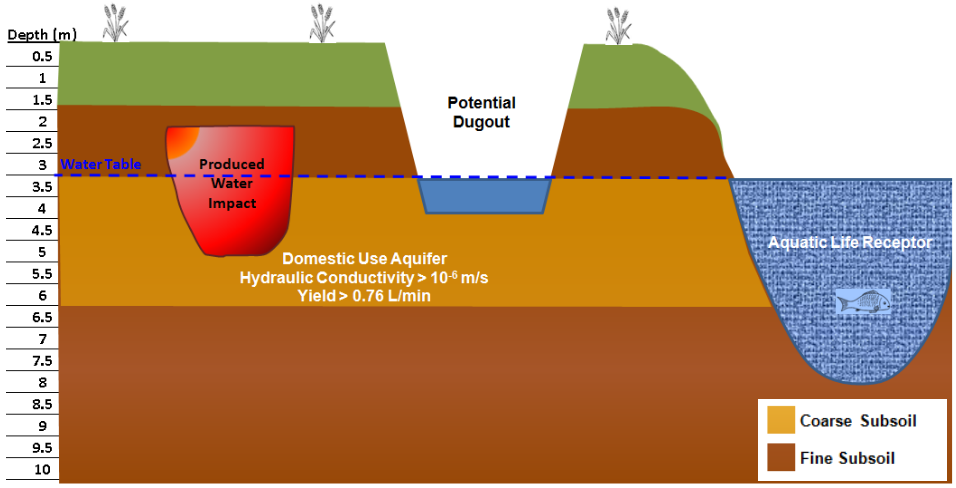


Tier 2A
Under Tier 2A, a fine lithology would be entered into the SST. The root zone scenario would be an Unimpacted Root Zone. The dugout pathway is eliminated as the water table is deeper than 4 m. The thin coarse continuous interval at 3.5 m is thinner than 0.5 m and as a result it is not considered a DUA. Furthermore, this interval is within the vadose zone and is unsaturated. For the FAL receptor, the lithology is fine and the key vertical breakthrough depth interval is the shallow water table at 8 m. The coarse soil toggle for the FAL pathway should be checked since the lithology at the water table has relatively thick and not uncommon coarse intervals. For the DUA, a fine texture would be appropriate as the salinity impacts must leach through fine textured soils in order to reach the DUA. In the absence of slug test and pump test information and more detailed groundwater characterization, under a Tier 2A approach the discontinuous coarse intervals at 8 m must be assumed to be a DUA.

Tier 2B
Under Tier 2B, the lithology would similarly be fine for all receptors. The dugout pathway is eliminated based on water table depth. For the FAL receptor, monitoring wells screened across the shallow water table at 8 m would be required to derive site-specific hydraulic conductivity and gradient information. If hydraulic conductivity measurements from wells screened within the discontinuous coarse intervals at 8 m are greater than $1x10^{-6}$ m/s, the DUA must be assumed to at a depth of 8 m unless pump tests are conducted. If pump test results suggest a yield of 0.76 L/min can be met, the DUA is located at 8 m. If results suggest a yield of less than 0.76 L/min, the DUA is located at 10 m, which is the maximum depth of drilling.

Example #4

A fourth example involves a scenario with a water table at 3 m, an unimpacted root zone, and a top to bottom of impact of 2 to 5 m (see Figure below). Soil lithology is characterized by fine textured soil to a depth of 3 m, a coarse textured soil from 3 to 6 m, and a fine textured soil from 6 to 10 m.



Tier 2A

Under Tier 2A, the DUA is assumed to be at 3 m, which is the top of a continuous coarse interval (>0.5 m thick) characterized by clay contents < 18%. Given that impacts have been identified within the coarse interval, assumed to be a DUA, a Tier 2B assessment must be conducted – a Tier 2A assessment can not be applied for this scenario.

Tier 2B

Under a Tier 2B assessment, it is necessary to screen wells within the saturated coarse interval that may be a DUA. If the hydraulic conductivity results, in addition to pump test results if conducted, indicate the unit is a DUA, then it is necessary to determine the chloride concentration in the DUA within the impact area. If the DUA chloride concentration is less than 210 mg/L, it is possible to conduct a Tier 2B assessment and calculate appropriate SRGs. The site would be run as a fine texture since the objective is to define SRGs for the remediation of impacts outside of the DUA and to prevent future DUA concentrations from exceeding the aesthetic chloride drinking water objective of 250 mg/L. If monitoring well data for the DUA indicate that chloride concentrations exceed 210 mg/L, a Tier 2C guideline approach is required and Risk Management/Exposure Control measures should be implemented for the DUA pathway while a Remediation Action Plan is being developed. In this situation, closure can not be obtained.

4 MINIMUM GROUNDWATER INFORMATION AND PARAMETERS

Minimum groundwater investigation requirements are necessary for the development of Tier 2A and 2B guidelines. These are **minimum** requirements, and there are situations where the collection of data beyond the minimum will improve the accuracy and defensibility of SRGs calculated by the SST. The purpose of having minimum requirements is to avoid situations where site characterization work is insufficient, or poorly targeted, which would lead to the derivation of SRGs that have less accuracy in terms of predicting potential risk. Furthermore, additional data collection can refine areas and depths targeted for remediation, resulting in a lower probability for overestimating soil volumes requiring remediation, which would involve excavating and disposing of soils that were not associated with an unacceptable risk of potential adverse effects. Proponents must demonstrate that they have investigated and characterized the site appropriately, and have considered the minimum investigation requirements outlined herein.

4.1 Water Table Depth

The depth of the water table is a parameter in the SST that primarily influences SRGs for livestock and irrigation watering, FAL, and the DUA. SRGs for the livestock and irrigation watering pathways are determined based on the predicted peak chloride breakthrough concentrations occurring between the depth of the water table and a maximum depth of 4 m. The pathways can be eliminated if the water table is greater than 4 m. SRGs for the FAL pathway are dependent on the peak chloride concentration occurring at the water table depth, as well as peak concentration attenuation during subsequent lateral transport towards the FAL receptor. SRGs for the DUA are influenced by the water table depth as this determines the thickness of the saturated zone over which lateral attenuation of the saline plume can occur during downward leaching of chloride impacts towards a DUA.

4.1.1 Tier 2A

The average water table depth under a Tier 2A approach is determined from observations and recordings during the drilling of site investigation boreholes. Detailed logging of soil lithology, transitions, and characteristics such as colour and degree of saturation will improve the estimation of an appropriate water table depth for entry into the SST. For estimating the water table depth under Tier 2A approach, the following characteristics can be used as a minimum:

1. soil lithology information – transition from brown mottled fine till to grey till can be indicative of a longer-term historical water table depth; and/or,
2. transitions from dry or partially saturated soils to saturated soils, or the presence of water in the borehole once a certain depth has been reached, can be indicative of the general depth of the water table.

If the water table is not identified based on soil information (*e.g.*, presence of brown/grey interfaces, water flowing into the borehole during drilling, *etc.*), the user selects the maximum depth of drilling as the water table depth (*i.e.*, it is assumed the water table is at the maximum drill depth). This is not a conservative assumption if the water table was shallower. For Tier 2A assessments, groundwater ranges (*e.g.*, 2 to 4 m) are defined to reflect the absence of measured data from monitoring wells. The midpoint of the range is used to calculate SRGs. An example is provided below:

Borehole	Relevant Log Notes	Located within the Impact Area?	Estimated Water Table Depth (m)
BH11-01	Transition from brown to grey at 3.5 m, soils had a greater moisture content at 3.7 m	No	3.5
BH11-02	Soils were saturated at 4 m, water began filling the auger hole	No	4.0
BH11-03	Transition from brown to mottled to grey with mottling starting at 3 m and grey soils at 3.75 m, greater moisture content in soils at 3.75 m	No	3.75
BH11-04	Soils were saturated at 3.25 m, water began filling the auger hole	No	3.25
BH11-05	Borehole dry to maximum drill depth of 6 m, brown loam till and no transitions to grey	Yes, but EC/SAR close to background levels with similar texture at same depth	- - [1]
BH11-06	Soils were saturated at 3.6 m, water began filling the auger hole	No	3.6
Average: **SST Tier 2 A Selection:**			**3.6; 2 – 4 m SST Bucket**

1- A value of 6 m could be used to assist in calculating the average, but given the number of boreholes with measured shallower water table depths, there may be a specific rationale for this borehole being dry to 6 m (top of a knoll in a background area for example). If all boreholes were dry to 6 m, a 6 m water table depth would be entered into the SST

4.1.2 Tier 2B

To determine the average water table depth under a Tier 2B approach, a minimum of three monitoring wells is required. The wells can be located in background or impacted areas, although an absence of wells in background locations can complicate the calculation of background TDS concentrations in groundwater (see next section). If there are distinct SubAreas in terms of groundwater depth (*e.g.*, coarse till portion of the site with a deep water table of 7 m and a fine till portion of the site with a shallow water table of 3 m), a minimum of three monitoring wells would be required for each SubArea to determine the average water table depth per SubArea. Each SubArea would be run as a distinct scenario in the SST. A minimum of two monitoring events is required to calculate an annual average depth. The events should occur during distinct seasons (*e.g.*, summer, fall). The use of data collected during periods where the water table may be higher due to snowmelt or heavy spring rains must be avoided.

Certain factors can influence the water table depth, and should be considered when selecting representative monitoring well locations. The water table depth can be shallower if there is an absence of vegetation (or poor plant growth) due to an associated reduction in transpiration. The water table can be shallower (or mounded) if historical discharges of produced water to an unlined pit occurred in an area of soils with lower hydraulic conductivity. It is not uncommon for a shallower water table to be located in closer proximity to a former flare or blowdown pit where historical disposal of saline water occurred, associated with radial groundwater flow in multiple directions away from the centre of the pit. Mounding of the water table in a salt affected area can also occur in fine till with elevated SAR values due to sodium in the produced water, resulting in swelling/dispersion of clay and reduced permeability. To minimize the influence of these factors on SST SRGs, water levels from monitoring wells more peripheral to the impact area are usually more appropriate for estimating the annual average water table depth. It should further be noted that wells screened across deep groundwater should not be combined with shallow groundwater wells for determining the shallow water table depth, because this inappropriately incorporates aspects of vertical gradient into the calculation of a water table depth. The example below meets minimum SST requirements, since more than three background monitoring wells are available with two monitoring events per well. The average water table depth can be rounded to the nearest metre (*e.g.*, 3.4 = 3.0 m, 3.6 = 4.0 m) for entry into the SST. Deep groundwater well data has been excluded from the calculation of the average shallow water table depth.

Well	Date	Screen Depth (Including Sand Pack)	Shallow Water Table Depth (m)	Deep Groundwater Depth (m)	Located within Impacted Area?
MW1A	July 2011	1.5 – 4.5	1.4	- -	No
MW1A	September 2011	1.5 – 4.5	2.2	- -	No
MW1B	July 2011	6.0 – 9.0	- -	2.9	No
MW1B	September 2011	6.0 – 9.0	- -	3.8	No
MW2	July 2011	2.0 – 4.0	1.9	- -	No
MW2	September 2011	2.0 – 4.0	2.1	- -	No
MW3	July 2011	1.5 – 3.5	2.1	- -	Yes, elevated chloride and SAR, but the water table was similar to other values at the site
MW3	September 2011	1.5 – 3.5	3.0	- -	- -
MW4	July 2011	7.0 – 10	- -	3.9	No
MW4	September 2011	7.0 – 10	- -	4.2	No
MW5	July 2011	5.5 – 8.5	- -	3.4	No
MW5	September 2011	5.5 – 8.5	- -	3.9	No
MW6	July 2011	1.0 – 4.5	1.2	- -	No
MW6	September 2011	1.0 – 4.5	2.1	- -	No
Average: SST Tier 2 B Selection:			**2.0 2 m**		

4.2 Background TDS in Shallow Groundwater

Background TDS in shallow groundwater is used for the development of SRGs for the livestock watering and irrigation watering pathways. Background TDS affects the size of the chemistry buffer in a potential future constructed dugout, which can be located anywhere on a site.

4.2.1 Tier 2A

Background soil concentrations of sulphate and bicarbonate (carbonate data can also be included, although carbonate concentrations are frequently non-detect) are used to estimate a background groundwater TDS concentration in the absence of monitoring well data. The estimated groundwater TDS concentrations are subsequently used in the SST to calculate SRGs for the irrigation water and livestock watering pathways. At sites where it is estimated the water table will be shallower than 4 m and the irrigation and livestock watering pathways may be active (*i.e.*, not eliminated), it is recommended that background boreholes (n=4 for Good soils, n=6 for Fair, Poor, Unsuitable soils) be drilled to a depth of 6 m with samples collected throughout the profile at depths of 1 to 1.5 m, 2 m, 3 m, 4 m, 5 m, and 6 m. Soil chemistry results should demonstrate chloride concentrations < 100 mg/kg at all sample depth intervals.

Chemistry data from soil sample collection depth intervals of ± 2 m above/below the estimated water table are used in the estimation of groundwater TDS. For example, if the water table is at 3 m, background soil sulphate, bicarbonate, and carbonate data from 1 to 5 m is used to estimate background groundwater TDS. If the water table is at 2 m, data from 0.3 m (or below the maximum topsoil depth) to 4 m is used. Topsoil samples are not to be used in the estimation of background groundwater TDS from soils data. Background groundwater TDS is estimated from concentrations of anions in soil using a pore water conversion algorithm, and milliequivalent ion balance, as shown in the equations below (the calculations are done internally in the SST). The average calculated sulphate can be done on a borehole by borehole basis, entered into the SST, and the average subsequently taken (average of the boreholes) or the average of all the data can be used and input once into the SST to estimate a groundwater TDS.

Borehole	Soil Depth (m)	Soil Sulphate (mg/kg)	Soil Bicarbonate (mg/kg)	Soil Carbonate (mg/kg)	Soil Chloride (mg/kg)	Saturation (%)	Average Calculated Sulphate (mg/kg)[2]	SST Calculated Ground water TDS (mg/L)
BH11-01	1.0	145	n.m.	n.m.	42	55		
BH11-01	2.0	162	n.m.	n.m.	34	58		
BH11-01	3.0	133	n.m.	n.m.	38	54	141.4	872
BH11-01	4.0	109	n.m.	n.m.	31	49		
BH11-01	5.0	158	n.m.	n.m.	40	61		
BH11-02	1.0	112	n.m.	n.m.	32	49		
BH11-02	2.0	118	n.m.	n.m.	24	68		
BH11-02	3.0	101	n.m.	n.m.	37	52	113.4	699
BH11-02	4.0	132	n.m.	n.m.	33	59		
BH11-02	5.0	104	n.m.	n.m.	26	53		
BH11-03[1]	1.0	127	n.m.	n.m.	27	58		
BH11-03[1]	2.0	133	n.m.	n.m.	38	57	123.7	763
BH11-03[1]	3.0	111	n.m.	n.m.	22	53		
BH11-04	1.0	106	n.m.	n.m.	8	48		
BH11-04	2.0	104	n.m.	n.m.	12	47		
BH11-04	3.0	103	n.m.	n.m.	14	49	106.0	654
BH11-04	4.0	101	n.m.	n.m.	7	52		
BH11-04	5.0	116	n.m.	n.m.	9	58		
Average:	- -	- -	- -	- -	- -		**121.1**	**705**
SST Calculated:	- -	- -	- -	- -	- -	- -	- -	**705**

1 – BH11-03 was drilled to a shallower depth of 3 m, however, the pattern of sulphate concentrations were similar and levels in other boreholes were not observed to increase at a deeper depth suggesting the average would be under-represented by one borehole having a shallower maximum depth of sampling

2 – the average calculated sulphate can be done on a borehole by borehole basis, entered into the SST, and the average subsequently taken (average of the boreholes) or the average of all the data can be used and input once into the SST to estimate a groundwater TDS

n.m. – not measured

Reporting requirements include a table showing measured background soil sulphate, bicarbonate, and carbonate (sulphate is required as a minimum) and soil saturation percentage as well as chloride concentrations. The corresponding calculation of arithmetic average anion concentrations must be provided and work should be shown.

Using soil samples 2 m above and 2 m below the water table to estimate TDS if the EC profile shows that the samples above the water table are consistent with samples below the water table.

4.2.1.1 Estimation of Groundwater TDS from Soil Salinity Anion Concentrations

A mathematical algorithm was used to estimate groundwater TDS from soil salinity, which included an adjustment to account for gypsum solubilisation during saturated paste extraction (versus pore water gypsum solubility) and the associated influence on estimated groundwater TDS concentrations. A greater amount of gypsum is solubilised in a saturated paste compared to pore water due to the addition of solvent or solubilizer (water) to make a paste. The adjustment is graphically shown below the following equation, and was based on empirical data funded by Environment Canada/PTAC (Equilibrium, 2012). The adjustment primarily affects estimated TDS concentrations greater than 1,600 mg/L, or sulphate pore water concentrations of approximately 1,100 mg/L and greater. It is assumed that half of the matching cation milliequivalent (for charge balance) is due to calcium and half is due to sodium. This essentially results in a factor for converting sulphate to TDS of 1.45. It should be noted that sulphate concentrations are reported in different manners, which can affect the estimation of background TDS in groundwater – this issue is address later in the manual.

$$if\ BSC_{SO4} < THLD$$

$$BGWC_{TDS} = \left(BSC_{SO4} \times \frac{\rho}{\theta_T} \times \frac{2}{MW_{SO4}}\right) \times (0.5 \times MW_{Na} + 0.5 \times MW_{Ca}) + \left(BSC_{SO4} \times \frac{\rho}{\theta_T}\right)$$

$$if\ BSC_{SO4} > THLD$$

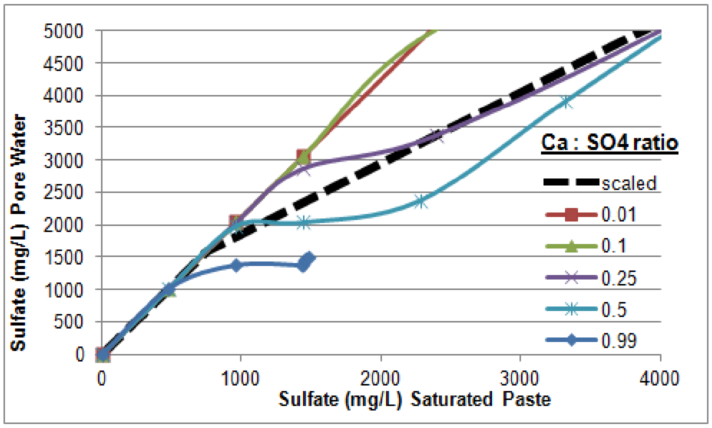
$$BGWC_{TDS} = \left\{\left([BSC_{SO4} - THLD] \times \frac{\rho}{\theta_T} \times \frac{2}{MW_{SO4}}\right) \times (0.5 \times MW_{Na} + 0.5 \times MW_{Ca}) + \left([BSC_{SO4} - THLD] \times \frac{\rho}{\theta_T}\right)\right\} \times ADJ + \left\{\left([THLD] \times \frac{\rho}{\theta_T} \times \frac{2}{MW_{SO4}}\right) \times (0.5 \times MW_{Na} + 0.5 \times MW_{Ca}) + \left([THLD] \times \frac{\rho}{\theta_T}\right)\right\}$$

where,

$BGWC_{TDS}$	=	Estimated Background Groundwater Concentration (mg/L) for TDS
BSC_{SO4}	=	Background sulphate concentration in soil (mg/kg, arithmetic average)
THLD	=	Threshold soil sulphate soil concentration (mg/kg) that results in an estimate sulphate pore water concentration of > 1,100 mg/L, above which changes in gypsum solubilisation is addressed fine soils 258 coarse soils 233 heavy clay 369
ρ	=	Dry bulk density of soil – texture dependent (g/cm^3) fine soils 1.62 coarse soils 1.685 heavy clay 1.4
Θ_T	=	Porosity – total (assumes saturated soils, unitless) fine soils 0.381 coarse soils 0.357 heavy clay 0.47
MW_{SO4}	=	Molecular weight of sulphate (96 g/mol)
MW_{Na}	=	Molecular weight of sodium (22.99 g/mol)
MW_{Ca}	=	Molecular weight of calcium (40.08 g/mol)
2	=	Adjustment for milliequivalent charge of sulphate
0.5	=	Adjustment for 50% of cation milliequivalent due to sodium and 50% due to calcium
ADJ	=	Adjustment Factor of 0.6 to account for reduced gypsum solubility at pore water sulphate concentrations > 1,100 mg/L – graphically represented below.

Note – this equation is internal to the SST and the tool user does not have to utilize the above mentioned thresholds or mathematical algorithms

The extent of gypsum solubilisation at concentrations greater than 1,100 mg/L is a function of the cation composition in solution. The graph below presents sulphate pore water concentrations as a function of sulphate saturated paste concentrations. Providing sulphate is the predominant anion and concentrations of other anions are relatively very low, greater proportions of calcium in solution (for example, a Ca:SO_4 ratio of 0.99 on a milliequivalent basis, which is a cation solution composed of 99% calcium) can cause the formation of gypsum ($CaSO_4$), which will precipitate out of the soil solution because of its low solubility. When water is added to a soil sample in order to make a saturated paste, some of the precipitated gypsum may re-dissolve. At low calcium levels in solution in a sulphate environment with minimal concentrations of other anions (for example, a Ca:SO_4 ratio of 0.01 where the cation solution is composed of 1% calcium), the sulphate is highly soluble (such as in the case of a predominantly sodium sulphate solution), and as a result the addition of solvent does not alter the sulphate concentration in a saturated paste compared to pore water. The dashed black line shows the scaled adjustment used in the SST.



Equilibrium, 2012

The contribution towards TDS from bicarbonate and carbonate is calculated in a similar manner, with exception of the absence of an adjustment factor. A similar approach is considered for determining the matching cation milliequivalent.

The saturation percentage of background soils is required. The arithmetic average of data from soil samples considered in the background dataset is entered into the SST, although it is not used to estimate background groundwater TDS and instead is used for tracking purposes and to provide additional information regarding background soils.

4.2.1.2 Laboratory Reporting of Sulphate

There are multiple expressions of sulphate data used by analytical laboratories in Alberta. Examples are provided below:

- Soluble Sulphate (SO4)
- Sulphur as Sulphate
- Sulphate (SO4-S)
- **Sulphate-S**
- Sulphate (SO4)
- Sulphate

In all of above listed cases, with one exception, the values reported by laboratories are for sulphate and account for the molecular weight of sulphur and four oxygen atoms. These numbers can be directly used to calculate background TDS. The exception is the reporting of sulphate as **Sulphate-S**. If the starting data being used is on a milliequivalent basis, the following adjustment does not need to be made. But if reported in units of mg/L saturated paste or mg/kg soil, the **Sulphate-S** concentrations need to be multiplied by three (molecular weight of sulphate (96) divided by the molecular weight of sulphur (32), both having a 2- charge. The other ways of reporting sulphate do not require an adjustment.

$$SO_4 = (Sulphate - S) \times \frac{96}{32}$$

Where,

SO_4	=	sulphate as sulphate
Sulphate-S	=	sulphate reported on a sulphur mass basis (units of mg/L or mg/kg)

96 = molecular weight of sulphate
32 = molecular weight of sulphur with a 2- charge

It should be noted that laboratory measurement techniques for sulphate that involve Inductively Coupled Plasma (ICP) typically are measuring the mass of sulphur, and adjustments are made internally by the lab (except when results are reported as sulphate-S) so that the results are reported as mass of sulphate – hence, Sulphur as Sulphate, or Sulphate (SO4-S). The ICP methodology (the method used by any lab can be found at the back of laboratory data sheets for a particular dataset) can measure other sulphur-based compounds, such as inorganic sulphur, thiosulphates, peroxodisulphates, sulphite, and sulphides, which may be expressed incorrectly as sulphate. Most laboratories will conduct ion balances to improve the accuracy of sulphate reporting when based on an ICP methodology. A more accurate method that is specific for detecting sulphate in soil (or water) is Ion Chromatography (IC).

Checking original laboratory data sheets is a requirement to determine the method of sulphate data reporting – summary tables of laboratory data completed by third parties may not necessarily report sulphate correctly and may also mistakenly report ion concentrations as mg/kg when they were reported by the lab in units of mg/L saturated paste. Incorrect guidelines may be calculated as a result of not checking original lab sheets.

4.2.2 Tier 2B

Background TDS in groundwater under a Tier 2B approach is calculated from data obtained from monitoring wells with low chloride concentrations (< 470 mg/L chloride, equivalent to 100 mg/kg chloride or closure in soil; see below for adjustments made to address elevated chloride concentrations when determining background TDS values). If an insufficient number of monitoring wells are located in background areas, data from background boreholes may be used to supplement the background groundwater dataset, as per a Tier 2A approach. For a Tier 2B analysis, a minimum of 3 background monitoring well locations (or background borehole locations with sufficient sampling depths and data to estimate groundwater concentrations) is required for calculating the arithmetic average background TDS. Two groundwater sampling events per monitoring well are required. TDS data from wells screened shallower than 6 m are acceptable; however data from groundwater wells screened at depths greater than 6 m are not used to determine background TDS because the dugout pathway is operational over the depth range of 2 to 4 m. . An example dataset is provided below.

Background monitoring wells generally will have chloride concentrations less than 30 mg/L (essentially background in most areas of Alberta), which will result in minor contribution towards TDS due to chloride. Technically, chloride concentrations of up to 470 mg/L in groundwater are within the range of what represent lateral and vertical chloride closure in the SST (*i.e.*, 100 mg/kg chloride in soil and considering a pore water conversion using soil bulk density and porosity). However, the use of monitoring well data with chloride concentrations above 30 mg/L will have an unacceptable influence on the calculated groundwater TDS concentration. For example, 470 mg/L chloride with an associated milliequivalent amount of cation could contribute more than 750 mg/L towards TDS, which exceeds the lowest boundary of the irrigation watering guideline (defines good irrigation water, 640 mg/L TDS).

The adjusted TDS is calculated according to the following equation, which must be completed in a software program (such as Microsoft Excel) outside of the SST. The contribution to TDS from chloride above 30 mg/L, and associated milliequivalent of cation (assumed to be 50% calcium and 50% sodium), is removed from the adjusted TDS value for each relevant data point. This can be accomplished by multiplying the chloride concentration in groundwater by a factor of 1.61 to estimate the equivalent TDS. For example, a chloride concentration of 60 mg/L would represent a TDS concentration of 96.4 mg/L, assuming the cations are composed of 50% calcium and 50% sodium. The factors for converting chloride (1.61) to TDS versus sulphate (1.45) to TDS differ in alignment with molecular weight differences.

$$BGWC_{TDS\_ADJ} = BGWC_{TDS} - \left\{\left([BGWC_{Cl} - 30] \times \frac{1}{MW_{Cl}}\right) \times \left(0.5 \times MW_{Na} + \frac{0.5}{2} \times MW_{Ca}\right) + [BGWC_{Cl} - 30]\right\}$$

Where,
$BGWC_{TDS\_ADJ}$ = Adjusted for Chloride Background Groundwater TDS Concentration (mg/L)
$BGWC_{TDS}$ = Measured Background Groundwater TDS Concentration (mg/L)
$BGWC_{Cl}$ = Measured Background Groundwater Chloride Concentration (mg/L)
MW_{Na} = Molecular weight of sodium (22.99 g/mol)
MW_{Ca} = Molecular weight of calcium (40.08 g/mol)
MW_{Cl} = Molecular weight of chloride (35.45 g/mol)
2 = Adjustment for 2+ charge of calcium
0.5 = Adjustment for 50% of cation milliequivalent due to sodium and 50% due to calcium
30 = Baseline acceptable background chloride concentration (mg/L) in a background monitoring well

A spreadsheet can be requested from SSThelp@eqm.ca for completing this calculation outside of the SST. Using the example dataset below, the unadjusted TDS (576.4 mg/L) that cannot be used because of the incorporation of a monitoring well with chloride concentrations above 30 mg/L was adjusted to a concentration of 459.1 mg/L, which could be entered into the SST. An alternate approach would involve calculating the average TDS using the three wells (minimum dataset requirement) with chloride concentrations less than 30 mg/L, which would equal 465.2 mg/L, and the one monitoring well with elevated chloride concentrations above 30 mg/L (MW6) would not be considered in the dataset. A similar result was obtained using either approach.

If only two monitoring wells were available for a particular site with lower level chloride impacts available, soil data from background soil boreholes could be included using the algorithms provided above to estimate a groundwater TDS concentrations. These values derived from soil boreholes can be averaged in with measured groundwater TDS concentrations from monitoring well data, to determine an arithmetic average background TDS for the site.

Well	Date	Screen Depth (Including Sand Pack)	Shallow Water Table Depth (m)	Deep Groundwater Depth (m)	TDS (mg/L)	Chloride (mg/L)	Adjusted TDS (mg/L)
MW1A	July	1.5 – 4.5	1.4		430	7.2	430
MW1A	September	1.5 – 4.5	2.2		376	11.1	376
MW1B	July	6.0 – 9.0		2.9	Not used	Not used	Not used
MW1B	September	6.0 – 9.0		3.8	Not used	Not used	Not used
MW2	July	2.0 – 4.0	1.9		389	13.6	389
MW2	September	2.0 – 4.0	2.1		490	13.1	490
MW3	July	1.5 – 3.5	2.1		536	21.4	536
MW3	September	1.5 – 3.5	3.0		570	22.6	570
MW4	July	7.0 – 10		3.9	Not used	Not used	Not used
MW4	September	7.0 – 10		4.2	Not used	Not used	Not used
MW5	July	5.5 – 8.5		3.4	Not used	Not used	Not used
MW5	September	5.5 – 8.5		3.9	Not used	Not used	Not used
MW6	July	1.0 – 4.5	1.2		896	312	442.9[1]
MW6	September	1.0 – 4.5	2.1		924	332	438.7[2]
Average Shallow Groundwater TDS					***576.4*** *Cannot be used due to MW6*		**459.1** *Input into SST*

1 – calculated by subtracting 30 mg/L chloride from 312 mg/L chloride (equals 282 mg/L), multiplying 282 mg/L by 1.61 (factor to adjust for cations) resulting in an estimated contribution to TDS of 453.1 mg/L, and subtracting 453.1 mg/L from 896 mg/L to determine an adjusted TDS of 442.9 mg/L – refer to equation above

2 – calculated by subtracting 30 mg/L chloride from 332 mg/L chloride (equals 302 mg/L), multiplying 302 mg/L by 1.61 (factor to adjust for cations) resulting in an estimated contribution to TDS of 485.3 mg/L, and subtracting 485.3 mg/L from 924 mg/L to determine an adjusted TDS of 438.7 mg/L – refer to equation above

Reporting requirements include a table showing measured background groundwater TDS and chloride, as well as the calculated adjusted TDS for locations with chloride concentrations up to 470 mg/L. The corresponding calculation of arithmetic average TDS concentrations must be provided. A spreadsheet can be requested from Equilibrium for completing this calculation outside of the SST.

4.3 Background Chloride in Shallow Groundwater

A background chloride concentration in shallow groundwater is required to provide an assessment of potential cumulative chloride exposure to aquatic life inhabiting the interface between surface water and groundwater (*i.e.*, sediment dwelling) from background and site-related impacts. The possibility exists for chloride concentrations to be naturally elevated under specific conditions. The possibility also exists that impacts have occurred adjacent to the nearest relevant surface water receptor due to a different site, in which case, the allowable chloride contribution from the site under study for the aquatic life pathway should be reduced since a reduced buffer is present upgradient of the surface water body (*i.e.*, the guideline is based to some extent on the potential for cumulative effects – existing and potential future impacts).

4.3.1 Tier 2A

Under Tier 2A, a default background chloride concentration in shallow groundwater of 30 mg/L is assumed. This value cannot be changed at the Tier 2A level of assessment. If there is evidence that an aquatic life receptor has been impacted with chloride by another site, a Tier 2B assessment is likely required including the measurement of chloride concentrations at the point of groundwater discharge into the impacted aquatic life receptor.

4.3.2 Tier 2B

Under a Tier 2B approach, background chloride concentrations in groundwater *at the point of discharge into a surface water body that can support an aquatic ecosystem (i.e., a FAL)* are required for development of the SRG for the FAL pathway. The background chloride concentration can be determined from a monitoring well screened across shallow groundwater and located immediately upgradient of the FAL. In general, it may prove to be impractical to install a well immediately upgradient of the FAL receptor as it may be hundreds of metres from the site and impacted area, in which case the Tier 2A default of 30 mg/L may be used in a Tier 2B scenario. However, if there is evidence that the aquatic life receptor of concern has been impacted by chloride from another site, data must be collected in terms of groundwater concentrations at the point of discharge into the aquatic life receptor so that cumulative risks can be properly addressed, and incorporated into the development of SRGs for the site.

4.4 DUA Depth

The depth to a DUA is used directly in the calculation of SRGs for the DUA pathway. The final SQG calculated by the SST for the DUA pathway is not just dependent on the depth of the DUA, more importantly it is the thickness of unimpacted till (buffer) between the base of chloride impact and depth of the DUA.

4.4.1 Tier 2A and 2B

The depth to a DUA is generally established using a similar investigation approach for both Tier 2A and 2B. It is determined based on borehole drilling coupled with careful logging of soil texture. During drilling, two situations may occur that could suggest a DUA depth has been identified:

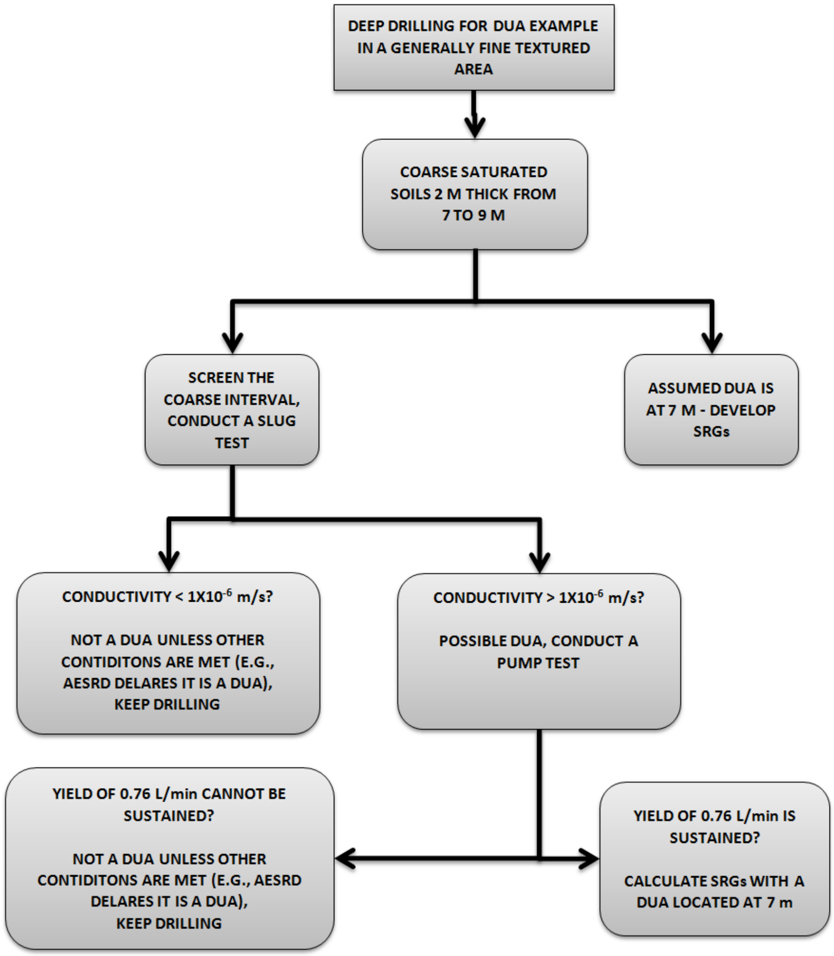
1. Presence of saturated coarse soils with a thickness of greater than 0.5 m (note, multiple thinner sand units can be grouped together and can potentially be considered a DUA depending on the depth interval over which they occur; see ESRD 2014a for further details); or,
2. Bedrock is encountered (not just auger refusal, bedrock should be identified).

The depth to a DUA becomes the depth to saturated coarse soils or bedrock. If these two situations are not encountered, the DUA depth is represented by the deepest depth of drilling to a maximum of 20 m. In Alberta, it is possible to encounter coarse saturated intervals of till with a thickness of greater than 0.5 m, which could potentially be defined as a DUA. Unless it is determined that such an interval is unsaturated, has a hydraulic conductivity of less than 10^{-6} m/s, or a yield following a pump test of less than 0.76 L/min, the unit is considered a DUA as defined by ESRD (2014a).

The SST was not designed to model salt ion transport through bedrock and typically the bedrock surface (excluding rafted bedrock intervals) is assumed to be the DUA depth. In some instances, it may be appropriate to model bedrock as if it was overlying till as per ESRD (2014a). Detailed investigations of bedrock would be required including a characterization of the extent and nature of fracturing. The development of SRGs that take into consideration transport through bedrock material should only be undertaken at the Tier 2C level of assessment.

Deep drilling for defining the depth of a DUA should be completed in a background (unimpacted) location, upgradient or cross-gradient from chloride impacts, and the borehole filled with bentonite (rather than drill cuttings), to avoid creating a preferential flow path between a salt impacted soil depth interval and a potential DUA located at a deeper depth. Preferably, the maximum depth of drilling will extend a minimum of 3 m beyond the maximum depth of impact to allow for some buffer thickness of unimpacted soil (soils with chloride concentrations < 100 mg/kg) in the calculation of a DUA SRG. The depth to DUA entered into the SST can be varied, and the influence on calculated guidelines for the protection of DUA pathway can be examined. In this manner, the proponent can evaluate the cost/benefit associated with deeper drilling in order to establish a more accurate measurement of the actual depth to DUA at a site.

Logic Flow Chart for Identifying a Potential DUA for Evaluation of Salinity Impacts in the SST



4.4.2 Regional Water Well Search

A regional water well search can be useful in identifying a unit that historically has been used as a DUA. The depth to a DUA however must be established from site-specific drilling work conducted at the site as part of a site investigation. Regional water well records can be variable and not necessarily reflective of conditions beneath a site that may produce a potential DUA, and thus a regional water well search is considered to be insufficient information by itself for identifying the depth of a DUA.

4.5 Distance to Aquatic Life Receptor

The distance to a Freshwater Aquatic Life (FAL) receptor is used in the calculation of chloride plume dispersion during transport between the site and receptor, which is ultimately used to calculate a relevant SRG. FAL receptors generally include creeks, rivers, sloughs, lakes, and wetlands. Essentially, FAL receptors include any water body that would be classified as a fully functional aquatic ecosystem by an aquatic biologist. In certain cases, dugouts may be considered as a FAL receptor when the dugout is used as a commercial fish farm. A FAL receptor for developing SRGs in the SST can be determined in part based on the Stewart and Kantrud (1971) Wetland Classification System, and the following classes:

A. Class I – Ephemeral Wetlands (typically considered to not be a functional aquatic life ecosystem, and thus it is not a SST FAL receptor);
B. Class II – Temporary Wetlands (considered to be a SST FAL receptor providing the Class II temporary wetland connects with a Class III or other clearly defined SST FAL receptor – otherwise, it is not considered a SST FAL receptor);

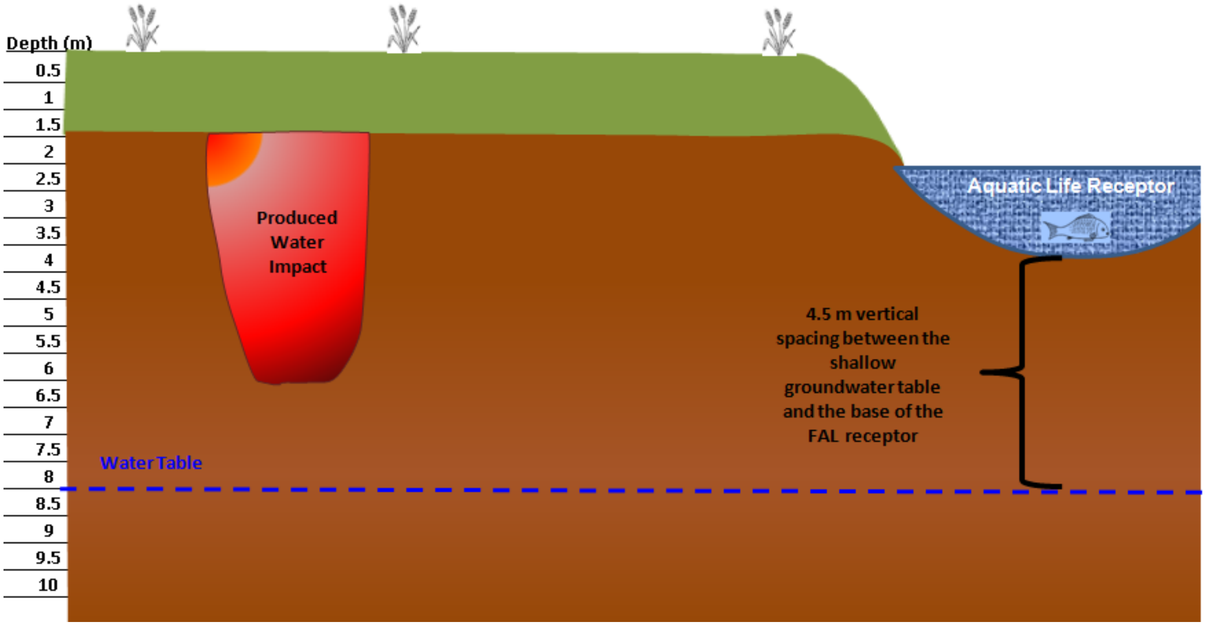
C. Class III – Seasonal Ponds and Lakes (considered a SST FAL receptor due to the presence of emergent wetland grasses, sedges, and rushes);
D. Class IV – Semi-permanent Ponds and Lakes (SST FAL receptors with emergent and submerged aquatic vegetation species, such as cattails, bulrushes, and pondweeds);
E. Class V – Permanent Ponds and Lakes (SST FAL receptors with standing water devoid of vegetation, and wetland plants on the periphery, such as cattails, red swampfire, and spiral ditchgrass);
F. Clase VI – Alkali Ponds and Lakes (SST FAL receptors where deep water is typically not permanently present, the pH exceeds 7, and salinity is naturally elevated, characterized by salt tolerant wetland plants such as red swampfire and spiral ditchgrass, and provides an attractive environment for shore birds); and,
G. Class VII – Fen Ponds (SST FAL receptors dominated by fen vegetation in the deepest portions, with wetland meadow/low prairie vegetation frequently encountered on the periphery, floating mats of emergent vegetation such as sedges, grasses, and other herbaceous plants).

Clear diagrams showing the site and all potential nearby surface water bodies must be reported. It should be noted that if the distance to a FAL receptor in the SST is less than 50 m for source dimensions of 15 x 15 m, 25 x 25 m, and 50 x 50 m, a Tier 2C analysis must be conducted. If the distance is less than 100 m for 75 x 75 m and 100 x 100 m source dimensions, a Tier 2C analysis must be conducted. Situations where the chloride contamination is within the high water mark boundary of a SST FAL receptor would require a Tier 2C assessment.

Subsoil SST SRGs for the FAL receptor are calculated based on the potential reduction in peak chloride concentration as the salinity plume is transported via groundwater flow from the site to the nearest FAL receptor of concern. The SRGs are also dependent on the contribution of facility-related chloride impacts, added to a reasonable worst case estimate of a mean background chloride concentration, towards the FAL chloride water quality guideline of 120 mg/L. Subsoil SRGs protective of the FAL pathway in the SST do not take into consideration the potential dilution associated with the mixing of groundwater discharge into a surface water body. Instead, the guidelines are based on preventing an exceedence of 120 mg/L chloride at the groundwater/surface water body interface. Several key species reside in the groundwater/surface water sediment interface, some of which are sensitive to salt toxicity (*e.g.*, mussels). The distance between the site and the high water mark of a FAL receptor that can be entered into the SST ranges from 50 to 1,000 m.

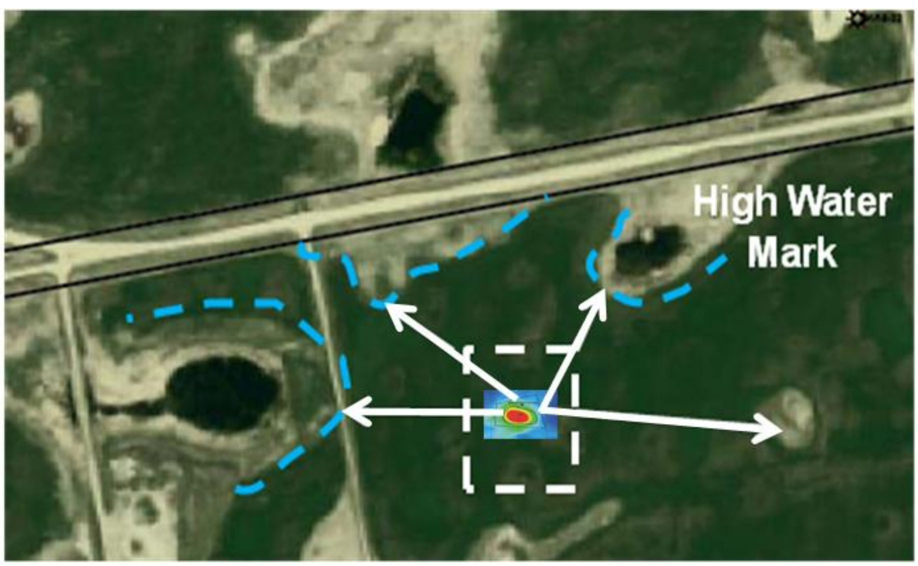
Situations may arise where a salinity plume cannot lead to an increase in chloride concentrations for a particular FAL receptor in the SST. An example is provided below. A relatively deep groundwater table is present at the site (8 m). The measured distance from the sediment bottom of the closest relevant SST FAL receptor (relatively shallow, 1.75 m deep water column) to the groundwater table surface, is 4.5 m. Providing the FAL receptor contains water (at least during certain portions of the year such that it may be classified as a FAL receptor), the hydraulic head will be downward, and the probability of groundwater discharging into the FAL receptor will be relatively negligible. For this situation, the FAL receptor can be eliminated from consideration and the distance to the next nearest SST FAL receptor, if there is one, must be used.

Eliminating a FAL receptor in such a manner ultimately requires empirical data to support such an argument. An example of a minimum empirical data requirement in this regard would be the drilling of a borehole near the receptor to determine the depth to groundwater, as well as measuring the depth of the water column (or essentially identifying the depth of the sediment floor), in the SST FAL receptor. Water table depths can vary over years and particularly decades. Thus, it is possible that in the future, the water table may rise and increase the potential for discharge into the FAL receptor. A minimum of 4 m separating distance is required between the base of the sediment layer in a FAL receptor and the depth of the shallow groundwater table, in the absence of further information. A stronger argument could be made with a shallower water table if a temporary vertical nest is installed beside the FAL receptor, and it is confirmed that recharge (downward conditions) prevail. In which case, the potential for groundwater discharge into surface water at this FAL location would be considered relatively negligible.



4.5.1 Tier 2A

For a Tier 2A site investigation for which groundwater information has not been collected through the installation of monitoring wells, it is necessary to identify the proximity of the site to FAL receptors in all directions from the site because groundwater flow direction cannot be determined. The shortest distance in any direction is calculated, documented, and input into the SST. The distance is from the estimated edge of the high water mark of the FAL receptor (which can be determined from aerial photographs and ground reconnaissance) to the edge of the salinity impacted area (see figure below), under the assumption that groundwater flow may be in the direction of the closest FAL receptor.

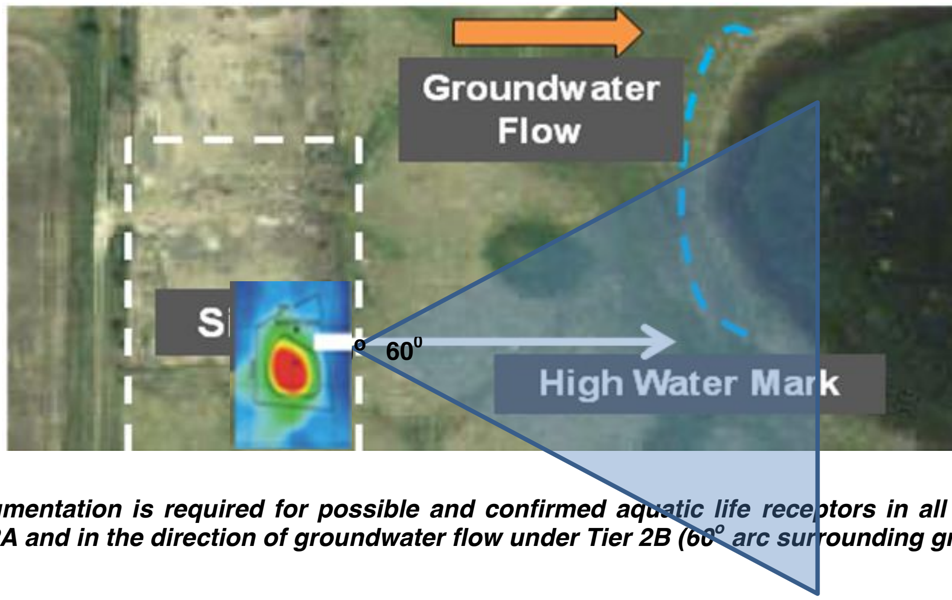


4.5.2 Tier 2B

For Tier 2B site investigations, the proximity of the site to relevant FAL receptors is calculated using information on the lateral flow direction of shallow groundwater. As with Tier 2A, the distance is estimated from the edge of the salinity impact to the edge of the high water mark for the nearest FAL life receptor located downgradient of shallow groundwater flow. The distance to a FAL receptor can vary if the site is separated into SubAreas associated with different directions of groundwater flow. The distance may also vary for SubAreas that are located further away from the FAL where groundwater flow is in the same direction.

Groundwater flow is typically calculated to be a single vector. However, variability is associated with the direction of groundwater flow based on number of monitoring wells, well spacing, well depths, and season of measurement. To account in part for this variability and uncertainty, relevant FAL receptors for Tier 2B are considered if they fall within a 60^{o} arc (or 30^{o} arc on either side) surrounding the predominant groundwater flow direction vector.

Tier 2B subsoil SRGs are similarly calculated based on potential attenuation between the site and water body and the contribution of facility-related impacts towards the FAL guideline for chloride of 120 mg/L. The SRGs do not consider potential dilution associated with groundwater discharge into a surface water body – *i.e.,* as with Tier 2A, the subsoil salinity guideline is based on preventing exceedences of 120 mg/L at the groundwater/surface water interface in a FAL receptor.



Proper documentation is required for possible and confirmed aquatic life receptors in all directions of the site under Tier 2A and in the direction of groundwater flow under Tier 2B (60^{o} arc surrounding groundwater flow).

4.6 Hydraulic Conductivity and Gradient in Shallow Groundwater

Shallow groundwater conceptually represents the water bearing zone through which chloride impacts can be transported from a site to a FAL receptor.

4.6.1 Tier 2A

Shallow groundwater conductivity and gradient parameters cannot be changed for Tier 2A assessments. Default parameters are assumed in the SST program, as follows:

Shallow Groundwater:	Coarse Soil	Hydraulic gradient	0.028 m/m
		Hydraulic conductivity	$2x10^{-6}$ m/s
Shallow Groundwater:	Fine Soil	Hydraulic gradient	0.028 m/m
		Hydraulic conductivity	$2x10^{-7}$ m/s

4.6.2 Tier 2B

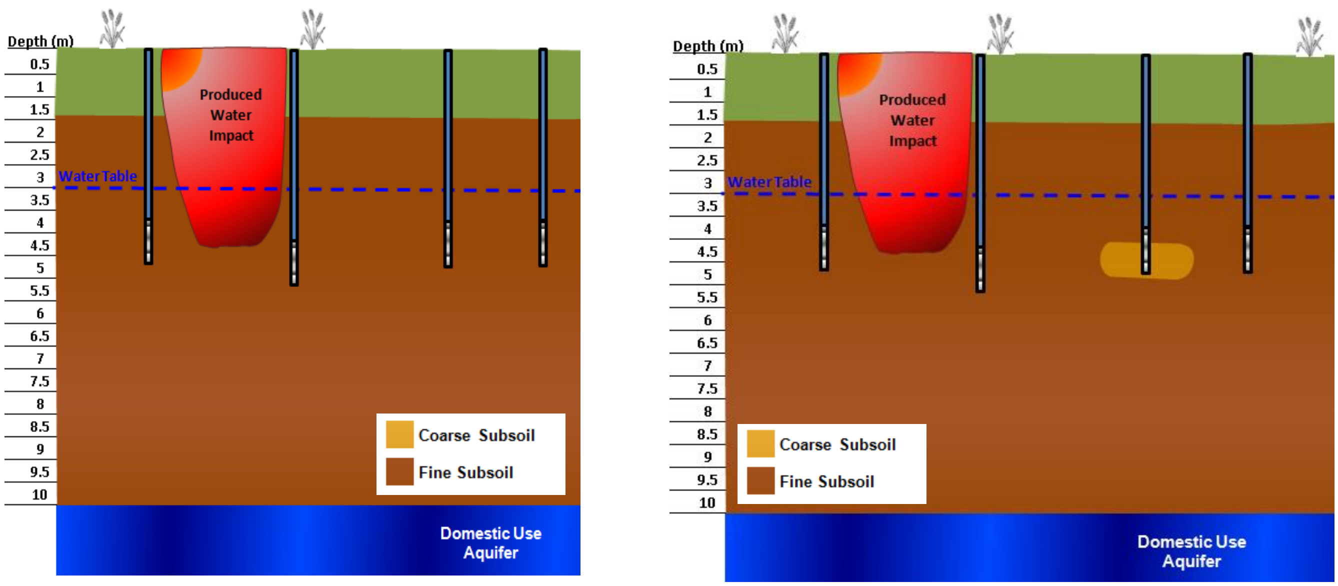
For Tier 2B guideline calculations, monitoring wells must be installed to determine a more refined estimate of the hydraulic conductivity and hydraulic gradient of shallow groundwater across a site. Hydraulic conductivity combined with hydraulic gradient measurements will allow for the calculation of a site-specific shallow groundwater velocity and associated attenuation factor for the FAL receptor. A site can be separated into SubAreas providing that there are significant differences in hydraulic conductivity and gradient measured within a site, such as where distinct soil lithology exists and/or where multiple groundwater vectors may be present. For example, if the southern portion of a site is predominantly coarse sand and the northern portion of the site is predominantly fine clay till, it may be warranted to divide the site into two distinct hydrogeological environments for SST guideline calculations.

Efforts should be made to identify preferential flow pathways (*e.g.*, continuous sand lenses) through which a salinity plume may reach a downgradient FAL receptor, and wells should be screened across preferential flow pathways if they are in close proximity to the water table surface.

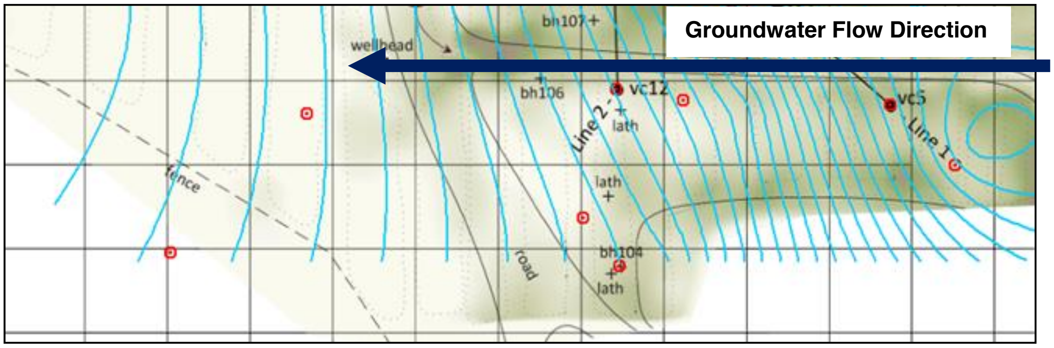
The maximum possible groundwater velocity in the SST is 10 m/yr. A Tier 2C assessment must be conducted if the shallow groundwater velocity exceeds 10 m/yr. It should be noted that a groundwater velocity of approximately 3.5 m/yr (Darcy velocity of 0.88 m/year) may indicate that the hydraulic conductivity of shallow groundwater could meet the definition of a DUA.

A minimum of three shallow groundwater monitoring wells is required per site. If three wells are installed, the maximum hydraulic conductivity measurement must be used to represent the conductivity of shallow groundwater, which is input into the SST. If more than three wells are installed, the arithmetic average is input into the SST.

A careful review of borehole logs is required when selecting data for calculating the arithmetic average. A minimum of three wells provides a small subset of data that must be considered representative of soils across the entire site. As a result, the statistic selected for representing shallow groundwater should be based in part on the results of borehole logs. An example is provided below, shown as cross sections through four or more shallow monitoring wells. For the panel on the left which is predominantly homogeneous texture, an arithmetic average would be the representative statistical value entered into the SST for shallow groundwater. For the panel on the right, the use of an arithmetic mean would be skewed based on the monitoring well installed within an isolated, and 'rare', pocket of coarse soil within a predominantly fine till. This pocket, if not encountered frequently within the till, will have a minimal influence on the bulk transport of chloride in shallow groundwater. Data from this location should be excluded from the calculation of an arithmetic average unless supporting information can be provided to indicate it is indicative of bulk conductivity at the site.



A seasonal average hydraulic gradient is calculated based on two monitoring events each from a distinct season (winter, spring, fall, summer). The events should avoid periods of snowmelt/spring runoff, which may reflect a short term change in the annual average gradient. Gradients from both seasons can be averaged and entered into the SST. For example, if a gradient for a site was 0.04 in fall and 0.02 in winter, a value of 0.03 would be entered. Care should be taken if there are more dramatic differences in gradients measured between events. It is possible to get gradients that are relatively unrealistic and large for most sites (*e.g.*, 0.1) if one or more wells have not fully recharged and/or have not been properly developed. Gradients can also be influenced by mounded water tables that can be due to changes in vegetation cover or the historical discharge of water to an unlined pit.



A US EPA online calculator is available that can be used to calculate lateral hydraulic gradients (*United States Environmental Protection Agency), 2011, January 19. Hydraulic Gradient. Retrieved March 23, 2011, from EPA On-Line Tools for Site Assessment Calculation: http://www.epa.gov/athens/learn2model/part-two/onsite/gradient3ns.html*). However, in some circumstances it can produce erroneous gradients, particularly if there is restricted well spacing. For example, three wells that are installed in a line with one well laterally offset will lead to an incorrectly calculated gradient. A groundwater contour diagram should be developed to allow for a professional assessment of flow direction and gradient prior to entered a gradient into the SST.

Clear documentation is required for calculations of shallow groundwater hydraulic conductivity and gradient values. Slug test results must be provided as well as the calculations used to convert these results to hydraulic conductivities. Groundwater contour diagrams must be submitted to provide an understanding of well spacing and associated data used to calculate the hydraulic gradient as well as flow direction.

4.7 Hydraulic Conductivity and Gradient in Deep Groundwater

The characterization of deep groundwater must be determined based on a conceptual understanding of how deep groundwater parameters are used to develop SRGs for the DUA pathway. Deep groundwater represents the saturated till through which chloride will spread laterally and vertically as it is transported downward towards a DUA. Professional judgement is required to properly select well screen depth intervals for characterizing deep groundwater.

4.7.1 Tier 2A

Deep groundwater conductivity and gradient parameters cannot be changed for Tier 2A assessments. Default parameters are assumed in the SST program, as follows:

Deep Groundwater:	Coarse Soil	Hydraulic gradient	0.028 m/m
		Hydraulic conductivity	5×10^{-8} m/s
Deep Groundwater:	Fine Soil	Hydraulic gradient	0.028 m/m
		Hydraulic conductivity	5×10^{-9} m/s

4.7.2 Tier 2B

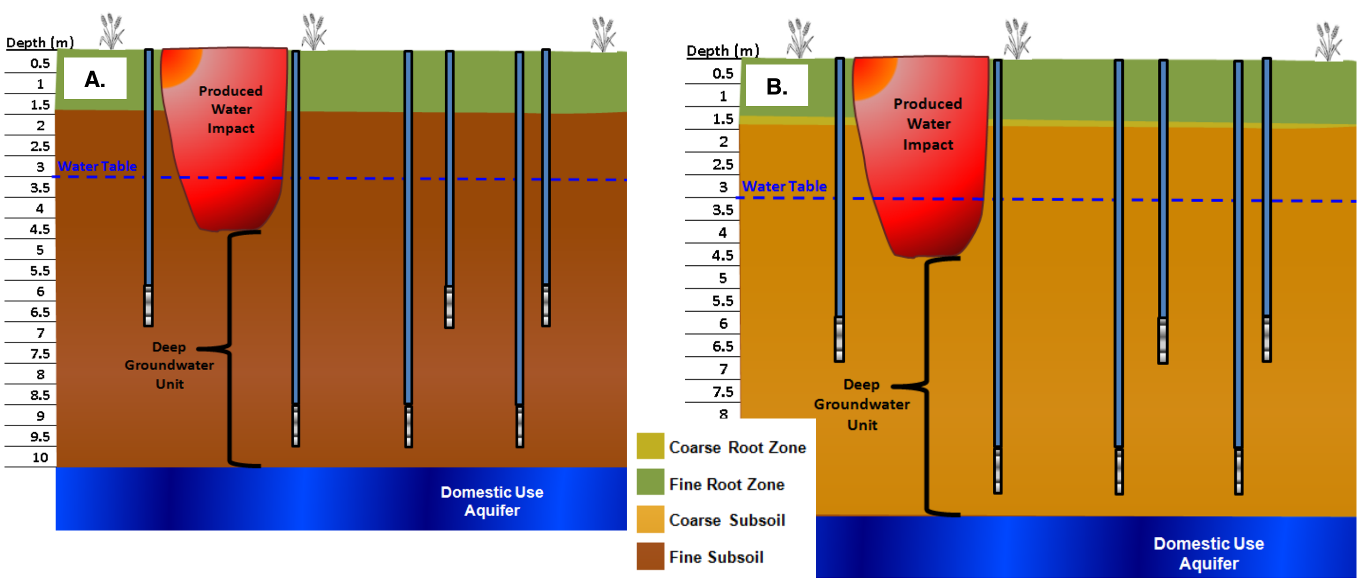
For Tier 2B guideline calculations, an option is available to enter site-specific data into the SST to characterize the properties of deep groundwater, which are used for calculating the extent of plume attenuation as it leaches downward towards a DUA. Deep groundwater parameters do not affect guidelines for other pathways. It is not essential to have deep groundwater monitoring wells and data to conduct a Tier 2B assessment – Tier 2A default values can be used and Tier 2B SRGs subsequently calculated. As with Tier 2A, a site can be separated into SubAreas providing that there are significant differences in hydraulic conductivity and gradient measured within a site, such as where distinct soil lithology exists and/or where multiple groundwater vectors may be present. For example, if the southern portion of a site is predominantly coarse sand and the northern portion of the site is predominantly fine clay till, it may be warranted to divide the site into two distinct hydrogeological environments for SST guideline calculations.

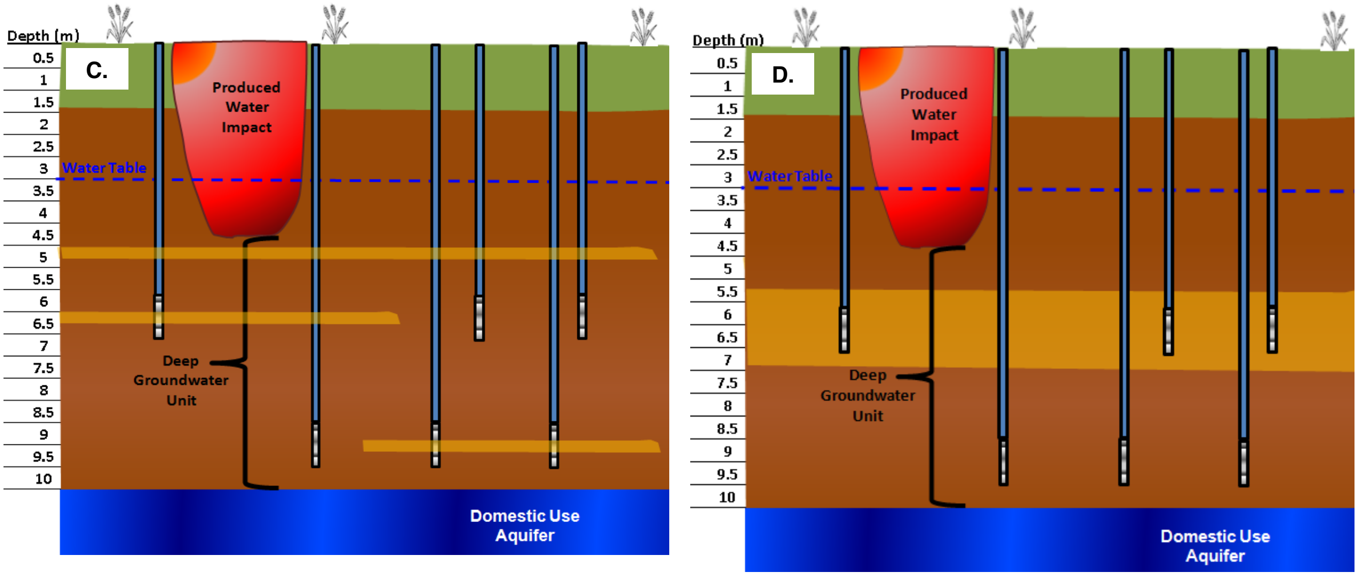
As with shallow groundwater, a minimum of two monitoring events is required for elevations data, and the events must occur in distinct seasons. The direction of flow is not used in the calculation of a guideline. The hydraulic gradient and a statistical representation (arithmetic average) for hydraulic conductivity is used. If the velocity is greater than 1 year, a maximum velocity of 1 m/yr is used in the SST.

Defining parameters for deep groundwater involves a combination of borehole log interpretation coupled with monitoring well data. A minimum of three monitoring wells should be installed to determine a more refined estimate of the hydraulic conductivity and hydraulic gradient of deep groundwater across a site. Several examples of deep groundwater well placements relative to salinity impacts, as a function of variable lithology, are provided below. Four panels are shown. Each of these panels demonstrates the correct placement of deep groundwater wells for parameterization of SST deep groundwater input values. The examples below have been truncated to a DUA depth of 10 m, although a DUA depth of down to 20 m may be entered into the SST. The first two panels (A&B) demonstrate the simplest possible scenario for deep groundwater. In each of these scenarios, the saturated subsoil between the base of impact and the DUA is relatively homogeneous, and data from any monitoring wells screened within this interval would be considered representative of deep groundwater. The arithmetic average hydraulic conductivity for these wells would be entered into the SST.

In Panel C, there is a frequent occurrence of relatively thin discontinuous sand intervals. Deep groundwater wells can be screened in a manner to include or exclude these intervals, but judgement should be made such that there is a reasonable weighting towards the incorporation of monitoring well data with inclusion/exclusion of sand intervals. The hydraulic conductivity statistical value used for this scenario would be the arithmetic average. However, if the presence of coarse intervals is relatively infrequent (*e.g.*, a few isolated sand pockets), the geometric mean should be applied. An example of where a geometric mean may be appropriate would be if three deep groundwater wells had hydraulic conductivity values equal to $5x10^{-8}$ m/s and a single value was measured at $5x10^{-6}$ m/s. The arithmetic average would be $1.3x10^{-6}$ m/s, which is highly skewed towards the single value that represents a small portion of till at the site. In this manner, professional judgement can be used with the goal that deeper groundwater characteristics should be considered representative of the site as a whole.

In Panel D, a relatively thick coarse interval is present within a predominantly fine till. Providing the saturated coarse interval is determined to not meet the definition of a DUA, if non-default deep groundwater parameters are to be used in a SST assessment, deep groundwater wells must be screened within both the coarse interval and fine interval. The arithmetic average hydraulic conductivity from wells within both the coarse and fine interval is entered into the SST. The vertical leaching rate of salts towards the DUA and root zone in this scenario is strongly influenced by fine textured soil above and below the coarse interval, and the site would be run as fine textured.





4.8 Hydraulic Conductivity and Gradient of the DUA

The hydraulic conductivity and gradient of the DUA is used primarily in calculating the value of the DF3 parameter, which represents the extent of till water chloride concentration dilution as it leaches and mixes into a DUA. These values directly affect the SRG for the DUA pathway.

4.8.1 Tier 2A

Under a Tier 2A approach, in the absence of measured DUA parameters, default DUA parameters are assumed that cannot be adjusted, as follows:

1. DUA hydraulic conductivity - 1×10^{-6} m/s
2. DUA hydraulic gradient 0.028 m/m

4.8.2 Tier 2B

For Tier 2B guideline calculations, it is not essential to characterize a DUA, if encountered during drilling to a depth of 20 m (maximum depth considered in the SST) or shallower. The default parameters used for a Tier 2A can be used as defaults at the Tier 2B level. Depending on the resulting SRG guideline for the DUA pathway and extent of remediation required, the proponent may opt to install monitoring wells screened within the DUA to characterize DUA parameters such as hydraulic conductivity and gradient.

A minimum of three wells is required and the wells must be screened solely within the DUA and not overlapping with till above or below the unit defined as a DUA. Water elevations should be determined from a minimum of three wells, from a minimum of two different monitoring events. A seasonal average hydraulic gradient is calculated based on the minimum of two monitoring events.

Slug tests should be performed on all wells screened within the DUA and geometric as well as arithmetic mean values calculated. The arithmetic mean is used to confirm whether the unit may meet one definition of a DUA. Specifically, if the arithmetic mean hydraulic conductivity is greater than 1×10^{-6} m/s, the unit is considered a DUA in the SST (in the absence of a pump test to establish yield requirements). If the arithmetic mean is less than this threshold value, the unit is not considered a DUA and the DUA may be located at a deeper depth. <u>For situations where the arithmetic mean exceeds 1×10^{-6} m/s, the geometric mean is entered into the SST for the DUA hydraulic conductivity</u>. The geometric mean will produce a more conservative SRG protective of the DUA compared to the use of an arithmetic mean. Situations may arise where the product of the site-specific DUA gradient and hydraulic conductivity (*i.e.*, Darcy velocity (or flux)) is less than 0.88 m/year. This is the velocity associated with the use of default DUA parameters (hydraulic conductivity of 1×10^{-6} m/s (31.5 m/year) x hydraulic gradient of 0.028 = 0.88 m/year). In these situations, default DUA parameters should be used (hydraulic conductivity of $1x10^{-6}$ m/s and a gradient of 0.028). This can also be checked within the SST by entering the site-specific DUA hydraulic gradient and conductivity and comparing the displayed value with a default DUA velocity of 3.5 m/year (Darcy velocity of 0.88 m/year divided by an effective porosity of 0.25 = groundwater velocity 3.5 m/year). If the DUA velocity calculated by the SST is less than 3.5 m/year using site-specific data, default DUA parameters should be applied.

4.9 Background Chloride in DUA

The background chloride concentration in a DUA is used to provide an assessment of potential cumulative risk from background chloride plus future site-related chloride impacts. The possibility exists for chloride concentrations to be elevated naturally or due to impacts from an upgradient site.

4.9.1 Tier 2A

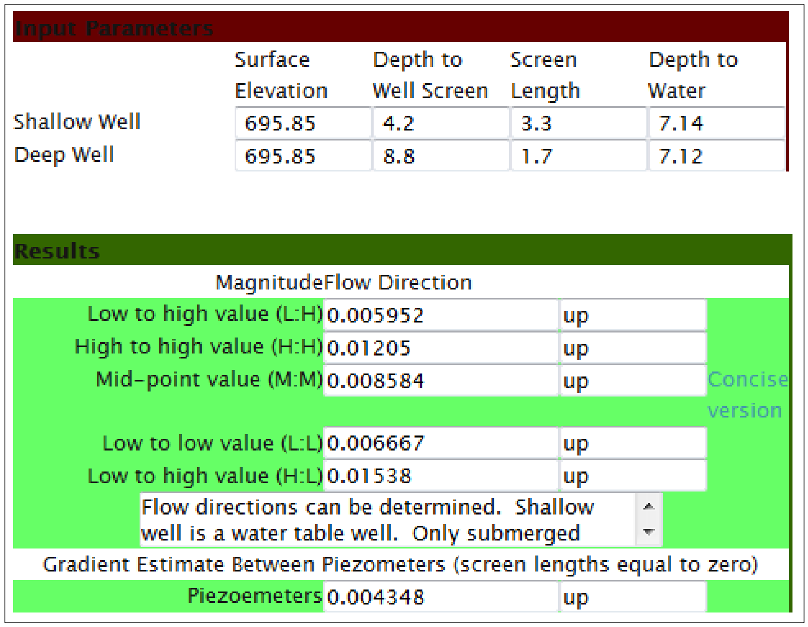
The default chloride concentration in a DUA is 30 mg/L under a Tier 2A approach. This value cannot be adjusted.

4.9.2 Tier 2B

As with a Tier 2A approach, a default value of 30 mg/L can be assumed in the absence of site-specific data for the background DUA chloride concentration, in situations where monitoring wells have not been installed and screened across the DUA. If a DUA has been characterized at a site, the arithmetic average DUA chloride concentration is input into the SST. If the average background chloride concentration exceeds 210 mg/L, a Tier 2C analysis must be conducted due to the proximity of background to the Tier 1 chloride guideline value (250 mg/L) for the drinking water pathway.

4.10 Vertical Hydraulic Gradient

A vertical gradient may be calculated from nested well data and used to estimate a vertical drainage rate, which affects SRGs for various pathways and receptors in the SST. There are a number of rules that must be considered in order for the vertical gradient from nested well information to be considered acceptable as input into the SST. The calculation of an appropriate vertical gradient on a site-specific basis is a complicated process, requiring a thorough understanding of hydrogeological conditions as well as fate and transport processes. Gradient information may be misrepresented and could lead to the calculation of incorrect SRGs used to guide remediation efforts. Vertical gradients may be calculated using the US EPA online vertical gradient calculator. *US EPA (United States Environmental Protection Agency), 2011, January 19. Vertical Gradient Calculator. Retrieved March 23, 2011, from EPA On-line Tools for Site Assessment Calculation: http://www.epa.gov/athens/learn2model/part-two/onsite/vgradient.html*. An example input and output from the calculator is provided below.



4.10.1 Tier 2A

Under a Tier 2A analysis, monitoring wells are not installed, and a default vertical gradient is assumed in the SST based on geographical region and Climate Moisture Index.

4.10.2 Tier 2B

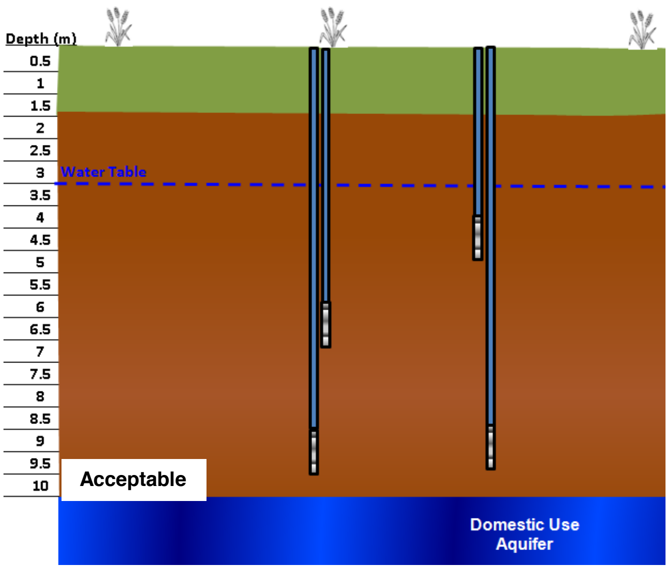
Under a Tier 2B analysis, it is possible to use nested well information in order to determine an appropriate vertical gradient for the site. A minimum of two water elevation measurement events is required from distinct seasons to calculate an average annual vertical gradient. The groundwater elevations used for calculating a vertical gradient must have stabilized such that the wells are responding to changes in groundwater conditions (as opposed to still being in a recovery mode). This can take a significant length of time in higher clay content soils. Poor well development will lead to incorrect gradients. If wells are installed within the same porous media and relatively large gradients are measured (*e.g.*, > 0.1), providing other conditions mentioned under this section are met, a large gradient may be indicative that one of the wells has not properly recovered or has not been sufficiently developed. <u>A minimum vertical offset distance of 0.5 m should be present beneath the base of the shallow nested well screen and the top of the deeper well screen.</u>

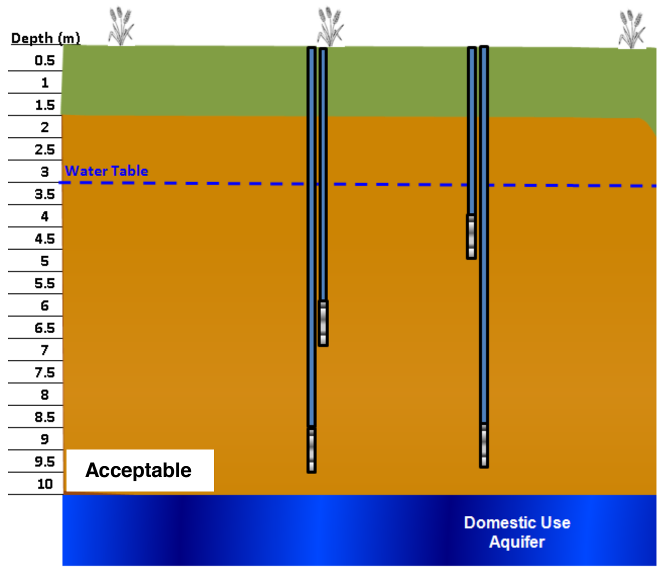
Caution should be used when selecting locations for nested wells to ensure the calculated gradient is relevant for the site. For example, a nested well located near a dugout may not provide representative results for a site that is located more distal from the dugout, as the head of water in the dugout (or other surface water feature) may alter the measured gradient. Similarly, a nested well installed in a background location on the top of a nearby knoll may not be representative of the vertical gradient and subsequent salinity transport for a site located within a topographic depression.

Vertical gradients calculated from periods when recharge conditions are dominant (as in spring snowmelt) must not be used for entry into the SST, as these conditions may have a temporal and significant affect on the average annual gradient, and would be considered less representative of conditions that prevail over most of the year. A minimum of two measurements are required during the year outside of the spring snowmelt period. If the gradients are significantly different (*e.g.*, one measurement is weak recharge (*e.g.*, -0.001), the second is strong recharge (0.08), or, one measurement is a strong discharge (-0.04), the other is a strong recharge (0.06)), additional measurement events are required to produce an annual average gradient. There may be situations where a weak recharge (*e.g.*, 0.002) and weak discharge (-0.002) may be measured for a well that has a nearly static drainage rate. Additional measurements are similarly required until there is a more consistent pattern of predominantly recharge or discharge during the course of a year. Alternately, the SST can be run and SRGs calculated using the default vertical gradient.

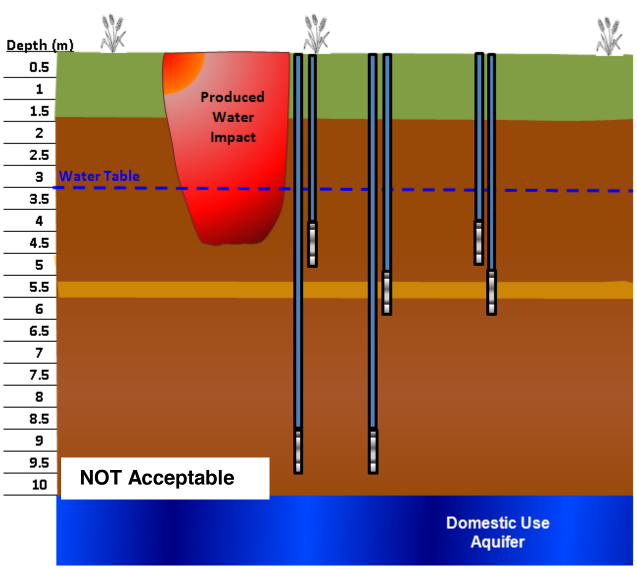
For sites with total source dimensions of less than 50 x 50 m, a minimum of one nested well is required if a site-specific vertical gradient is to be calculated. If total source dimensions are greater than 50 x 50 m up to 100 x 100 m, a minimum of two nested wells is required. For total source dimensions of greater than 100 x 100 m, a minimum of three nested wells is required. Additional nested wells are required if geology is laterally complex (*e.g.*, half the site is coarse and the other half fine, distinct groundwater depths that may indicate a difference in vertical gradient, portions of the site in close proximity to a sough or surface water feature, distinct topography that may indicate a difference in vertical gradient).

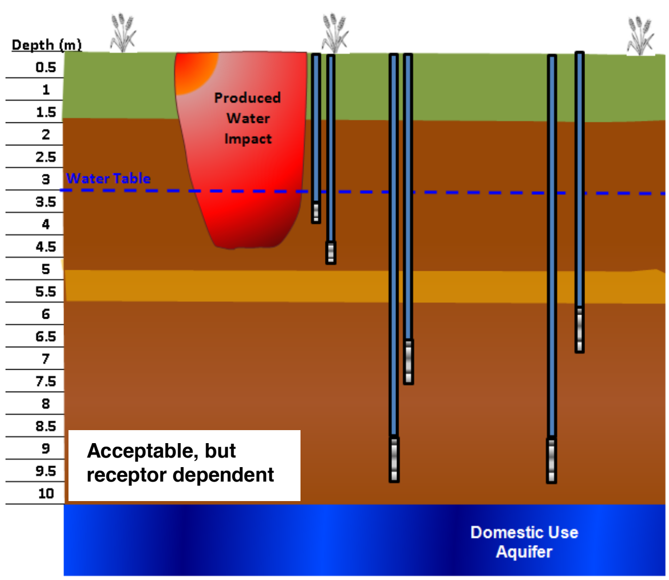
Nested wells must be constructed within the same porous media (*e.g.*, both within a fine till or both within a coarse till). Other rules that related to the completion of nested wells are shown below. The two options for nested wells below installed within either a fine or coarse soil are considered acceptable.



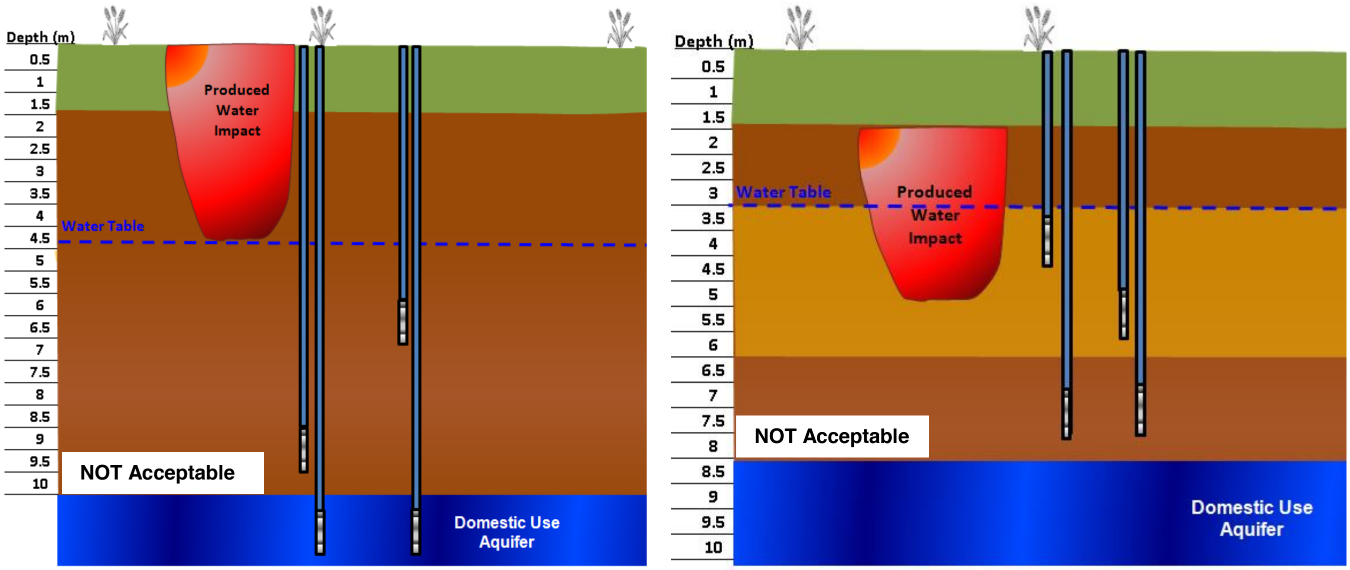


The nested wells shown below are <u>not</u> acceptable. In the left panel, the wells are installed either spanning a continuous coarse interval or one of the wells is within the coarse interval. In the right panel, each nest is considered acceptable for one or more SST receptors, but not all receptors. The wells screened above the coarse interval may be acceptable for the root zone, FAL, and dugout pathways, but not the DUA pathway. The opposite argument can be made for the nested wells screened beneath the coarse interval – the gradient calculated from these wells may be acceptable for the DUA, but not for other receptors. In this case, it is necessary to install separate nested wells above and below the coarse interval. Two distinct SST runs with distinct vertical gradients would be required if significantly different gradients are measured between well nests located above and below a continuous coarse interval. Alternately, the more conservative SRGs calculated using either gradient can be applied.

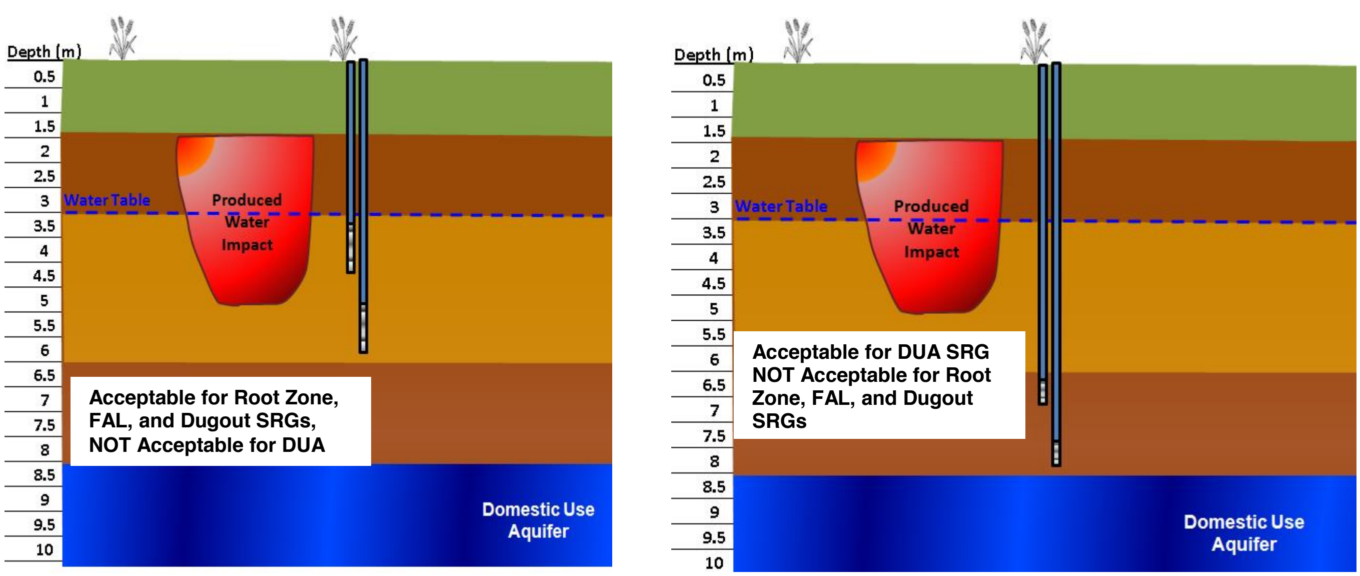




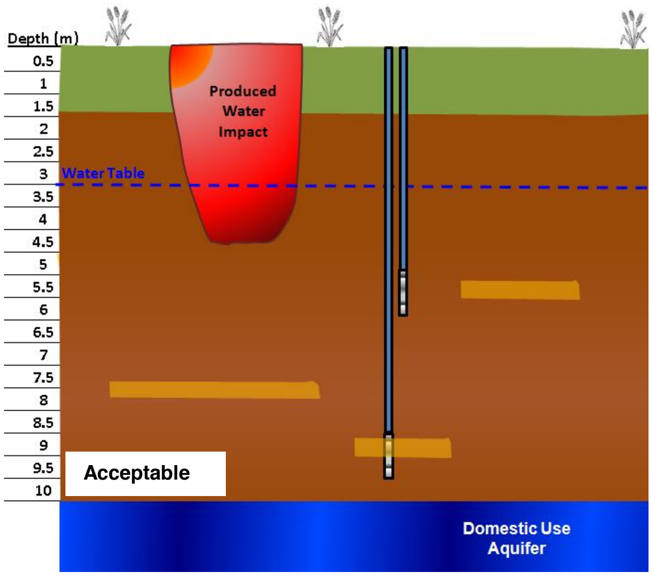
The nested well arrangements below are not acceptable for use in the SST. One of the wells of a nest can not be screened within or across the DUA. For the panel on the right, one of the wells is installed within a distinct texture, which similarly is not acceptable.



The nested well arrangements below are considered acceptable for use in the SST, but only for a select number of receptors. In the left panel, the wells have been installed within a single porous coarse media with an absence of soils of differing texture between the two screens. The vertical gradient from these wells would be considered acceptable for calculating SRGs for all pathways with exception of the DUA. The water table is at the top of the coarse interval at 3 m and the measured vertical gradient will be applicable to the root zone, dugout, and FAL receptors. For the DUA, there is an underlying continuous fine textured soil beneath the coarse interval within which the nested wells are located. The vertical gradient within this fine unit may differ, and as a result, additional wells would be required such as in the panel to the right in the figure below. For complex lithology scenarios such as the example below, multiple screened nests within different lithologies will be required if the default vertical gradient is to be changed for an SST assessment. Multiple SST runs may be required. The lithology governing the vertical transport rate of salts towards the root zone and DUA receptors is fine soil. Coarse soil governs the lateral transport rate towards a FAL receptor. The selection of soil texture for input into the SST is always based on the texture that governs the environmental transport of salts to receptors of concern.



The presence of discontinuous and relatively isolated coarse intervals within a predominantly fine textured soil (and the converse would apply to a predominantly coarse textured soil) will have a relatively minimal influence on the net vertical gradient at a site. An example is provided below. The nested wells installed below would be considered sufficient for calculating a vertical gradient. This example highlights the importance of borehole logs from investigation locations across a site, in order to determine whether variable texture intervals (*e.g.*, coarse intervals within a predominantly fine textured soil) are relatively continuous across a site, and may influence the calculation of a vertical gradient.



5 MINIMUM SOIL INVESTIGATION REQUIREMENTS

Minimum soil investigations required to characterize SST input parameters are generally similar between Tier 2A and Tier 2B approaches, with a few exceptions. Soil parameters required by the SST include:

1. Soil Texture and Lithology;
2. Background Root Zone Salinity;
3. Background Dugout Scenario Salinity;
4. Impacted Root Zone Salinity;
5. Lateral Closure of Salinity Impact;
6. Source Length and Dimensions
7. Vertical Closure of Salinity Impact; and,
8. Backfill Material.

5.1 Soil Texture and Lithology

An understanding of soil lithology is a requirement for the development of subsoil SRGs. Laboratory data for soil texture are required to develop borehole logs that are less influenced by field investigator judgment, which varies between practitioners and their experience. (*e.g.*, one practitioner's silty clay may be another practitioner's sandy loam). Soil texture (% sand, %silt, %clay) data by hydrometer are required for:

4. boreholes located within the salt impacted area;
5. background boreholes within the deeper portion of the root zone (1.0 to 1.5 m soil depth for the SST, although it is recommended that data be collected for a typical topsoil depth (0 to 0.3 m) and the shallower root zone (0.3 to 1.0 m)); and,
6. material intended to be used as backfill.

For selected boreholes in the salt impacted area, a minimum of three textural analyses are required for each unique and significant soil lithology unit identified in the field, for integration into the development of borehole log interpretations. A minimum of three textural analyses are required for the root zone over the 1.0 to 1.5 m depth interval for background locations, and it is recommended that a minimum of three samples be collected at shallower soil depths. Saturation percentage data from unimpacted background boreholes can be used to assist in defining soil texture at various depth intervals. For backfill material, a minimum of three textural analyses are required. The rationale for this is to ensure that textures are reasonably similar between the impact area, background, and any backfill material brought to the site.

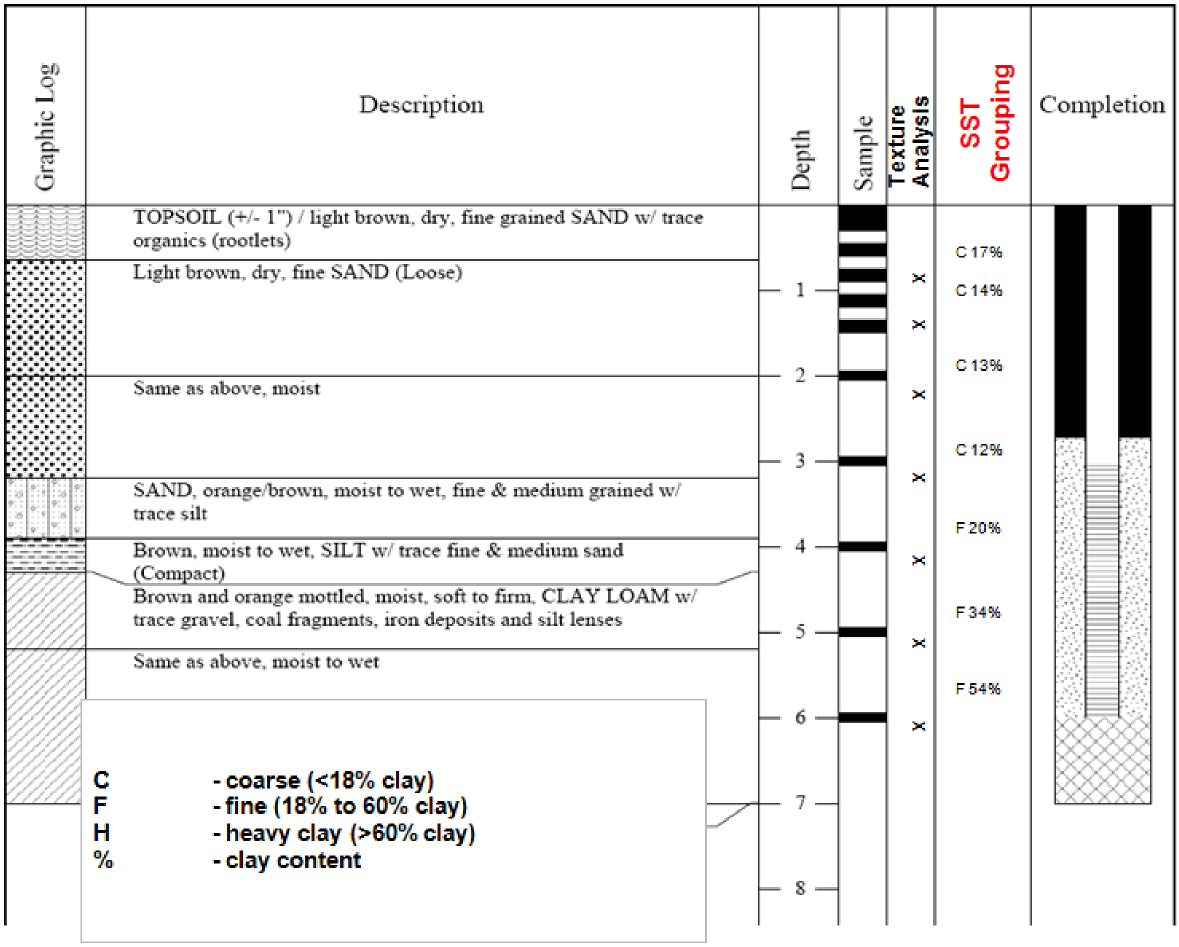
The % sand, % silt and % clay should be noted from laboratory results and soils classified into the following general categories for use within the SST:

1. Heavy Clay Soil: clay content > 60%;
2. Fine Soil: clay content 18 to 60% (includes clay, silty clay, silty loam); and,
3. Coarse Soil: clay content < 18% (includes sandy loam, silt, loamy sand, sand).

Soil textural information can be recorded in tables or on borehole logs for site-specific SST guideline documents submitted to ESRD. An example of a borehole log that includes a recording of depth intervals where textural analyses are collected as well as the SST equivalent textural category is provided below followed by an example of a texture summary table. A combination of borehole logs, saturation percentage data, and soil texture should be used to select the correct soil lithology in the SST.

Thick sand/gravel deposits that meet the definition of a DUA are not considered to be soil lithologies through which salinity is modeled for vertical or lateral transport in the SST. These deposits would be considered receptors of concern. If salt contamination has entered such a zone, a Tier 2C assessment would be required because the impacts are already within a DUA. The SST models salinity transport to receptors of concern, not within receptors of concern.

Muskeg or peat layers have not been incorporated into the SST. The SST can be used to develop guidelines for mineral soils beneath peat layers. ***Guidelines produced by the SST are not applicable to depths intervals of muskeg/peat***. Consult ESRD for assistance with determining appropriate salinity guidelines for muskeg/peat layers.



This is an example of reporting requirements. Soil texture profiles must be reported, but do not necessarily have to be incorporated into borehole logs, and can be provided in tabular or graphical form.

Borehole	Location	Depth	Texture by Hydrometer				
		(mbgs)	% Sand	% Silt	% Clay	Lab Classification	SST Classification
BH12-14	Impact	0.0-0.3	56	21	24	Sandy Clay Loam	Fine
BH12-05	Impact	0.0-0.3	65	11	24	Sandy Clay Loam	Fine
Average	**Impact**	**0.0-0.3**	**61**	**16**	**24**	**- -**	**Fine**
BH11-6	Background	0.0-0.3	60	18	23	Sandy Clay Loam	Fine
BH11-77	Background	0.0-0.3	59	26	15	Sandy Loam	Coarse
Average	**Background**	**0.0-0.3**	**60**	**22**	**19**	**- -**	**Fine**
BH12-14	Impact	0.3-0.6	71	20	9	Sandy Loam	Coarse
BH12-05	Impact	0.3-0.6	71	13	16	Sandy Loam	Coarse
Average	**Impact**	**0.3-0.6**	**71**	**17**	**13**	**- -**	**Coarse**
BH11-6	Background	0.3-0.6	63	21	17	Sandy Loam	Coarse
BH11-77	Background	0.3-0.6	64	21	15	Sandy Loam	Coarse
Average	**Background**	**0.3-0.6**	**64**	**21**	**16**	**- -**	**Coarse**
BH12-14	Impact	1.0-1.5	57	19	25	Sandy Clay Loam	Fine
BH12-04	Impact	1.0-1.5	38	18	45	Clay	Fine
Average	**Impact**	**1.0-1.5**	**48**	**19**	**35**	**- -**	**Fine**
BH11-6	Background	1.0-1.5	73	16	12	Sandy Loam	Coarse
S10-36	Background	1.0-1.5	58	23	20	Sandy Clay Loam	Fine
BH11-77	Background	1.0-1.5	31	18	51	Clay	Fine
Average	**Background**	**1.0-1.5**	**54**	**19**	**28**	**- -**	**Fine**
BH11-26	Impact	2	87	7	5	Sand	Coarse
BH09-09	Impact	2	90	7	2	Sand	Coarse
BH11-10	Impact	2	75	12	13	Sandy Loam	Coarse
BH11-26	Impact	3	31	18	51	Clay	Fine
BH09-05	Impact	4	25	22	53	Clay	Fine
BH11-10	Impact	4	63	14	23	Sandy Clay Loam	Fine
BH11-26	Impact	5	17	26	57	Clay	Fine
BH11-26	Impact	6	59	26	15	Sandy Loam	Coarse
BH09-09	Impact	6	64	21	15	Sandy Loam	Coarse
BH11-26	Impact	7	7	47	46	Silty Clay	Fine
BH11-26	Impact	8	19	23	58	Clay	Fine
BH09-09	Impact	8	40	18	43	Clay	Fine
BH11-10	Impact	9	33	26	41	Clay	Fine
BH11-10	Impact	10	2	28	70	Heavy Clay	Heavy Clay
Average	**Impact**	**1.5-10**	**44**	**21**	**35**	**- -**	**Fine**
BH11-6	Background	1.75	41	20	40	Clay	Fine
BH11-6	Background	2.75	23	34	44	Clay	Fine
BH11-6	Background	4.25	20	27	54	Clay	Fine
BH11-6	Background	5.75	73	16	12	Sandy Loam	Coarse
BH11-6	Background	9.75	13	32	56	Clay	Fine
Average	**Background**	**1.5-10**	**34**	**26**	**41**	**- -**	**Fine**
BF12-01	Backfill		7	47	46	Silty Clay	Fine
BF12-02	Backfill		40	20	41	Clay	Fine
BF12-03	Backfill		33	22	46	Clay	Fine
Average	**Backfill**	**1.0-1.5**	**27**	**30**	**44**	**- -**	**Fine**

5.2 Background Root Zone Salinity

Background root zone salinity (1.0 to 1.5 m) is determined from background boreholes drilled at a site outside of the area disturbed by construction or reclamation that has chloride concentrations less than 100 mg/kg. Chloride concentrations >100 mg/kg are considered to have been impacted by produced water releases (primarily sodium chloride), although road salt, manure applications, and low lying slough areas can be associated with soil chloride concentrations > 100 mg/kg. A soil chloride concentration of 100 mg/kg at any depth interval is approximately equivalent to a saturated paste EC of 0.4 dS/m for a fine textured soil and an EC of 0.6 dS/m for a coarse textured soil (‘rough rule of thumb’). It should be noted that a soil chloride concentration of 100 mg/kg will be greater than the 'true' background at many contaminated sites (*e.g.*, 8 mg/kg can be encountered in Alberta tills), but 100 mg/kg is considered a reasonable approximation for identifying the boundaries of the area that has been impacted by facility operations and for obtaining vertical and lateral closure.

The following soil investigations are required (note, these should be considered to be minimum requirements) for characterizing background root zone salinity:

1. If background soil is in the Good soil quality category, four boreholes are required for background investigations with sample collection over the depth interval of 1.0 to 1.5 m. If background soil is in the Fair, Poor, or Unsuitable soil quality category, six or more boreholes are required; and,

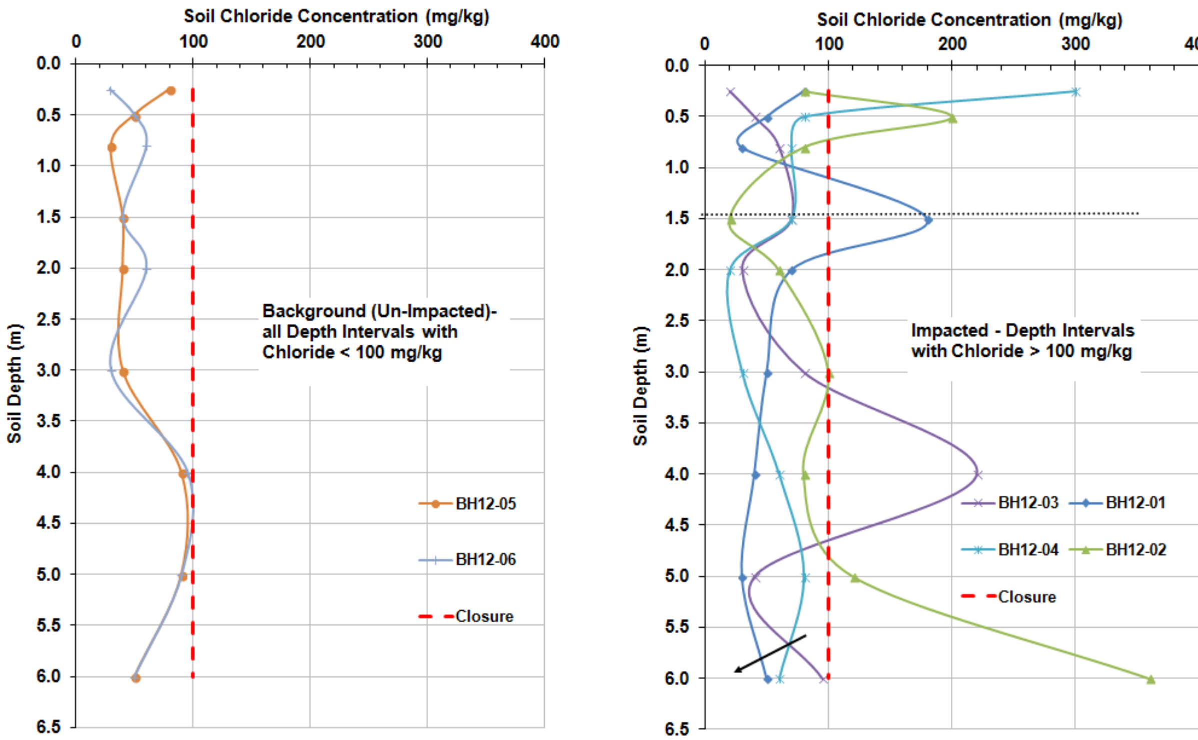
2. If root zone statistics indicate there is a two category jump when comparing the difference between the mean and 95th percentile values (*e.g.*, Good to Poor or Fair to Unsuitable spans more than two categories), additional data is required and it may be necessary to divide the site into two distinct areas under a Tier 2B analysis.

It is not acceptable to use data from depth intervals that overlap the 1.0 to 1.5 m depth interval as well as other depths. For example, using data from a sample collected over the interval 0.75 to 1.25 m or 1.25 to 1.75 m is considered unacceptable. The sampling interval required for the SST is from 1.0 to 1.5 m.

Samples should be submitted to the laboratory for shallower depth intervals (*e.g.*, 0 to 0.3 m, 0.3 to 0.6 m, 0.6 to 1.0 m) as well as the depth interval required for data input into the SST (1.0 to 1.5 m). This will assist in determining whether shallower soils within the impacted area have salinity EC and SAR values that exceed the site-specific Tier 1 guidelines developed for the site based on background salinity. Any exceedence of Tier 1 guidelines at depths shallower than 1.0 m is a trigger for remediation, risk management, and/or exposure control measures. Samples should be submitted for detailed salinity, including the following parameters: EC, SAR, pH, calcium, magnesium, potassium, sodium, chloride, and sulphate. If data from soil depths below the topsoil layer are to be used to assist in estimating background groundwater total dissolved solids (see the section below on soil investigations for the dugout pathway), samples should be analyzed for bicarbonate and carbonate.

Situations may arise where chloride concentrations are below 100 mg/kg within the 1.0 to 1.5 m depth interval, but are elevated within the shallower and/or deeper soil depth interval. A background borehole is one that has chloride concentrations at all depth intervals that are less than 100 mg/kg. If chloride concentrations greater than 100 mg/kg are found above or below the 1.0 to 1.5 m depth interval, the borehole is classified as impacted. Examples of background (un-impacted) and impacted boreholes are shown below.

There are exceptional circumstances where a borehole with a slight exceedence of 100 mg/kg chloride may be acceptable for inclusion in the background dataset, but only for a single borehole. This is for situations where the minimum dataset requires inclusion of this borehole to avoid initiating an additional field investigation program to drill a single additional background location. An example would be the drilling of background boreholes at a site where three of the boreholes have less than 100 mg/kg chloride at all depth intervals and one background borehole has for example a maximum of 125 mg/kg chloride at various depths depth of 0.5 m, 2 m, etc. The SST submission should include rationale for the inclusion of this borehole within the background borehole dataset. Furthermore, the user should determine the contribution of the additional chloride concentration above 100 mg/kg towards background EC/salinity, and document the expected contribution and how it may affect the assessment and SRGs calculated.

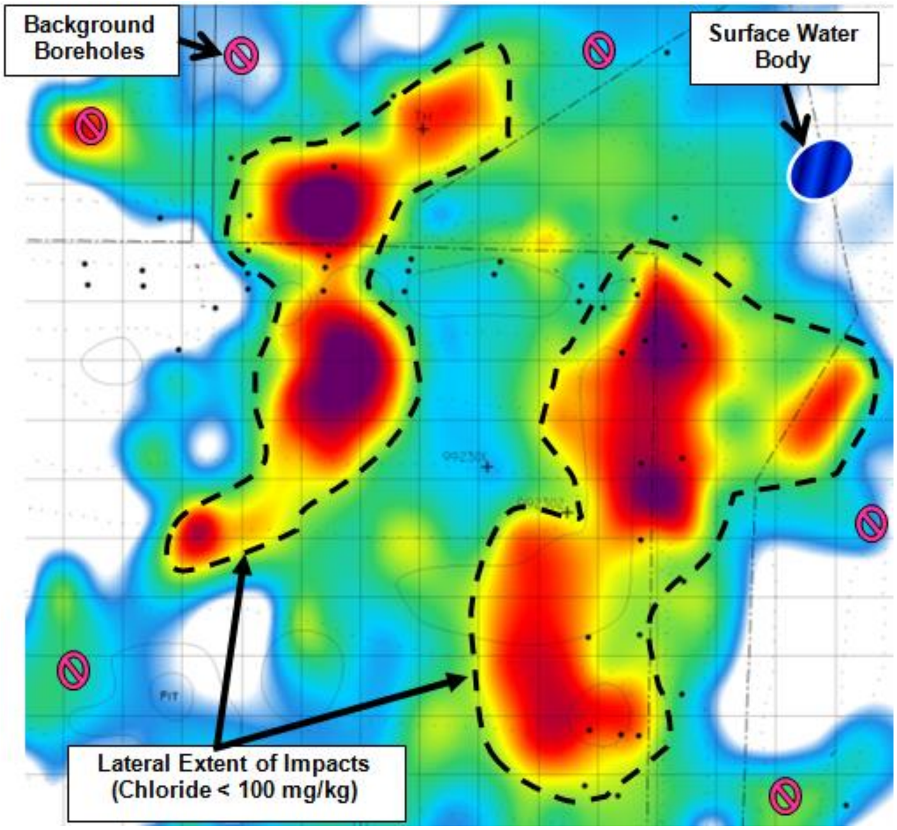


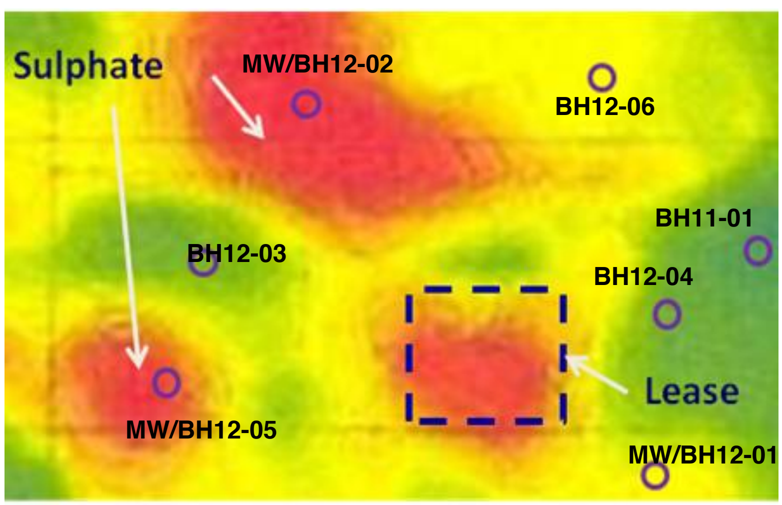
Background boreholes are drilled in locations that are laterally distant from the impacted areas. These boreholes should be drilled at locations that are more distant from the salinity impacts, compared to hydrocarbon impacts, since salts diffuse and disperse to a greater extent into unimpacted soils surrounding an area of salt impact. Background locations must be located outside of the area disturbed by construction or reclamation.

Background salinity can be highly variable in Alberta. Background soil salinity characterization programs should include an evaluation of available information including EM surveys to understand the potential for natural variability of background salinity, prior to conducting intrusive field investigations. The objective is to equally select borehole locations in areas with high, moderate, and low background salinity levels (in other words, most of the background boreholes should not be preferentially situated in areas with high, or low, background salinity levels, unless sub-areas are developed in which case both high and low background salinity environments will be thoroughly characterized). This allows for the development of subsoil SRGs for protection of the root zone pathway where chloride-related contributions towards salinity stress on the deeper range (1.0 to 1.5 m) of plant rooting depths is generally within the variable range of background salinity stress on plant roots.

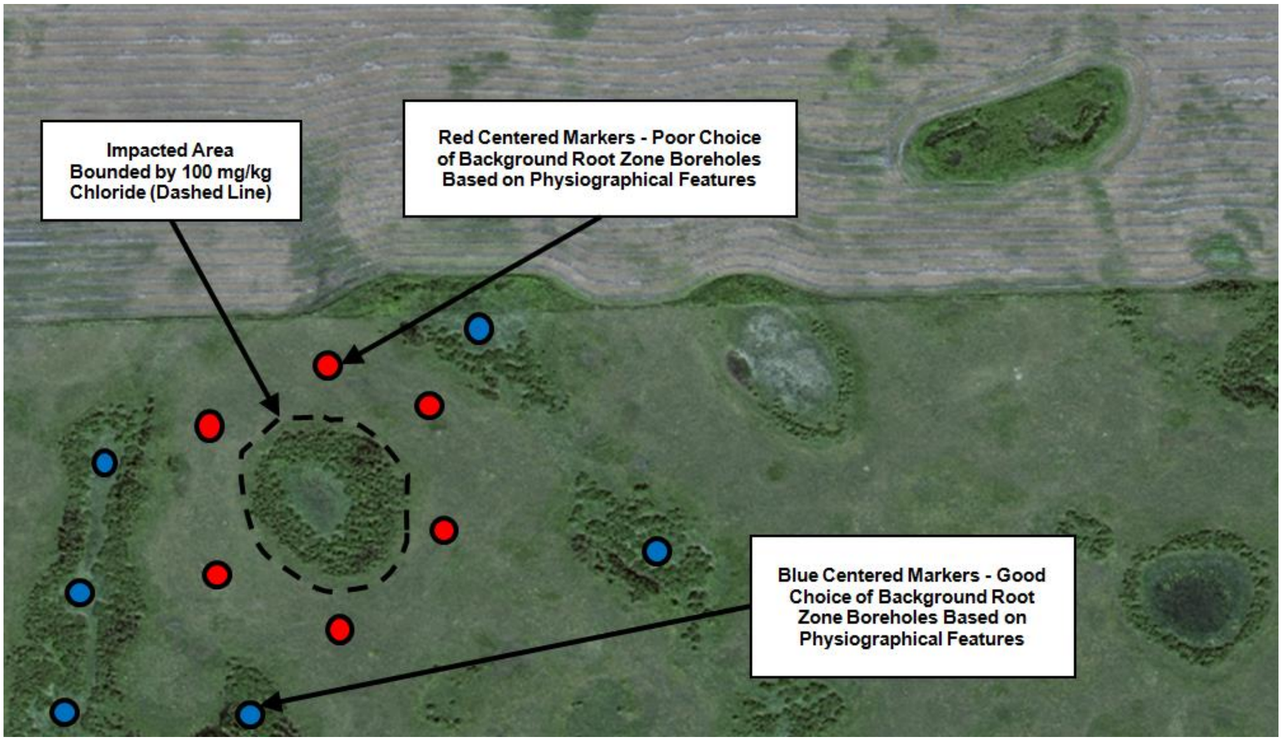
Background root zone salinity levels (due primarily to sulphate and carbonate, and potentially nitrate from agricultural operations) in Alberta soils often fall within three unofficial groupings that have relevance for the SST: 1) lower variability; 2) higher variability with distinct physiographical features; and, 3) higher variability with no apparent distinct physiographical features. An example of lower variability would be soils in some areas near Edmonton where background salinity is low and EC values may vary by less than 1.5 dS/m (from the minimum to the maximum value). An example of higher variability with distinct physiographical features would be an area of coarse soils adjacent to an area of fine soils with a difference in water table depth, which can have distinct background salinity levels. An alternate example would be an area surrounding a particular Class I wetland where the groundwater table is relatively deep. In this case, the Class I wetland may have lower salinity levels due to greater recharge produced by water runoff into the wetland. For the higher variability with no apparent distinct physiographical features grouping, an example would be soils in certain parts of southeast Alberta where background salinity levels vary in a manner often unrelated to distinct physiographical features.

Two examples are provided below for the proper sighting of background borehole locations, in relation to chloride impacted areas, for salinity environments with high variability and no apparent distinct physiographical features. The six background boreholes in each example were evenly distributed between areas anticipated to have relatively low, moderate, and high background root zone salinity levels, based on the EM survey results.





An example is provided below for the proper and improper sighting of background borehole locations, in relation to a chloride impacted area, for salinity environments with greater salinity variability and distinct physiographical features. Airphotos are frequently of use in assisting with background borehole location selection for root zone soil chemistry and texture characterization for this type of grouping. In this example, a pipeline break occurred within a Class II wetland, which did not meet the criteria of a Freshwater Aquatic Life Receptor based on ground evaluation and consulting an aquatic biologist. The outer boundary of the chloride impacted area is defined by the black dashed line. Improper borehole location selection is highlighted by the red markers that show one set of proposed background locations. These are considered improper because the salinity and texture in the area surrounding the Class II wetland is unlikely to be similar to conditions within the boundary of the wetland. The blue markers highlight proper sighting of background boreholes. They are within similar physiographic features, and the soil texture and chemistry is expected to be more similar to the impacted area. The drilling of a few background boreholes where the red markers are located can be used to support whether the blue marker or red marker locations are the most appropriate for characterizing relevant background root zone chemistry and texture.



For sites with higher variability root zone salinity and distinct physiographical features and where an impact area extends across different features, multiple datasets of background root zone information must be generated, one for each distinct physiographical feature.

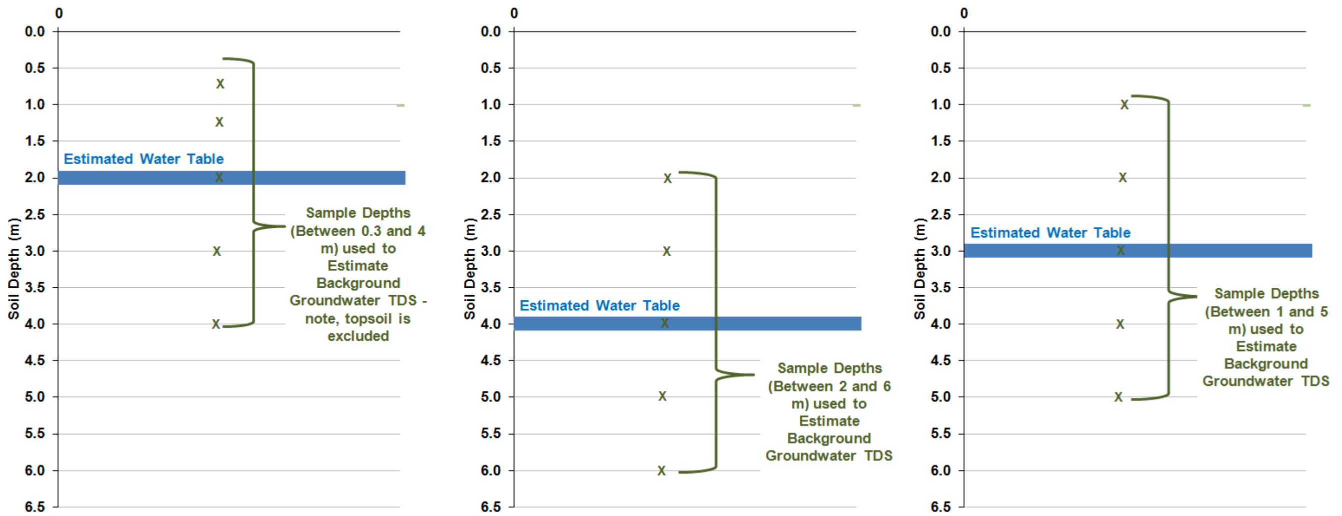
5.3 Background Dugout Scenario Salinity

Additional characterization of background soils to a greater depth will be required if the following situations occur:

1. A Tier 2A assessment is conducted, the water table is estimated to be shallower than 4 m, and the site is,
   a. Located within an Agricultural Land Use area,
   b. Located on Commercial/Industrial/Residential Land adjacent to Agricultural Land, or,
   c. Located in the Natural Land Use area where dugouts have been installed to provide water for livestock;
2. A Tier 2B assessment is conducted, the water table is measured to be shallower than 4 m, the site meets one of the land use conditions mentioned above, and insufficient background monitoring wells are available to characterize background groundwater TDS – in this situation, either more wells are installed in background areas and/or information from background boreholes drilled to a deeper depth are used to estimate background TDS.

Discrete samples should be collected at 1 m depth intervals to a maximum depth of 6 m (*e.g.*¸ 2, 3, 4, 5, and 6 m) for submission to the laboratory for estimating background TDS relevant to the dugout pathways. These boreholes can be combined with background root zone salinity characterization boreholes. Samples should be submitted for detailed salinity, including the following parameters: EC, SAR, pH, calcium, magnesium, potassium, sodium, chloride, carbonate, bicarbonate, and sulphate.

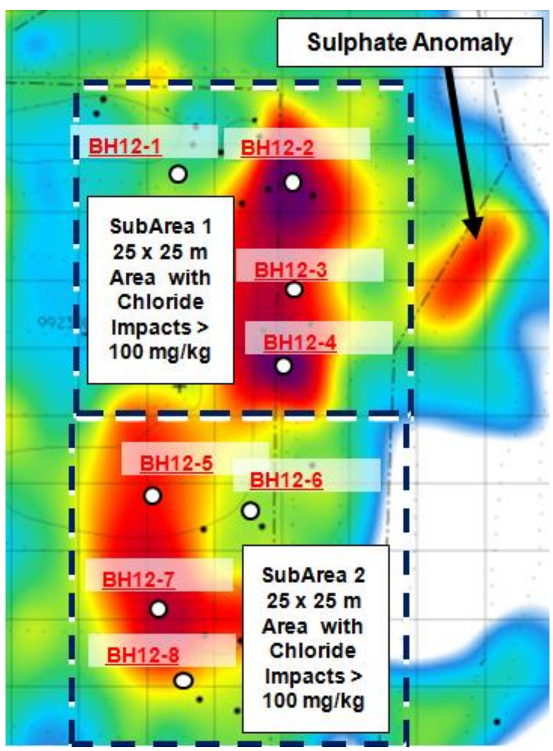
Soil data for input into the SST for these pathways are dependent on the water table depth. If the water table is estimated to be at 3 m, samples should be collected within 2 m below the water table. Samples from within 2 m above the water table will be acceptable if EC profiles show that salinity levels above the water table are consistent with those below the water table. Examples are shown below.



Note: Samples within 2 m above the water table are only acceptable if salinity levels (e.g. EC values or sulphate concentrations) are shown to be similar to levels below the water table.

5.4 Impacted Root Zone Salinity

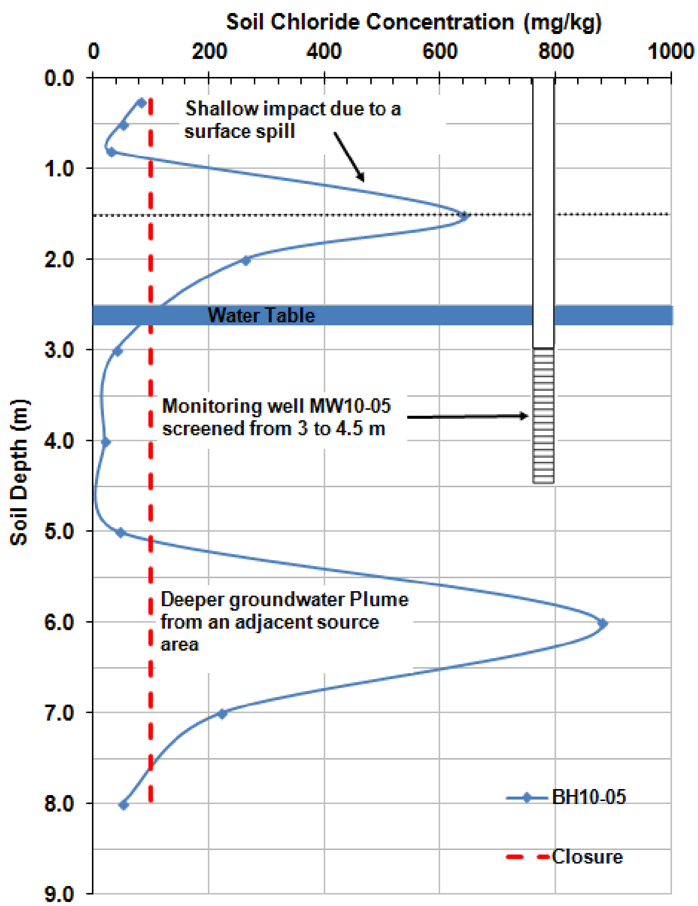
Impacted root zone salinity (1.0 to 1.5 m) is determined from drilling within the salinity impact area where impacts are present (chloride concentrations > 100 mg/kg) at some depth interval within the 1.0 to 10 m soil depth range. A minimum of four boreholes is required within the impacted area to characterize root zone salinity for comparison with background values and for developing an appropriate root zone scenario (unimpacted, impacted, excavate and backfill). It is possible that root zone impacts may not be present from 1.0 to 1.5 m, in which case the root zone is considered unimpacted and is expected to be overlying impacts at greater depths (> 1.5 m). This minimum number of boreholes is required in order to improve the dataset regarding the extent of chloride impacts within the root zone. If multiple SubAreas are considered for a site, a minimum of four boreholes is required per SubArea. An example is shown below.



As per the characterization of background salinity, it is not acceptable to use data from depth intervals that overlap the 1.0 to 1.5 m depth interval as well as other depths, such as 0.75 to 1.25 m or 1.25 to 1.75 m is considered unacceptable. The sampling interval required for the SST is from 1.0 to 1.5 m to characterize root zone impacts. Similarly, samples should be submitted to the laboratory for shallower depth intervals (e.g., 0 to 0.3 m, 0.3 to 0.6 m, 0.6 to 1.0 m) to assist in determining whether shallower soils within the impacted area have salinity EC and SAR values that exceed the site-specific Tier 1 guidelines developed for the site. Any exceedence of Tier 1 guidelines at depths shallower than 1.0 m is a trigger for remediation, risk management, and/or exposure control measures.

5.5 Lateral Closure of Salinity Impact

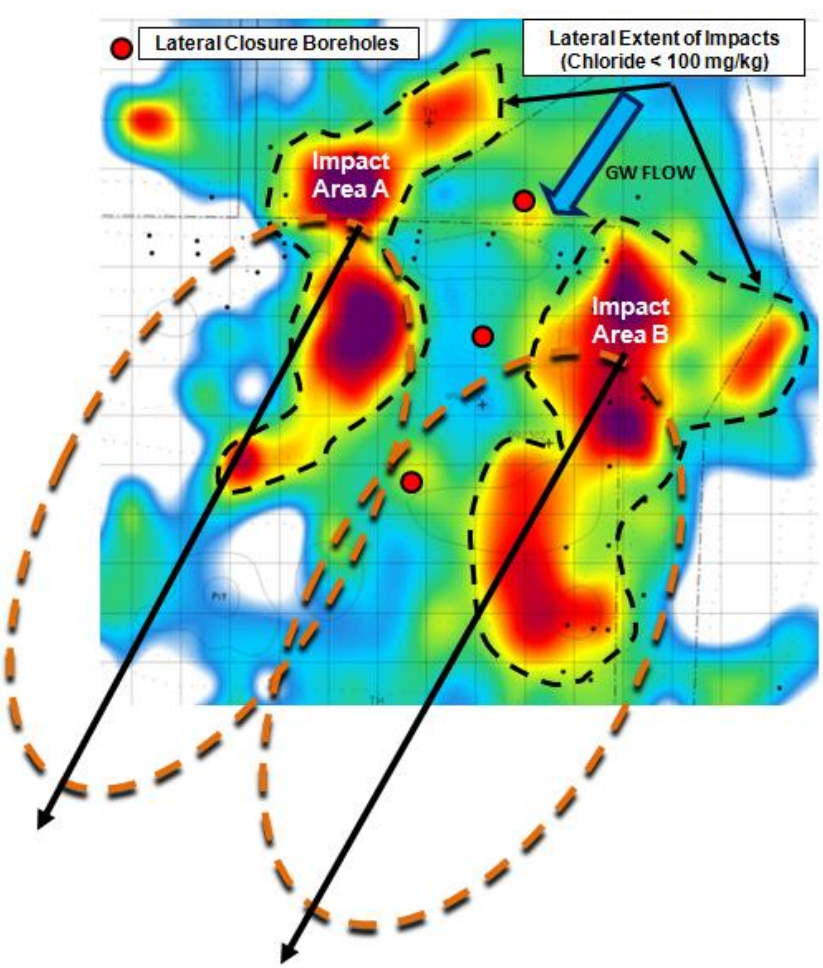
Soil investigation work required to achieve lateral closure can be determined in part by examining historical records of spills and source areas, existing borehole and monitoring well data, EM survey results, as well as other non-intrusive investigation techniques (*e.g.*, VCP, ERT, *etc.*). Lateral closure requires soil chemistry data at multiple depth intervals to confirm closure has been achieved. There are limitations associated with non-intrusive investigations for determining closure due to factors including: depth of impact; soil moisture; soil texture; and, background salinity characteristics. As a result, closure can not be achieved with non-intrusive investigations in the absence of soil chemistry data. Care should be taken when using monitoring well results as evidence of lateral (or vertical) closure. Monitoring wells produce chemistry results from the depth interval over which they are screened (as well as the depth of sand pack), which could be shallower or deeper than impacts in soil as highlighted in the example below. The well in the example below (MW10-05) could have low chloride concentrations indicative of closure compared to the non-closure soil chemistry results measured at BH10-05, assuming the well and borehole were installed immediately adjacent to each other.



For effective determination of lateral closure, soil samples should be collected at 1 m depth intervals and closure boreholes should be drilled to a sufficient depth that would identify any deeper groundwater plumes originating from source areas at the site. The use of field screening techniques such as a mudpress and Quantab strips can assist in determining soil chemistry closure in the field, but cannot be used in the absence of qualified laboratory analyses.

5.5.1 Touching versus Non-Touching Impacts

Under Tier 2B, it is possible to have two distinct impact areas (Impact Area A and B in the figure below) that will not be summative in terms of risk to the DUA and FAL receptors, depending on the groundwater flow direction (in other words, BAF values are not assigned to each distinct impact and summated to 100%). Minimum investigations are required to demonstrate areas are distinct by placing boreholes between the areas (see Figure below). A minimum of three boreholes is required and if concentrations are < 100 mg/kg chloride at all relevant soil depth intervals (*i.e.*, to the maximum depth of impact for either area), then the impacts can be considered distinct and 'non-touching', and not cumulative in terms of risk if groundwater flow does not result in one impact area being located downgradient of another. Although there may be some overlap between the chloride groundwater plumes over time (represented by hypothetical groundwater plumes in the figure below - dashed orange lines) as they are transported from the impact source areas, providing the impact source areas are not touching as defined by having a separating distance with chloride concentrations less than 100 mg/kg, the probability for cumulative risks is considered low since peak concentrations arriving at the receptor of concern (*e.g.*, freshwater aquatic life receptor) will be associated with the centre, rather than the fringe, of each groundwater plume.



5.6 <u>Source Length and Dimensions</u>

Source dimensions are primarily defined using soil chemistry data and the information is used to develop SRGs for the FAL and DUA pathways and receptors, which are based on groundwater transport. Source length is used to define appropriate source dimensions for entry into the SST, which is based on the length of chloride impacted soil and groundwater for any vector across the impact area (Tier 2A) or in the direction of groundwater flow (Tier 2B). In SST Versions 2.5.3, source area must be considered in addition to source length. There are five default source dimensions:

15 x 15 m; 25 x 25 m; 50 x 50 m; 75 x 75 m; and 100 x 100 m, which are entered into the SST as respective source lengths: 15, 25, 50, 75, and 100 m. Any source dimension (length) can be entered into the SST. Multiple SubAreas can be run to represent an impact or for assessing source dimensions greater than 100 x 100 m, but the maximum length of SubAreas with the potential for cumulative risk (*i.e.*, overlapping plumes) cannot exceed 200 m and the maximum width cannot exceed 150 m. ***If the source dimension exceeds 200 x 150 m, a Tier 2C assessment is required.***

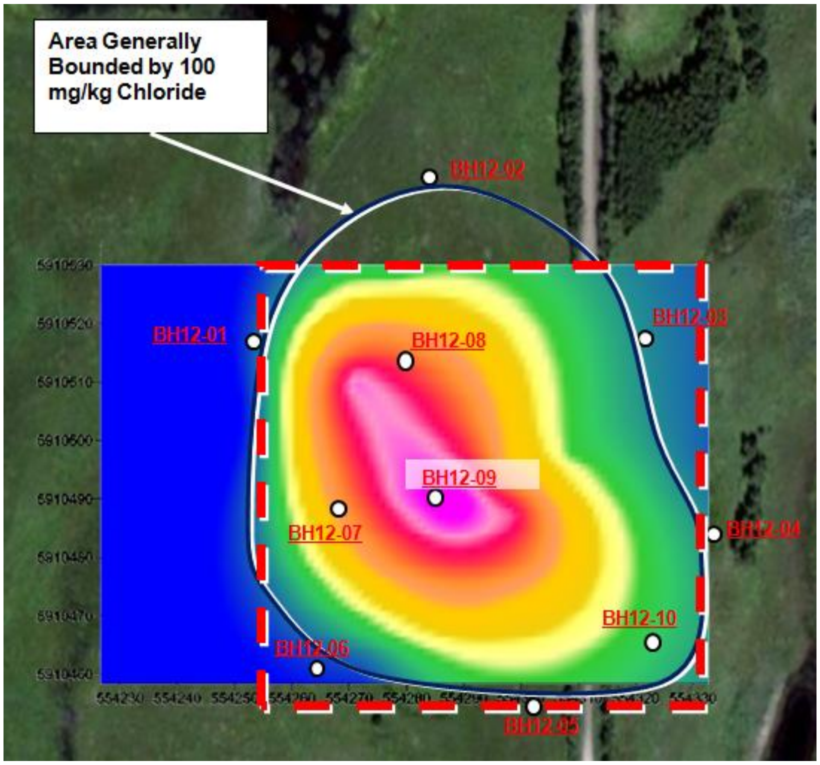
Lateral closure must be obtained in a manner that generally surrounds the chloride impact (*e.g.*, in all cardinal directions from the approximate centre of an impact, or north, south, east, and west). In SST Version 2.5.3, the chloride impacts are divided into one source area or multiple source SubAreas. SRGs are developed based on the potential for sources areas (or SubAreas) to have a summative loading of chloride at a receptor location, or have the potential for overlapping plumes. An example of source area implementation is as follows: If a source area of 35 x 25 m was determined, the source area that would encompass this length is 35 x 35 m, and this area would be selected for calculating SRGs (the SST would run this as a 50 x 50 m scenario). The selection of a 25 x 25 m dimension would be under-conservative. A minimum of four boreholes within an impacted area is required to define source concentrations. A greater number of boreholes are required to define closure, which must be located in all cardinal directions surrounding the impact area. If a site is subdivided into SubAreas, multiple boreholes (a minimum of four) should be drilled within each SubArea to adequately characterize the magnitude, depth, and lateral distribution of chloride impacts.

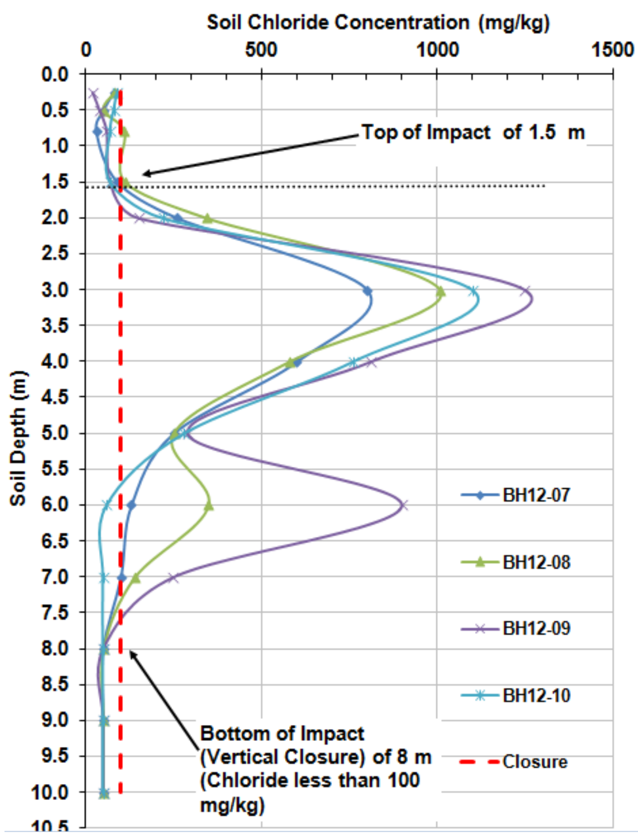
In some situations, chloride concentrations may exceed 100 mg/kg in background locations. This may occur in samples collected near the surface from slough bottoms, near salt blocks, livestock excrement, and peat. Background subsoil chloride concentrations will typically be less than 100 mg/kg and it is expected that lateral closure (chloride < 100 mg/kg) can readily be obtained for SST assessments of salt impacted sites.

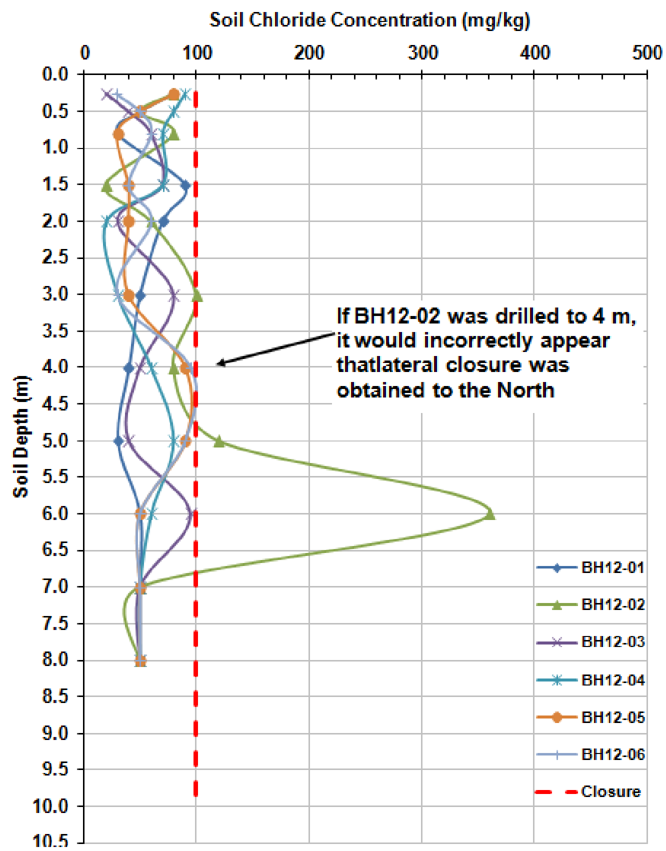
Source area can be reduced if an area has been remediated to concentrations below 100 mg/kg. For example, if chloride impacts at a flare pit (45 x 45 m) and wellhead (15 x 15 m) have the potential to lead to overlapping plumes and their cumulative source dimension fits within a 60 x 60 m area, the SST can be run with a source dimension of 60 m, which in the SST would default to a 75 x 75 m scenario. Alternately, the wellhead impact could be remediated to 100 mg/kg, and the remaining scenario would be a 45 x 45 m flare pit impact, which the SST would run as a 50 x 50 m scenario.

There are several geophysical tools available that can greatly assist with the selection of borehole locations in order to obtain lateral chloride closure based on laboratory chemistry data for both Tier 2A and Tier 2B assessments. These tools include Electro Magnetic (EM) surveys (*e.g.*¸EM31, EM38, EM34), Ohm mapper, and push probes with vertical conductivity profiling. ***However, chemistry data is mandatory for defining closure for Tier 2A and Tier 2B.***

It is important to have an understanding of vertical closure before lateral closure can be conclusively determined. An example is provided below. In this example, in the centre of impact at BH12-09, the maximum depth of impact was determined to be 8 m, with a peak chloride concentration occurring at 6 m, co-located with a coarse depth interval situated within a predominantly fine textured soil. If BH12-02 (located near the periphery of the impact to the north) was drilled to a depth of 4 m, all chloride concentrations would be less than 100 mg/kg and lateral closure achieved to the north. However, if BH12-02 was drilled to 8 m, evidence of a deeper groundwater plume likely originating from the centre of the impact would have been identified, which will increase the source length to the north. It is important to ensure that lateral closure boreholes have been drilled to an appropriate depth for defining closure, which can be guided by the maximum depth of closure in a more heavily impacted area. A similar closure problem can arise if limited depth wise samples are collected (*e.g.*, samples from 4 and 8 m, as opposed to 4, 5, 6, 7, and 8 m). Samples are required at 1 m depth intervals in subsoil.

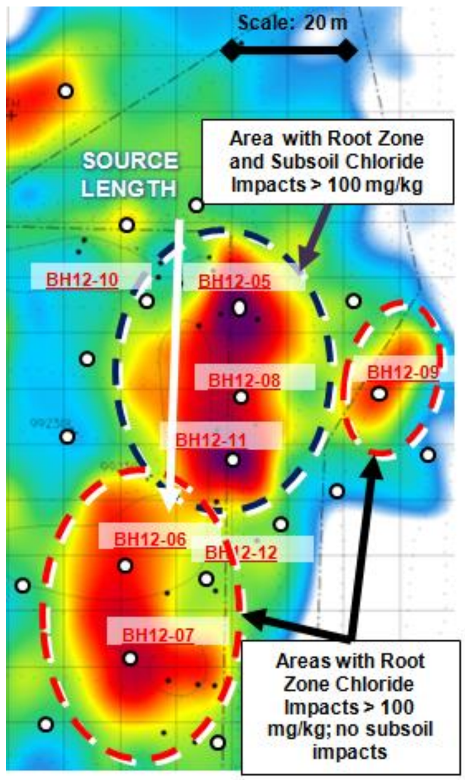






Impacts within the root zone, but lacking subsoil impacts, are not included in source length calculations. For example, in the figure below, the area circled by the blue dashed oval (a former flare pit) has both root zone and subsoil chloride impacts with concentrations > 100 mg/kg. Within the red dashed ovals (overland spills to low lying areas), subsoil chloride concentrations were < 100 mg/kg, however, root zone concentrations were > 100 mg/kg and the root zone was considered impacted. The area encompassed by the red ovals would not be included in source area calculations. A source area of 50 x 50 m would be selected for calculating SRGs providing lateral impact closure was obtained.

For a Tier 2A analysis, the source length is defined by the greatest length across the impacted area in any direction (edge to edge of chloride ≤ 100 mg/kg), which is determined from soil borehole information. For a Tier 2B analysis, the source length is defined by the greatest length (edge to edge) in the direction of groundwater flow. Source dimensions are defined from soil borehole information and salinity chemistry data. Using the square chloride impact source and BAF approach in SST Version 2.5.3, source area is more important than source length because by default the length will be incorporated. ***In addition, the entire lateral chloride impacted area must be encompassed by the dimensions of a single source or the dimensions of SubAreas (this applies to both Tier 2A and 2B).*** This requirement to define source length based on the greatest length across the impact is due to a lack of information under Tier 2A for groundwater flow direction, and since the DUA and FAL SRGs are more influenced by a greater source length in the direction of groundwater flow compared to source width. An appropriate source area (*e.g.*, 15 x 15 m or 75 x 75 m) is selected, for calculating SRGs. A chloride soil concentration of less than 100 mg/kg at all subsoil depth intervals is indicative of an unimpacted borehole, and can be used to define lateral closure and resulting source area or SubAreas.

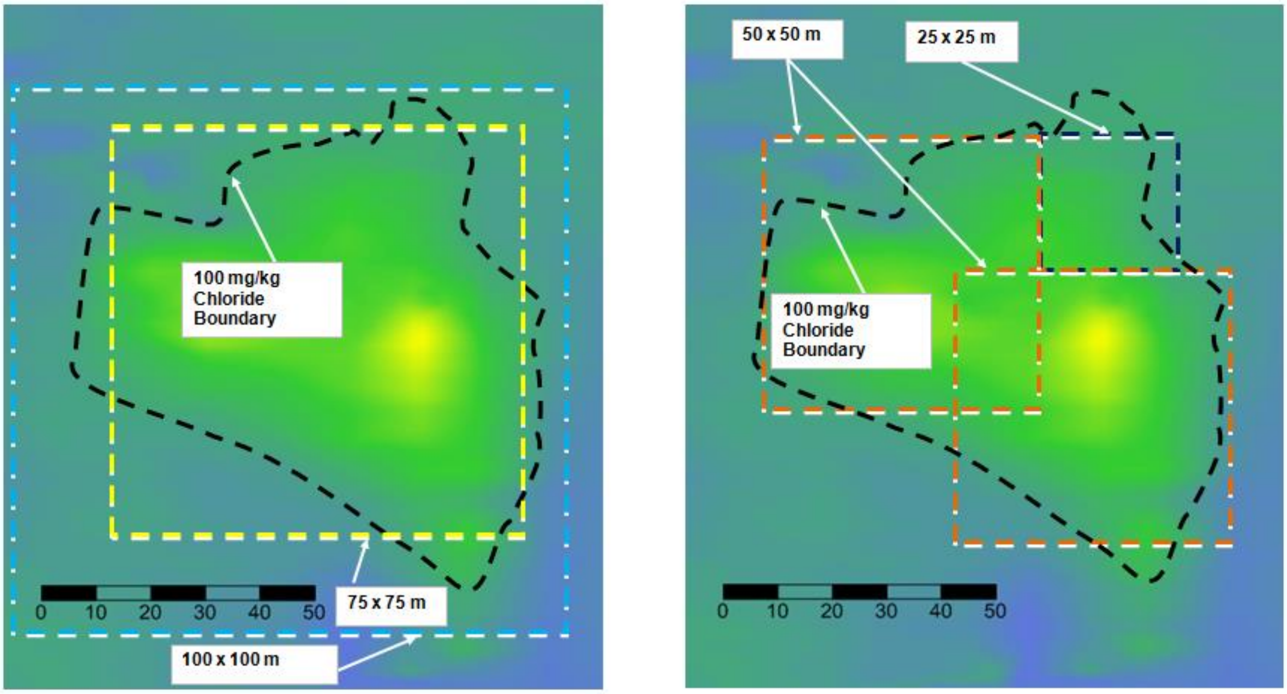


Proper documentation of lateral chloride closure is required for all SST submissions

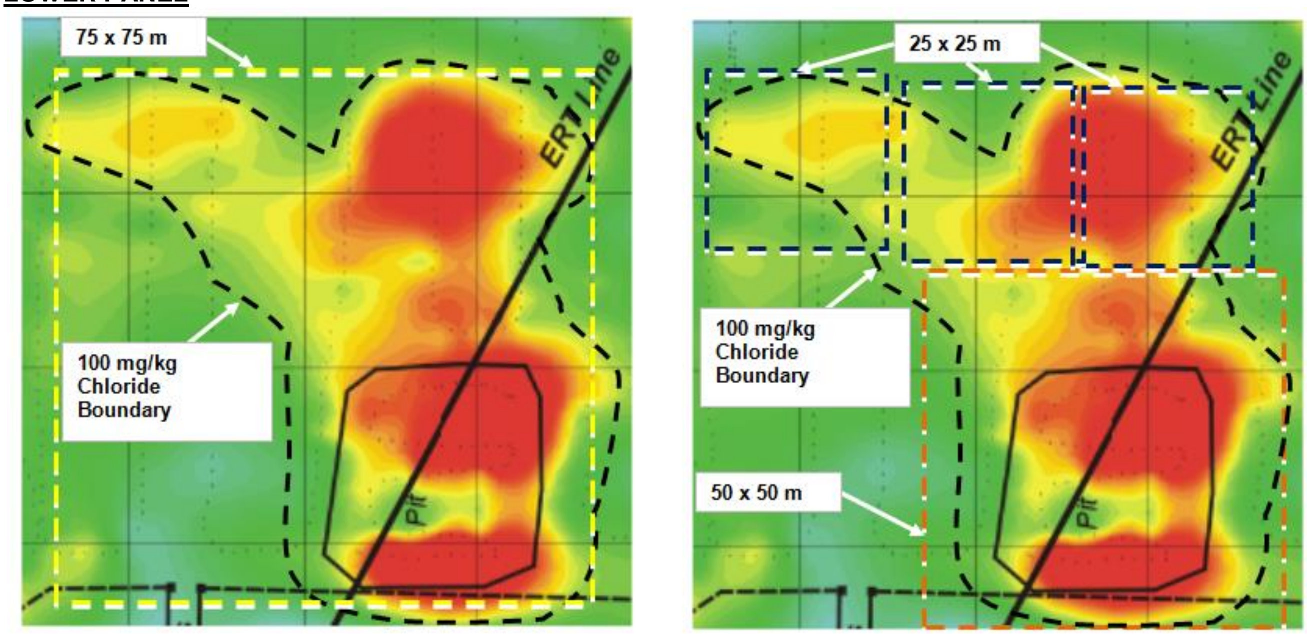
In the upper panel of the figure below, investigation work has been completed with multiple boreholes to determine a boundary of soil area impacted by chloride concentrations greater than 100 mg/kg (black dashed line). This area conservatively fits within a 100 x 100 m (10,000 m^2) source dimension (light blue dashed line) regardless of the direction of groundwater flow, and a source length of 100 m is entered into the SST. The chloride impacted area may also fit within a smaller 75 x 75 m area (yellow dashed line). A calculation must be made to estimate the area encompassed by the black dashed line and ensure it does not exceed the area represented by 75 x 75 m (yellow dashed line; 5,625 m^2). If the chloride bounded area does not exceed the 75 x 75 m area, a 75 x 75 m source dimension can be run and a source length of 75 m is entered into the SST. Alternately, the impact can be divided into three SubAreas (50 x 50 m (orange dashed), 50 x 50 m (orange dashed), and 25 x 25 m (purple dashed)). The area within the black dashed line (chloride > 100 mg/kg) must fit within the sum of the area for these three SubAreas (2,500 + 2,500 + 625 = 5,625 m^2). While dividing the impact into three SubAreas did not make a difference in total area compared to assuming a 75 x 75 m impact, the SubArea approach may lead to more effective remediation if the distribution of chloride impacts varies between the SubAreas in terms of chloride concentration as well as top and bottom of impact.

In the lower panel of the figure below, a second scenario is shown where the chloride impacted area (blacked dashed line delineating the 100 mg/kg chloride boundary) can fit within a conservative 75 x 75 m area (yellow dashed line; 5,625 m^2), and a source length of 75 m would be entered into the SST. Alternately, the impact could be divided into four SubAreas (25 x 25 m (purple dashed), 25 x 25 m (purple dashed), 25 x 25 m (purple dashed), 50 x 50 m (orange dashed); 625 m^2 + 625 m^2 + 625 m^2 + 2,500 m^2 = 4,375 m^2). A calculation must be made to ensure that the area encompassed by the black dashed line is less than the sum of the four SubAreas (4,375 m^2). The use of SubAreas in this scenario resulted in a more appropriate representation of lateral impact area and may result in more effective remediation if chloride concentrations vary in terms of chloride concentration as well as top and bottom of impact, between the SubAreas.

UPPER PANEL



LOWER PANEL



Groundwater flow direction must be documented to demonstrate the appropriate source length for a site.

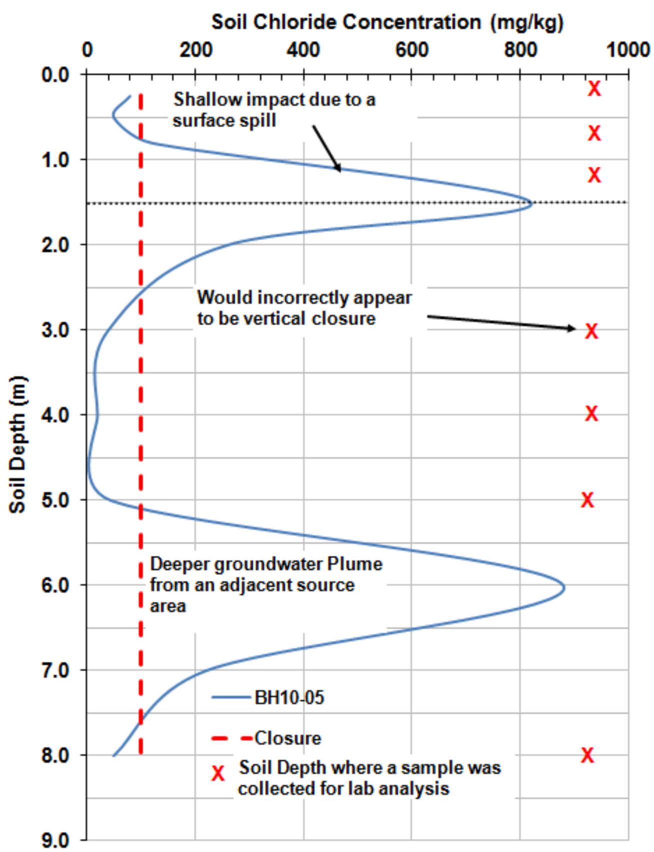
The area bounded by chloride ≤ 100 mg/kg must be measured and it must be demonstrated that this area is encompassed by the sum of square source areas entered into the SST

5.7 Vertical Closure of Salinity Impact Information

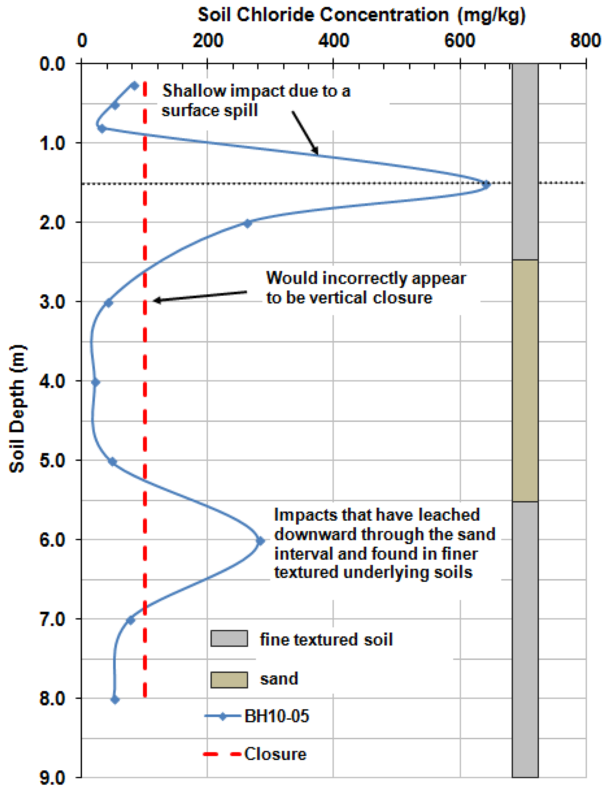
The vertical extent of impacts (both upper and lower boundaries) is a sensitive model parameter since potential risks are directly correlated with the vertical mass of salt impact. As a default input, the upper boundary is defined as the base of the root zone or 1.5 m. Top of impact depths deeper than 1.5 m are expected to apply in scenarios such as:

1. Areas that have become impacted due to a deeper groundwater plume that has migrated away from the source area where shallower impacts have not been observed; and/or,
2. Excavations that remove salt impacts in shallower soils.

The bottom of impact can be confirmed by having 2 or 3 soil samples with chloride concentrations less than 100 mg/kg (closure) at depths deeper than where concentrations above 100 mg/kg were observed. The use of VCP, ERT, and/or field screening techniques can assist in determining borehole drill depths where closure may be anticipated. Vertical closure for input into the SST must be determined from soil chemistry data (< 100 mg/kg chloride). Sampling should be continuous with depth and the selection of more vertically spaced depths for sample collection must be avoided as this can prevent an accurate determination of vertical closure. In the example below, the soil depths from which samples were collected and submitted to the laboratory had relatively larger vertical gaps within which soil samples were not collected. This can result in subsoil impacts not being identified and the corresponding mass of salt would not be properly represented by the SST input and resulting SRGs. The impacts between 5 and 7 m were not captured by the sampling interval in the example below, and a bottom of impact of 3 m would incorrectly have been input into the SST.



In situations where sands are encountered in the vadose zone beneath an impact and chloride concentrations are less than 100 mg/kg, it is possible that the impacts may have travelled through the coarse material and concentrations greater than 100 mg/kg may be found in deeper underlying fine till, as shown in the example below. Additional vertical drilling and sample collection can be used to ensure closure is obtained in this situation.



5.8 Backfill Material Information

SST assessments involving excavation and backfill require that the texture of backfill material is similar to the native material that was removed through excavation, and also require laboratory chemistry data for the backfill. Chemistry data is required to determine EC and SAR values (as well as ion concentrations such as chloride, sodium, *etc.*) in the root zone (< 1.5 m soil depth) for the Excavate and Backfill Root Zone Scenario. Chloride concentrations are required for subsoil (>1.5 m soil depth) and if concentrations are greater than 100 mg/kg, the materials would be considered impacted and the top and bottom of impact would take into consideration the depth interval over which the impacted backfill material was placed. These concepts are discussed further in the following section.

6 SRG ANALYSIS AND EXCAVATION RESULTS INTERPRETATION

Following the development of subsoil chloride Tier 2A or 2B SRGs for a site, they are then compared with measured concentrations of chloride in soil to identify whether an exceedence has occurred. GRGs can similarly be compared to groundwater chloride concentrations measured in samples from monitoring wells located within the boundary of the impacted area (defined as soil chloride concentrations > 100 mg/kg). Situations where SRGs or GRGs are exceeded by measured concentrations are considered triggers for remediation, and/or exposure control. Guidelines can be recalculated iteratively following an analysis of remediation options (such as excavation depth).

Subsoil SRGs are calculated for all relevant receptors (root zone, dugout pathways, FAL, and DUA). Examples are provided below in separate sections for the root zone/dugout pathways and for the FAL and DUA pathways, the latter two being dependent on source dimensions and, if applicable, the use of BAF factors.

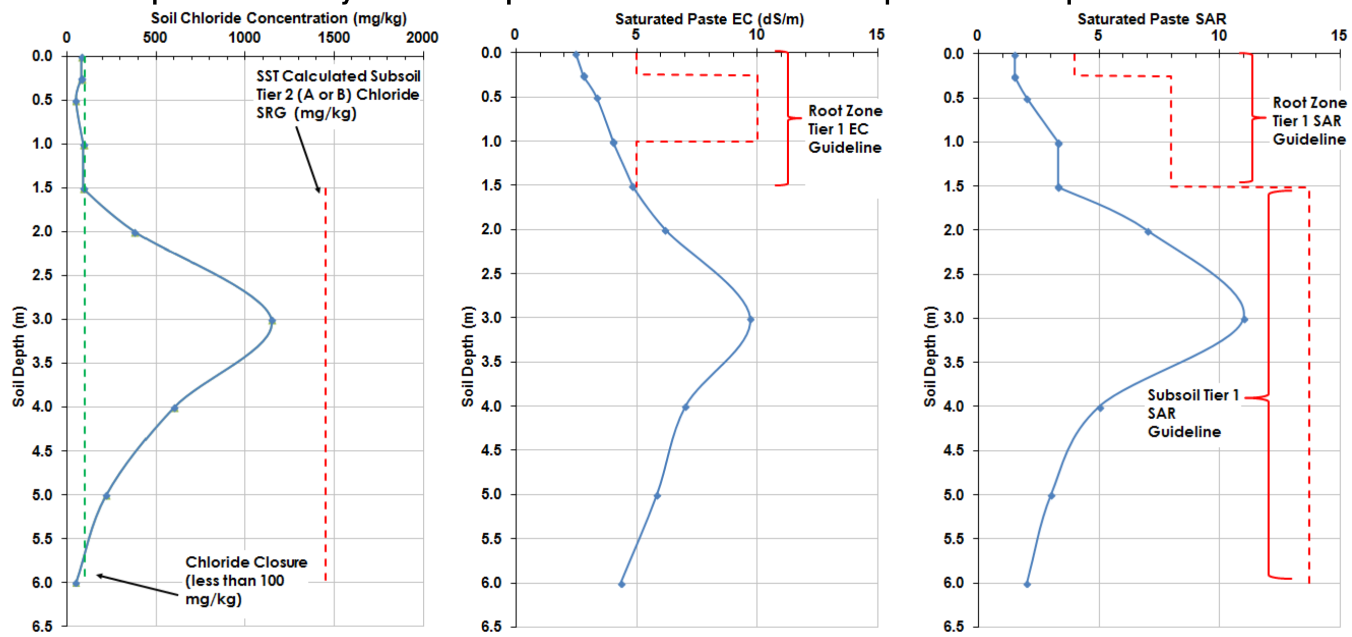
6.1 SRG Analysis

Measured values of EC and SAR within the shallower root zone (<1.5 m) at a site must similarly be compared against appropriate guidelines, which for the root zone is ESRD (2014a) Tier 1 EC and SAR guidelines. Exceedences are also considered triggers for remediation or exposure control (risk management).

Simplified examples for comparing values and concentrations within an impacted area against SST derived chloride subsoil SRGs, as well as root zone ESRD (2014a) Tier 1 EC and SAR guidelines, are provided below. The examples present results for a single borehole within an impacted area sampled to a depth of 6 m (shown as blue solid lines). Since Tier 1 EC and SAR guidelines can vary as a function of root zone depth, background data (not shown) were organized into depth intervals of 0 to 0.25 m (topsoil), 0.25 to 1 m, and 1 to 1.5 m (SST depth interval and deeper root zone) from which separate EC and SAR guidelines can be developed for each depth interval (shown graphically below by the dashed red line). It should be noted that a Tier 1 subsoil (> 1.5 m soil depth) SAR guideline is required for comparison with SAR values at depths deeper than the rooting zone in order to achieve site closure. *A Tier 2 subsoil sodium and/or SAR guideline algorithm will be included in the SST (Version 3.0) to be released in 2014*.

In the first example below, the appropriate SST root zone scenario would be Unimpacted. The subsoil chloride top and bottom of impact would be 1.5 m and 6 m, respectively, based on the information shown in the leftmost panel. It is possible that following a calculation of the 95% vertical mass, the bottom of impact could be shifted to 5 m – this calculation was not completed for this example as multiple borehole data would be required for a particular SubArea or site. Subsoil chloride concentrations (blue line in leftmost panel) were below the most constraining subsoil SRG calculated by the SST (a hypothetical guideline is shown, which would be the lowest SRG for the root zone, aquatic life, DUA, and dugout pathways; shown as a red dashed line from 1.5 to 6 m with a chloride concentration 1,450 mg/kg). As a result, subsoil chloride concentrations would not be considered a trigger for remediation. Root zone EC and SAR values measured in the impacted area (blue lines in the middle and rightmost panels, respectively) were below their respective guidelines (shown as red dashed lines; EC guidelines ranged from 5 to 10 dS/m; SAR guidelines ranged from 4 to 8). A Tier 1 subsoil (> 1.5 m) SAR guideline (SAR of 14) is shown in the rightmost panel that was derived from background data, and extends to a depth of 6 m. Measured subsoil SAR values within the impacted area (blue line) were below the subsoil Tier 1 SAR guideline (red dashed line). No excavation is required in this example for this borehole location.

Example 1: Chemistry within an Impacted Area and Guideline Comparison – Unimpacted Root Zone

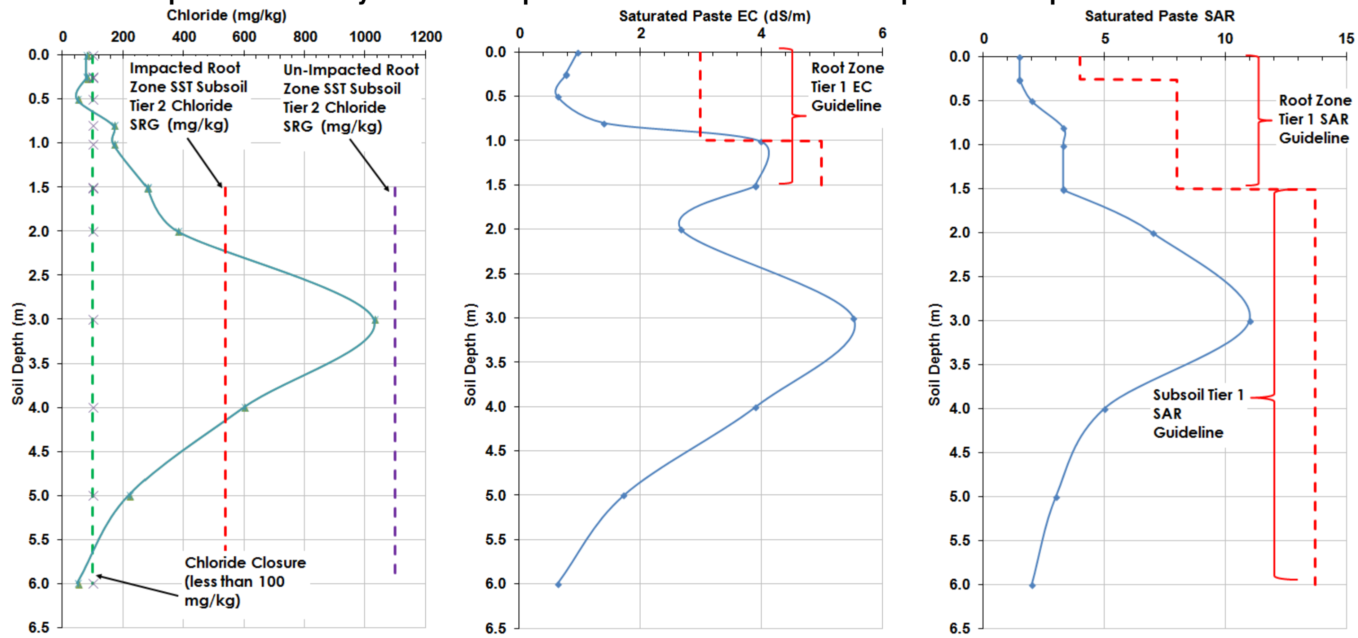


Leftmost panel – root zone and subsoil chloride; middle panel – root zone and subsoil EC; rightmost panel – root zone and subsoil SAR Subsoil chloride, root zone EC, and root zone as well as subsoil SAR SRGs shown as dashed red lines. A single vertical profile of chemistry data within the impacted area is shown as a blue line. 100 mg/kg chloride closure is shown as a dashed green line.

In the second example, the appropriate SST root zone scenario would be Impacted, because chloride concentrations were greater than 100 mg/kg over the depth interval of 1.0 to 1.5 m (leftmost panel) and EC and SAR values within this depth interval were below Tier 1 guidelines (middle and rightmost panels, respectively). The exceedence of chloride greater than 100 mg/kg is not automatically a trigger for remediation of the deeper root zone from 1.0 to 1.5 m. It should be noted that if EC or SAR Tier 1 guidelines were exceeded within the 1.0 to 1.5 m depth interval, this would be indicative of an Excavate and Backfill Root Zone scenario. The subsoil chloride top and bottom of impact for this example is 1.5 m and 6 m, respectively, based on the information shown in the leftmost panel. Subsoil (> 1.5 m) chloride concentrations (blue line in leftmost panel) exceeded the most constraining subsoil SRG (a hypothetical SRG of 540 mg/kg is shown (red dashed line), and was based on protection of the root zone). As a result, subsoil chloride concentrations were considered a trigger for remediation, exposure control, and or risk management. Root zone EC and SAR values measured in the impacted area (blue lines in the middle and rightmost panels, respectively) were below their respective guidelines (shown as red dashed lines; EC guidelines ranged from 3 to 5 dS/m; SAR guidelines ranged from 4 to 8). The Tier 1 subsoil (> 1.5 m depth) SAR guideline (SAR of 14; rightmost panel) was not exceeded.

Several options are subsequently available for this example. One option would be to excavate the root zone from 1.0 to 1.5 m, backfill with soils containing chloride concentrations less than 100 mg/kg as well as EC and SAR values that are similar to background, and re-run the scenario as an Unimpacted Root Zone. The resulting SRG for this example was 1,100 mg/kg (purple dashed line). Subsoil chloride concentrations did not exceed the Unimpacted Root Zone SRG, indicating no further excavation would be required for this borehole. If exceedences remained, deeper excavation would be required and the scenario could be re-run iteratively with a top and bottom of impact of 2 and 6 m, respectively (or 3 and 6 m, *etc.*), as opposed to 1.5 and 6 m, respectively.

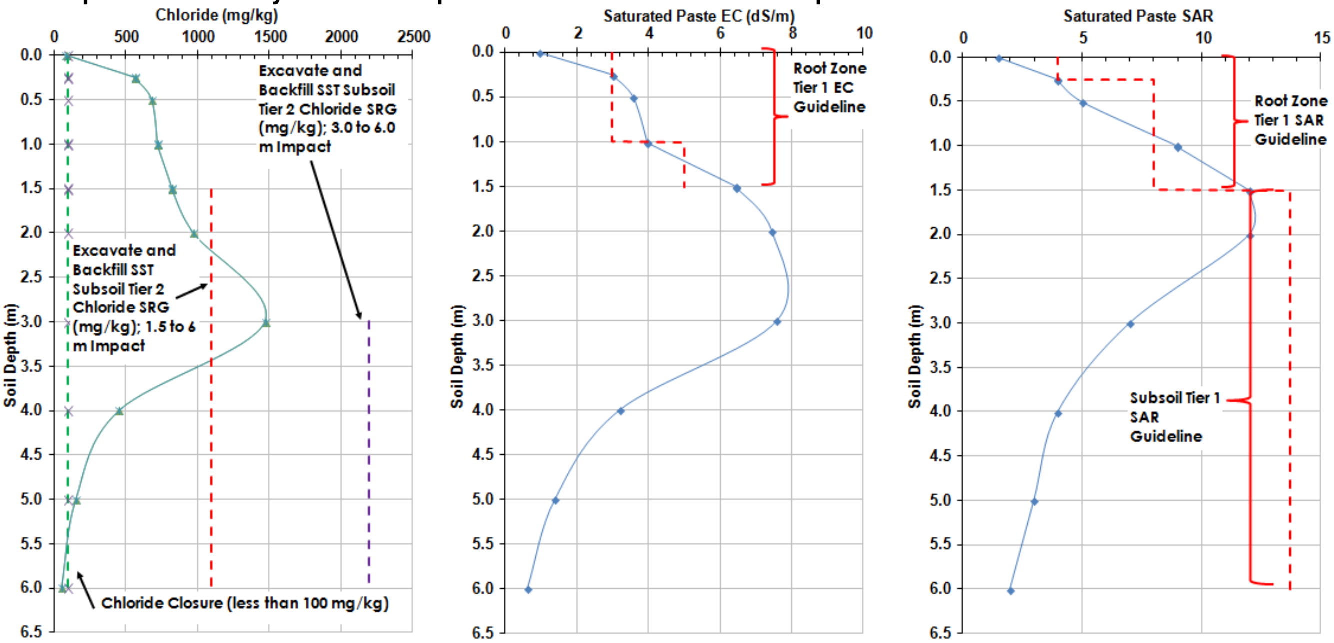
Example 2: Chemistry within an Impacted Area and Guideline Comparison – Impacted Root Zone



In the third example, the appropriate SST root zone scenario would be Excavate and Backfill, because chloride concentrations were greater than 100 mg/kg over the depth interval of 1.0 to 1.5 m (leftmost panel) **and** EC and SAR values within this depth interval (as well as shallower soils) exceeded Tier 1 guidelines (middle and rightmost panels, respectively). In other words, the blue lines representing impacted soil chemistry data exceeded the dashed red lines representing Tier 1 EC and SAR guidelines within the root zone. The root zone results in this scenario are a trigger for remediation prior to reclamation. The subsoil chloride top and bottom of impact for this example is 1.5 m and 6 m, respectively, based on the information shown in the leftmost panel. Subsoil (> 1.5 m depth) chloride concentrations (blue line in leftmost panel) exceeded the most constraining subsoil SRG (a hypothetical SRG of 1,100 mg/kg based on a root zone Excavate and Backfill scenario, and a subsoil SRG protective of the root zone; red dashed line). The subsoil chloride SRGs in this example can be influenced by the quality (*i.e.*, salinity) of backfill material. Lower salinity (EC) backfill material will result in a greater root zone buffer, and subsequently will allow for the calculation of a higher subsoil SRG value. Optimally, the backfill material selected has a salinity level that is similar to background soils.

One option for this scenario, given the subsoil SRG was exceeded, would be to iteratively determine SRGs associated with deeper excavations. A re-run of the scenario with a top of impact of 2 m and bottom of impact of 6 m produced a constraining SRG of 1,300 mg/kg. This guideline was exceeded at a depth of 3 m. A subsequent iterative re-run with a top of impact of 3 m and bottom of impact of 6 m produced a constraining SRG of 2,200 mg/kg (purple dashed line). An excavation of 3 m would be required for this scenario in order for there to be no subsoil exceedences.

Example 3: Chemistry within an Impacted Area and Guideline Comparison – Excavated and Backfill Root Zone

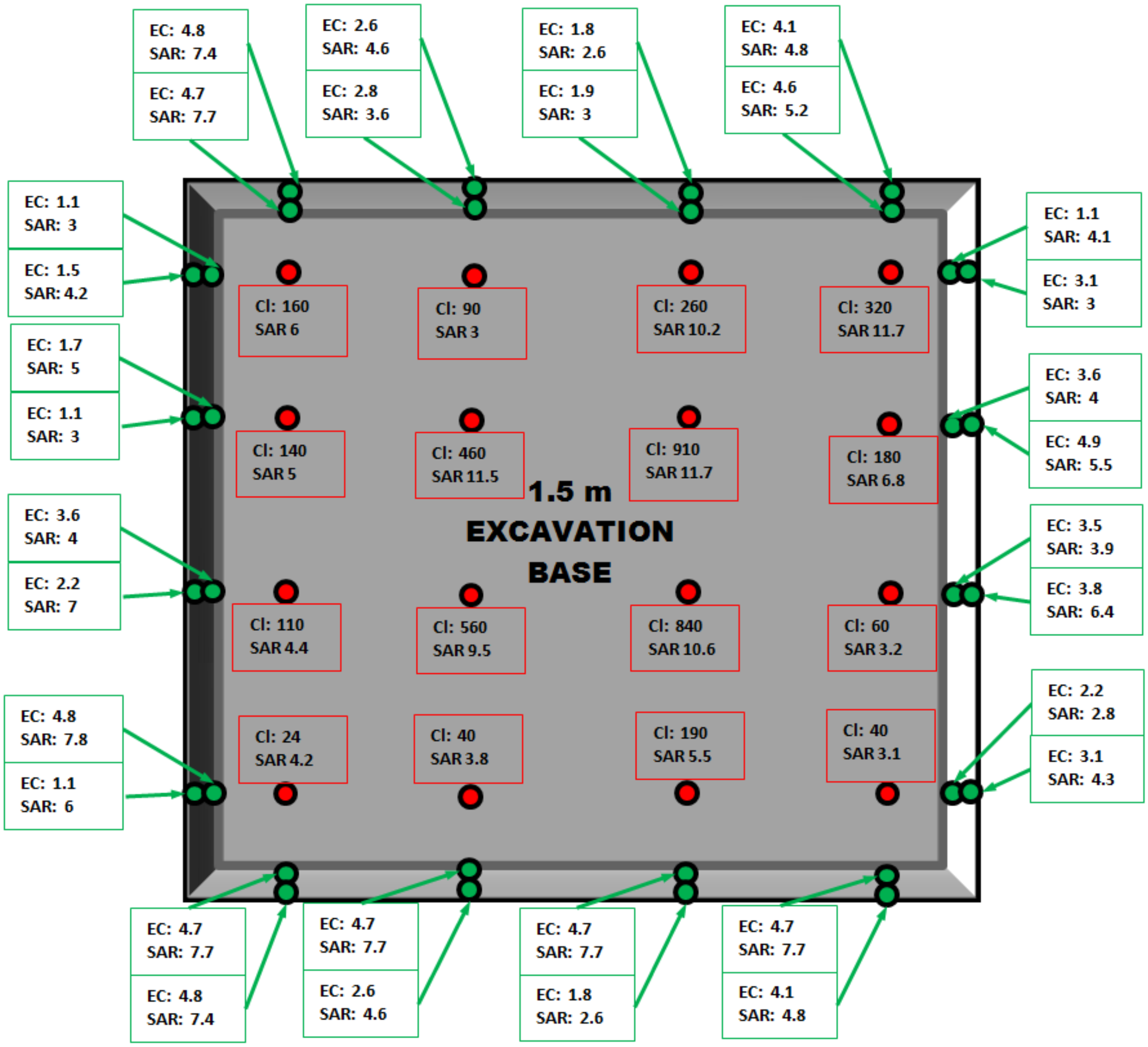


6.2 Excavation Confirmatory Sampling Analysis

Once excavation work has been completed, it is necessary to evaluate confirmatory excavation wall and floor samples to ensure that the calculated SRGs (or Tier 1 root zone EC and SAR guidelines) have not been exceeded. It should be noted that the assessment of excavation confirmatory sampling can be complex as multiple parameters and guidelines are considered. Several examples are shown below. Green dots represent wall samples that have been taken from within the root zone (0 to 1.5 m) for comparison with Tier 1 EC and SAR guidelines. In the examples where two green root zone dots are shown, one is assumed to represent the 0.3 to 1.0 m depth interval and the second represents the 1.0 to 1.5 m depth interval. These Tier 1 guidelines are not necessarily identical for both depth ranges. A topsoil confirmatory sample would also be required (not shown). The manner in which the root zone is subdivided into depth intervals for confirmatory sampling is based on professional judgement and reclamation requirements. A wall confirmatory sample is required within the depth range of 1.0 to 1.5 m for comparison with Tier 1 EC and SAR guidelines as part of an SST assessment, and wall samples are required at any number of depth ranges shallower than 1.0 m that must meet Tier 1 guidelines and reclamation requirements. Red dots represent floor or wall samples that have been taken from subsoil (>1.5 m depth). Results from these samples are compared with Tier 2A or 2B subsoil chloride SRGs and also to subsoil Tier 1 SAR guidelines.

The first example shown below involves a 40 x 40 m impacted area run as a single SubArea under a Tier 2A approach. Lateral closure was obtained beyond the 40 x 40 m boundary (chloride concentrations were less than 100 mg/kg) and vertical closure was obtained from multiple borehole locations at a depth of 4 m. The background EC and SAR Tier 1 guidelines for the root zone were 5 dS/m and 8, respectively. A subsoil SAR guideline of 12 was developed for application at soil depths greater than 1.5 m. This example could be an Impacted root zone or Excavate and Backfill root zone scenario. The most constraining SST calculated subsoil chloride SRG was 930 mg/kg providing the root zone (0 to 1.5 m) was excavated and replaced with backfill having a similar salinity (EC) as background. Confirmatory wall sample EC results within the root zone (green dots) ranged from 1.1 to 4.9 dS/m. SAR values in these samples ranged from 2.8 to 7.8. As a result, no further sidewall excavation was required – all samples met the appropriate Tier 1 root zone guidelines. Since the excavation wall was only within the depth range of the root zone (0 to 1.5 m), wall samples are not compared with a subsoil SRG for chloride. Confirmatory samples from the excavation base (1.5 m; red dots) had chloride concentrations ranging from 24 to 910 mg/kg and SAR values ranging up to 11.5. As a result, no further base excavation was required. A comparison of measured EC values in samples from the excavation based is not required since the base is at 1.5 m where the subsoil chloride SRGs comes into effect.

Example: Confirmatory Sampling Analysis – 40 x 40 m Impact, Root Zone Excavation, One SubArea

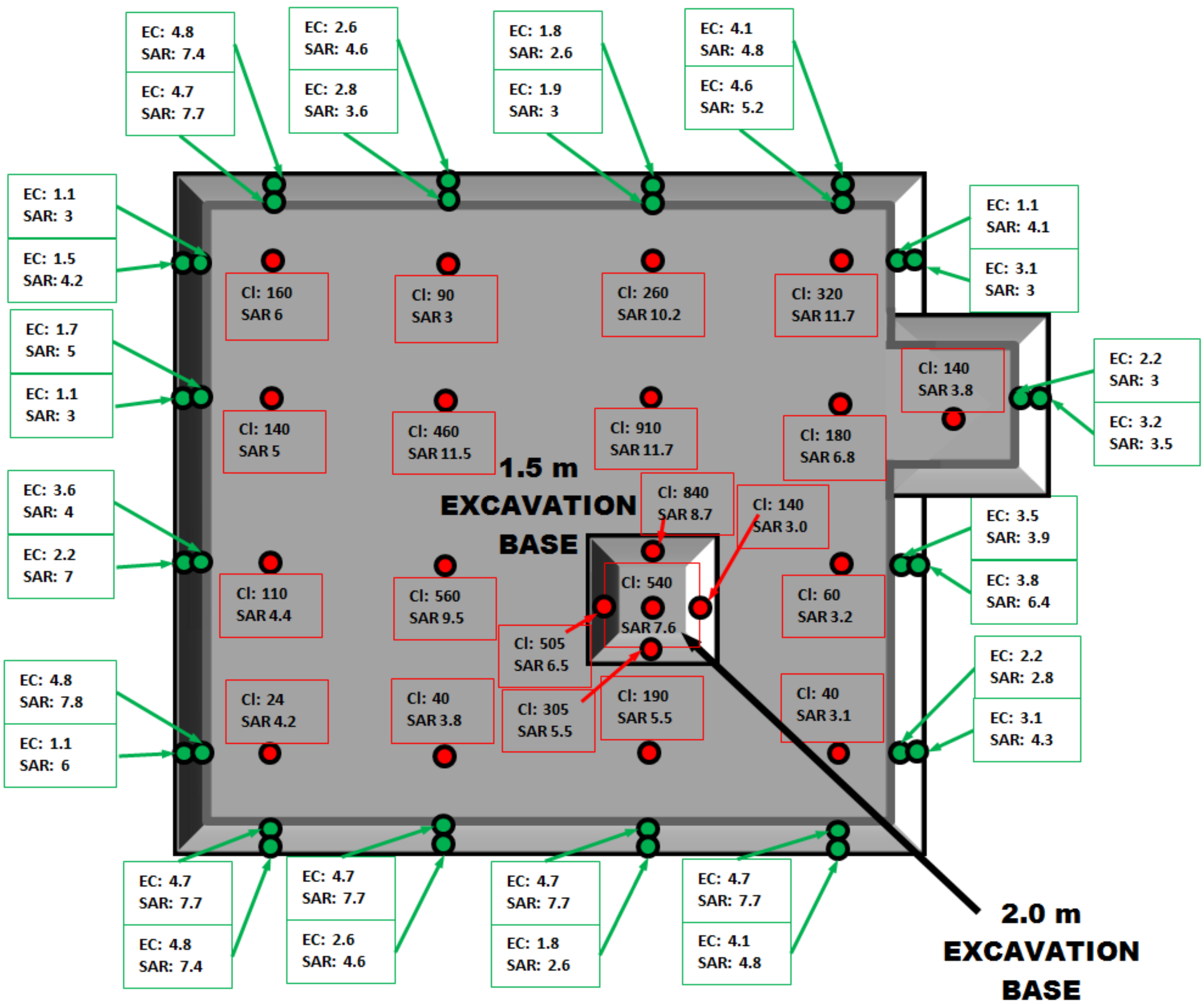


EC values are in dS/m; SAR values are unitless; Cl (Chloride) concentrations are in mg/kg soil

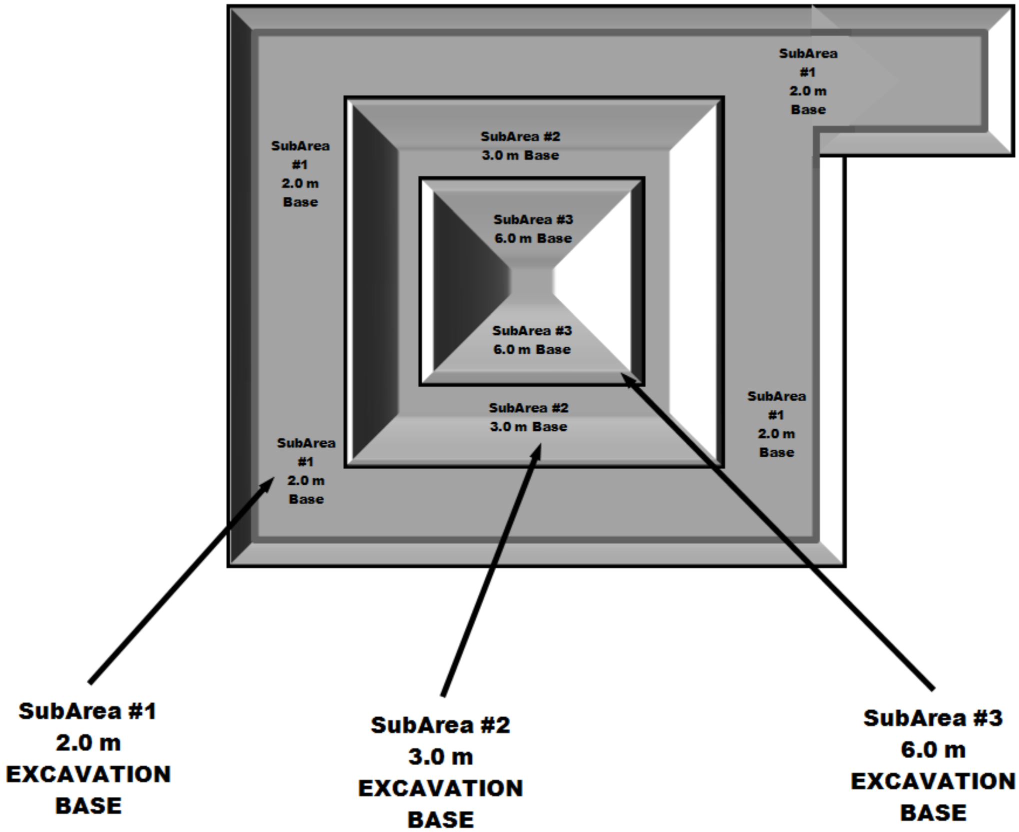
The second example shown below involves the same 40 x 40 m impacted area run as a single SubArea under a Tier 2A approach. However, two confirmatory sampling chemistry results were changed in the example. For the first change, one of the floor samples was assumed to have a chloride concentration of 1,150 mg/kg and a SAR of 14.5 at a depth of 1.5 m. Deeper excavation would be required in the area where the chloride exceedence is greater than the Tier 2A chloride SRG (assuming the same subsoil chloride SRG of 930 mg/kg is applicable) and where the subsoil SAR value is greater than the Tier 1 subsoil SAR guideline of 12. If deeper excavation is conducted to 2 m where a confirmatory base sample at 2 m has a chloride concentration of 540 mg/kg meeting the subsoil chloride SRG guideline of 930 mg/kg and SAR value of 7.6 meeting the Tier 1 subsoil SAR guideline of 12, no further subsoil excavation is required. Wall samples from 1.5 to 2 m within the 2 m excavation area must also meet the subsoil chloride SRG of 930 mg/kg.

The second change involved one of the wall samples in the NE corner of the excavation where within the root zone, an EC of 4.8 dS/m, SAR of 9.4, and chloride concentration of 205 mg/kg was measured. The SAR value exceeds the Tier 1 root zone guideline of 8 defined previously, which would be considered a trigger for further wall excavation until supplementary wall samples provide results below Tier 1 guidelines (*e.g.*, EC values of 2.2 and 3.2 dS/m, and SAR values of 3 and 3.5, shown in the supplementary wall samples in the example below). It should be noted that although the chloride concentration was low (*i.e.*, 205 mg/kg) and near what is considered closure (100 mg/kg) in the original wall sample where an exceedence was observed, it is possible to get facility-related SAR exceedences as chloride may have leached out of the root zone leaving behind elevated SAR levels. If it is hypothesized that the SAR value exceeding 8 is naturally occurring, further sampling can be conducted in background areas to determine if other similarly elevated SAR values are present. *With larger lateral (and vertical) excavations, additional samples may be required from newly exposed excavation wall faces. In the example below, only a single additional wall face was sampled in the NE additional excavated area and no wall face samples were collected from the area excavated to the deeper depth of 2 m.*

Example: Confirmatory Sampling Analysis – 40 x 40 m Impact, Root Zone Excavation, One SubArea, Wall and Floor Exceedences Requiring Additional Excavation

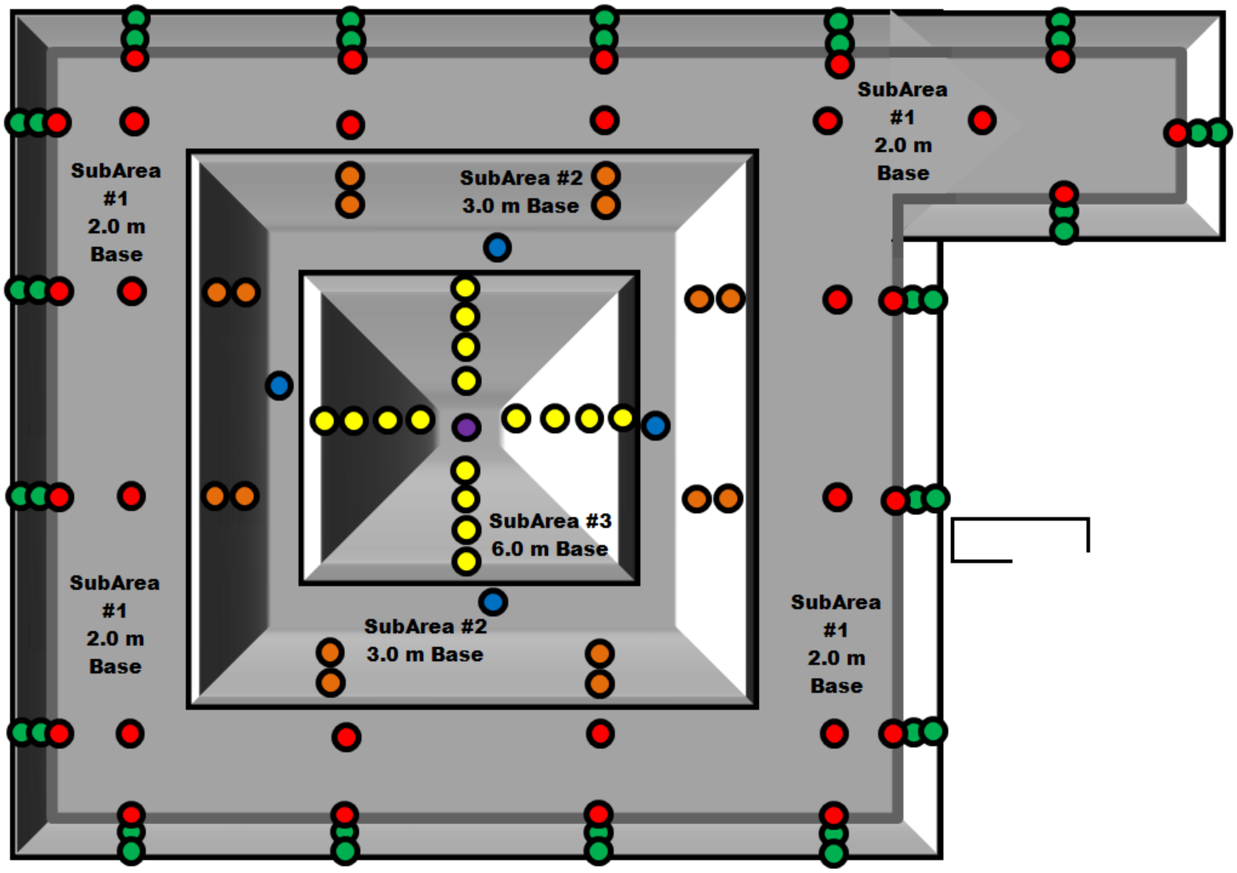


The third example shown below involves an impact that was split into three SubAreas under a Tier 2A or 2B approach. This is considered a complex example. SubArea #1 spanned an approximate 100 x 100 m source dimension area. The dimensions of SubArea #2 were 60 x 60 m and for SubArea #3 were 35 x 35 m. Tier 1 root zone and Tier 2 subsoil chloride guidelines were initially calculated for each SubArea. Exceedences were identified within the root zone (Excavate and Backfill scenario was required) and exceedences of Tier 2 SRGs were observed in subsoil for chloride and Tier 1 exceedences for SAR. Iterative analyses were conducted for each SubArea and it was determined that excavation was required to a depth of 2 m for SubArea #1, 3 m for SubArea #2, and 6 m for SubArea #3, for top and bottom of impacts of 2 to 4 m, 4 to 6 m, and 6 to 7 m. The final SRGs calculated (SubArea #1: 430 mg/kg; SubArea #2: 680 mg/kg; SubArea #3: 1,400 mg/kg) are shown in the following table for comparison against confirmatory sampling results. A subsoil SAR Tier 1 guideline of 12 was calculated. The excavation diagram below is colour coordinated and guidelines applicable to each sample depth interval have similar colour coding in the table below. *It is important to note that wall samples are compared against guidelines for the area surrounding the SubArea under consideration to ensure the appropriate vertical impact depth is represented (e.g., walls within the SubArea #2 excavation must meet SubArea #1 SRGs, because the walls have a vertical impact thickness similar to the surrounding SubArea).*



Summary of SRGs for Example #3

SubArea	Post Excavation Top to Bottom of Impact (m)	Parameter	Applicable Depth Range (m)	Confirmatory SRGs (units)	Apply to Excavation Face	Notes
Background	NA	EC SAR EC SAR Chloride	0.3 to 1.0 0.3 to 1.0 1.0 to 1.5 1.0 to 1.5 0.3 to 7.0	3.0 (dS/m) 4.0 5.0 (dS/m) 8 100 (mg/kg)	All All All All All	Used for comparing SubArea #1 walls and ensures the area surrounding the SubAreas meets background conditions and is unimpacted (chloride < 100 mg/kg)
1	2.0 to 4.0 m	EC SAR EC SAR Chloride SAR Chloride SAR	0.3 to 1.0 0.3 to 1.0 1.0 to 1.5 1.0 to 1.5 0.3 to 2.0 1.5 to 2.0 2.0 to 4.0 2.0 to 4.0	3.0 (dS/m) 4.0 5.0 (dS/m) 8 100 (mg/kg) 12 430 (mg/kg) 12	Wall Wall Wall Wall Wall Wall Base Base	Excavate and Backfill Root Zone; Backfill with EC and SAR same as background; backfill < 100 mg/kg chloride; subsoil from 1.5 to 2.0 m must meet background wall guidelines; base must meet the subsoil Tier 1 SAR guideline of 12 and the chloride base guideline of 430 mg/kg
2	3.0 to 5.0 m	EC SAR Chloride Chloride SAR Chloride SAR	0.3 to 2.0 0.3 to 2.0 0.3 to 2.0 2.0 to 3.0 2.0 to 3.0 3.0 to 5.0 3.0 to 5.0	NA NA NA 430 (mg/kg) 12 680 (mg/kg) 12	Wall Wall Wall Wall Wall Base Base	Backfill with chloride < 100 mg/kg and background EC & SAR to 3.0 m; no walls from 0 to 2.0 m, so no comparison required; walls from 2.0 to 3.0 (SubArea #1 depth range) must meet the SubArea #1 chloride and SAR subsoil SRG; Base must meet SubArea #2 subsoil SAR and chloride (680 mg/kg) SRG
3	5.0 to 6.0 m	EC SAR Chloride Chloride SAR Chloride SAR	0.3 to 3.0 0.3 to 3.0 0.3 to 3.0 3.0 to 5.0 3.0 to 5.0 5.0 to 6.0 5.0 to 6.0	NA NA NA 680 (mg/kg) 12 680 (mg/kg) 12	Wall Wall Wall Wall Wall Base Base	Backfill with chloride < 100 mg/kg and background EC & SAR to 3.0 m; no walls from 0 to 3.0 m, so no comparison required; walls from 3.0 to 5.0 (SubArea #2 depth range) must meet the SubArea #2 chloride and SAR subsoil SRG; Base must meet SubArea #3 subsoil SAR and chloride (1,400 mg/kg) SRG


SubArea
#1
2.0 m
Base
SubArea #2
3.0 m Base
SubArea
#1
2.0 m
Base
SubArea
#1
2.0 m
Base
SubArea #3
6.0 m Base
SubArea #2
3.0 m Base
SubArea
#1
2.0 m
Base

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8 GLOSSARY

Background concentration: The concentration of a chemical substance occurring in media removed from the influence of industrial activity at a specific site and in an area considered to be relatively unaffected by industrial activity (CSMWG, 1995).

Buffer: The difference between background concentrations and applicable guidelines.

Bulk density: Measure of the weight of the soil per unit volume.

Clay: Soil particle <0.002 mm and usually consisting of clay minerals but commonly including amorphous free iron oxides and primary minerals (CCME, 2006).

Cleanup: The removal of a chemical substance or hazardous material from the environment to prevent, minimize or mitigate damage to public health, safety or welfare, or the environment, that may result from the presence of the chemical substance or hazardous material. The clean-up is carried out to specified clean-up guideline (CSMWG, 1995).

Climate Moisture Index (CMI): The CMI is a measure of the relative amount of water that may be available to leach salts at a site. For example, a positive CMI value indicates that the annual precipitation is higher than the annual plant potential evapotranspiration. This means that there may exist excess soil water available for downward leaching of salts. A negative CMI means that the potential evapotranspiration is higher than the annual precipitation and if certain soil conditions exist, there may be the potential for upward transport of salts into the rooting zone driven by plant uptake and capillary rise (Downing and Pettapiece, 2006).

Contaminant: Any chemical substance whose concentration exceeds background concentrations or which is not naturally occurring in the environment (CCME, 2006).

Depth of impact: The vertical depth measurement of a borehole from the surface through the zone of contamination to the depth where chloride values fall below 100 mg/kg.

Dilution factor: The total number of unit volumes in which the material will be dissolved in. The diluted material must be thoroughly mixed to achieve a true dilution.

Discharge area: An area in which there are upward components of hydraulic head in the aquifer. Groundwater is flowing towards the surface in a discharge are and may escape as a spring, seep, or baseflow or by evaporation and transpiration (Fetter, 2001).

Domestic Use Aquifer (DUA): It is a hydrostratigraphic unit with a hydraulic conductivity of $\geq 10^{-6}$ m/s; a minimum thickness of 0.5 m; yield of 0.76 L/min or greater; is currently being used for domestic purposes; and any aquifer determined by Alberta Environment and Sustainable Resource Development to be a DUA.

Drainage boundary condition: A net downward rate of water flux that exists at the base of the modeled soil column where a domestic useable aquifer was assumed to be located.

Electrical conductivity (EC): EC is a measure of the ability of a substance to conduct electricity measured in dS/m (deciSiemens/metre). It is directly related to the total concentration of all dissolved cations and anions (electrolytes), and is used to express the magnitude of the total dissolved salt concentration in the soil solution (AENV, 2001).

Electromagnetic survey (EM survey): It measures the ability of the soil to conduct an electric current. The value, measured in *siemens*, is the reciprocal of resistivity.

Exposure pathway: The route by which an organism comes into contact with a contaminant. In the ecological effects-based procedure, exposure pathways are restricted to organisms in contact with contaminated soil or groundwater. In human health-based procedure, exposure pathways include contact through consumption of contaminated foods, direct soil ingestion, dust inhalation, dermal absorption, inhalation of contaminant vapours, and ingestion of contaminated groundwater (CCME, 2006; ESRD, 2014a).

Fish farm: A man-made body of water used to grow fish.

Groundwater: All subsurface water that occurs beneath the water table in rocks and geologic formations that are fully saturated (CSMWG, 1995).

Hydraulic conductivity: The rate of flow of water moving through a cross section of unit area of soil or geologic material, under a unit hydraulic gradient. In saturated materials, saturated hydraulic conductivity is a proportionality constant in the Darcy equation and is dependent on material properties (grain size and pore space) and on fluid properties (density and viscosity). The rate of flow of water in soil varies from very slow (less than 0.1 cm/hr) to very rapid (more than 50 cm/hr; AENV, 2001).

Hydraulic gradient: Change in the total hydraulic head divided by the change in distance in a given direction in a groundwater flow system (AENV, 2001).

Impacted soil: Any soil with chloride concentrations appreciably above background. For the purposes of the Subsoil Salinity Tool, 100 mg/kg is used for screening purposes.

Natural region: Extensive land mass (of the order of 20 000 km2) characterized by permanent geographic boundaries (geological, physiographic, etc.) and a certain uniformity and individuality of climatic, topographical, geomorphological and biological conditions. There are 6 Natural Regions recognized in Alberta (Downing and Pettapiece, 2006).

Natural subregion: Large land mass (of the order of 10 000 km2) characterized by permanent geographic boundaries (geological, physiographic, etc.) and a certain uniformity and individuality of climatic, topographical, geomorphological and biological conditions. There are 21 Natural Subregions recognized in Alberta (Downing and Pettapiece, 2006).

Outlier: It is an observation that is numerically distant from the rest of the data.

Perched water table: It is an aquifer that occurs above the main water table. This occurs when there is an impermeable layer of rock above the main aquifer but below the surface. Water percolating down is trapped above the second impermeable rock layer.

Porosity: It is a measure of the void spaces in a material, and is measured as a fraction, between 0–1, or as a percentage between 0–100%. (1 - Bulk Density/Particle Density) x 100%

Receptor: A receptor is a person or organism exposed to a chemical (CCME, 2006).

Recharge area: An area in which there are downward components of hydraulic head in the aquifer. Infiltration moves downward into the deeper parts of an aquifer in a recharge area (Fetter, 2001).

Remediation: The management of a contaminated site to prevent, minimize or mitigate damage to human health or the environment. Remediation may include both direct physical actions (e.g. removal, destruction and containment of contaminants) and institutional controls (e.g. zoning designations or orders - CCME, 2006).

Risk assessment: Characterization of the nature, magnitude, and likelihood of adverse effects on human health or ecosystems (receptors) from exposure to one or more contaminating substances through various routes of exposure (pathways).

Risk management: The selection and implementation of a strategy of control of risk, followed by monitoring and evaluation of the effectiveness of that strategy. Risk management may include direct remedial actions or other strategies that reduce the probability, intensity, frequency or duration of the exposure to contamination. The latter may include institutional controls such as zoning designations, land use restrictions, or orders. The decision to select a particular strategy may involve considering the information obtained from a risk assessment. Implementation typically involves a commitment of resources and communication with affected parties. Monitoring and evaluation may include environmental sampling, post-remedial surveillance, protective epidemiology, and analysis of new health risk information, as well as ensuring compliance (CSMWG, 1995).

Runoff: The total amount of water flowing in a stream. It includes overland flow, return flow, interflow and baseflow.

Salinity: The measure of the total soluble salts in soil. A saline soil is a nonsodic soil containing sufficient soluble salt to adversely affect the growth of most crop plants. The lower limit of saturation extract electrical conductivity of such soils is conventionally set at 4 dS m^{-1}. Actually, sensitive plants are affected at half this salinity and highly tolerant ones at about twice this salinity.. Salinity levels of the soil can be determined by determining the electrical conductivity (EC) of the soil. EC measures the influence of all dissolved ions (cations and anions) and does not differentiate between them. SSSA Glossary of Soil Science Terms. https://www.soils.org/publications/soils-glossary.

Sand: Soil particle between 0.05 and 2 mm in diameter (Downing and Pettapiece, 2006).

Saturated zone: The zone where voids in the soil or rock are filled with water at greater than atmospheric pressure. In an unconfined aquifer, the water table forms the upper boundary of the saturated zone (CSMWG, 1995).

Saturation percentage: The percent of soil pore water weight of a saturated paste to dry soil weight (AENV, 2001).

Seedbed: The soil prepared by natural or artificial means to promote the germination of seed and the growth of seedlings.

Silt: A soil separate consisting of particles between 0.05 to 0.002 mm in equivalent diameter (Downing and Pettapiece, 2006).

Site investigation: A survey of the type, and extent of contamination present, and an estimate of its impact on human health and the environment.

Slough: A Western Canadian term for a shallow prairie pond that largely disappears in late summer, often with a muddy bottom (Downing and Pettapiece, 2006).

Sodium Adsorption Ration (SAR): The empirical mathematical expression developed as an index of the sodium hazard in soils. The concentrations of sodium, calcium, and magnesium are expressed in meq/L:
$SAR = [Na]/([Ca]+ [Mg])^{1/2}$ (AENV, 2001).

Soil: The unconsolidated mineral matter on the surface of the earth that has been subjected to and influenced by genetic and environmental factors of: parent material, climate (including moisture and temperature effects), macro and microorganisms and topography, all acting over a period of time and producing a product - soil - that differs from the material from which it is derived in many physical, chemical, biological and morphological properties and characteristics.

Soil lithology: Mineralogy, grain size, texture, and other physical properties of granular soil, sediment, or rock.

Soil organic matter: The organic fraction of the soil; includes plant and animals residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population.

Soil profile: The vertical section of a soil which displays all its horizons and its parent material.

Source length: The greatest length across the impacted area in any direction (Tier 2A) or in the direction of the groundwater flow (Tier 2B); from the boreholes that have chloride concentrations of less than 100 mg/kg, which is indicative of an unimpacted borehole, across the most impacted boreholes to the boreholes that chloride concentrations of less than 100 mg/kg.

Standard deviation: It is a measure of the variability of the dataset.

Subsoil: The soil material beneath the topsoil (A horizon); includes the B and C soil horizons. Roughly, the part of the soil profile below plough depth. (Note that in the Canada-Wide Standard for Petroleum Hydrocarbons in Soil, subsoil is defined differently as earthy, non-soil materials below 1.5 meters in depth; AENV, 2001).

Surface soil: Ground surface to a depth of 1.5 m (ESRD, 2014a).

Surface water: Natural water bodies, such as rivers, streams, brooks and lakes, as well as artificial water courses, such as irrigation, industrial and navigational canals, in direct contact with the atmosphere (CSMWG, 1995).

Tier 1: Remediation guidelines are generic; that is, they are developed to protect the more sensitive end of the range and can therefore be used at most sites without modification (ESRD, 2014a).

Tier 2A analysis: A lower level of site investigation effort is proposed for Tier 2A, which will allow proponents to establish subsoil salinity remediation goals if site conditions do not allow for a greater level of investigation efforts or in situations where the cost for additional investigations may be better expended towards remediation efforts. As a consequence of the lower investigative effort/information requirements associated with the Tier 2A level, a greater level of conservatism has been built into the SST to account for potential sources of variability and uncertainty. Thus, the Tier 2A approach may lead to a greater expenditure of resources (via remediation) to achieve an equivalent level of risk based on a Tier 2B approach.

Tier 2B analysis: The Tier 2B approach allows for more refined predictions of risk based on fewer conservative assumptions. Tier 2B requires additional investigation efforts. The Tier 2B level allows for sites to be divided into sub-areas and separate guidelines developed for each sub-area. Different sub-areas of a site may pose significantly different risks due to variations in key parameters including, soil texture, groundwater depth, and, groundwater gradient.

Tier 2C analysis: Tier 2C analysis is for complex sites that have deep impacts (>10 m), highly complex soil stratigraphy, complex hydrogeology and has gravel or muskeg/peat soil lithology. Tier 2C falls outside the scope of the Subsoil Salinity Tool.

Topography: The shape of the ground surface, such as hills, mountains, or plains.

Total Dissolved Solids (TDS): It is an expression for the combined content of all inorganic and organic substances contained in a liquid which are present in a molecular, ionized or micro-granular (colloidal solids) suspended form. Generally the operational definition is that the solids must be small enough to survive filtration through a sieve size of two micrometres.

Vadose zone: The zone containing water under less than atmospheric pressure including soil water, intermediate vadose water, and capillary water. The zone is limited above by the land surface and below by the water table (AENV, 2001).

Water table: The boundary surface between the vadose zone and the groundwater; the surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere (AENV, 2001).

Wetland(s): Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, fens and other similar areas (AENV, 2001).