Subsoil Salinity Tool Version 3.0 User Manual

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The Subsoil Salinity Tool (SST) has been developed by Equilibrium Environmental Inc. under direction and guidance from Alberta Environment and Parks 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 Parks Tier 2 guideline framework.

Version 3.0

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TABLE OF CONTENTS   **PAGE #**

1   INTRODUCTION

This User Manual document presents technical background and user guidance for the Alberta Environment and Parks (AEP) Subsoil Salinity Tool (SST) Version 3.0. The SST tool is a software program designed by Equilibrium Environmental Inc. under contract to AEP 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. Where relevant, additional supporting technical detail is presented in the SST "Technical Manual".

1.1   Overview of Alberta Guidelines

Alberta's contaminated sites policy framework (ESRD 2014) 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 AEP (2019a,b). Tier 2 guidelines can also be calculated using Site-Specific Risk Assessment (SSRA) and alternate mathematical approaches, providing this has been approved by AEP. Exposure Control involves risk management through exposure barriers or administrative controls, and may include the use of SSRA. Sites can be remediated by following a Tier 1 or Tier 2 approach, including SSRA; the Exposure Control management option focuses on restricting exposure to contamination. Remediation is complete when Tier 1 guidelines have been identified or Tier 2 guidelines 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. Sites that meet these conditions are eligible for regulatory closure.   In comparison, Exposure Control requires the implementation and management of ongoing risk mitigation measures and unrestricted equivalent land use is prevented. Sites managed under the Exposure Control option are not eligible for regulatory closure

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 AEP (2019a). 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 and Sodicity

Tier 1 guidelines for salinity and sodicity 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). Elevated EC in soil may be due to natural salts or introduced anthropogenically through various oil and gas operations such as those involving produced water (containing primarily sodium chloride salts) or drilling waste. The potential negative effects of elevated EC include increased osmotic stress on vegetation leading to reduced water uptake, along with potential direct ion toxicity effects. EC is directly related to the total amount of dissolved ions present in soil, including balancing amounts of negatively-charged anions (primarily chloride, sulphate, bicarbonate, and carbonate) and positively-charged cations (primarily sodium, calcium, magnesium, and potassium). Of these anions, sulphate and bicarbonate are common naturally-occurring ions observed in background locations, whereas elevated chloride concentrations are generally due to anthropogenic impacts. All four of these cations are also commonly observed in background locations, though sodium concentrations tend to be further elevated in areas of produced water impacts. The equation below shows this proportionality between EC (in dS/m) and the total cations and anions in soil (ion concentrations expressed on a charge basis of milliequivalents per litre).

$$EC \propto sum\ of\ all\ cations + anions$$

SAR is defined in the equation below (AENV, 2001) and represents the ratio of sodium to calcium plus magnesium ions (all concentrations also on a milliequivalents per litre basis). The potential negative effects of elevated SAR include disruption of soil structure via the dispersion or swelling of clay particles, and a resultant reduction in hydraulic conductivity which may lead to poor infiltration or surface 'hard-pan'.

$$SAR = \frac{[Na]}{\sqrt{\frac{[Ca] + [Mg\}}{2}}}$$

The Tier 1 salinity 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 AEP 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. For such reasons, the 2019 update to the Tier 1 guidelines (AEP, 2019a) includes additional requirements for delineating soil chloride concentrations (on a mg/L saturated paste basis) as a pre-requisite to applying Tier 1 EC and SAR guidelines. This provides additional information regarding potential risk to various groundwater receptors, which can be evaluated in substantially more detail on a Tier 2 (SST) basis.

1.3   Tier 2 Guidelines for Salinity and Sodicity

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 and sodicity impacts located in subsoils at depths below ground surface of greater than 1.5 m. These guidelines are developed on an ion-specific basis (chloride and sodium), which differs from root zone soils (< 1.5 m) where guidelines are based solely on EC and SAR parameters. By determining the contribution of subsoil 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 subsoil sodium ions towards SAR in root zone soils, subsoil guidelines can be developed that are not expected to lead to an unacceptable risk of exceeding Tier 1 SAR guidelines for the root zone. In addition, 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 guidelines for a dugout into which groundwater may discharge. Such a dugout may also be used for irrigation water, with updated Version 3.0 protocol using a chloride-based irrigation threshold. Determining the contribution of sodium into irrigation water from a dugout also allows determination of subsoil sodium guidelines protective of Tier 1 SAR guidelines in irrigation water. Additional pathways for which Tier 2 guidelines are developed using the SST include the DUA (domestic use aquifer) and FAL (freshwater aquatic life) pathways for subsoil chloride, and the soil structure pathway for subsoil SAR.

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 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 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 AEP (2019a) salinity guidelines.

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 Alberta Energy Regulator (AER) post-remediation and/or reclamation as part of a reclamation or remediation certificate application for sites related to oil and gas activities, or to AEP for sites unrelated to oil and gas activities.

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.

Elevated SAR may also pose a risk to soil structure (either current-day or in the future) independent of vertical or lateral transport considerations. 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)
  - Source depletion via transport processes

- Not exceeding AEP (2019a) Tier 1 guidelines that apply to receptor locations
  - Root zone EC guidelines
  - Root zone SAR guidelines
  - Drinking water chloride (and sodium) guideline
  - Livestock watering TDS guidelines
  - Irrigation water chloride guidelines
  - Irrigation water SAR guidelines
  - Aquatic life chloride guidelines

- Not exceeding soil-structure thresholds for SAR

- 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
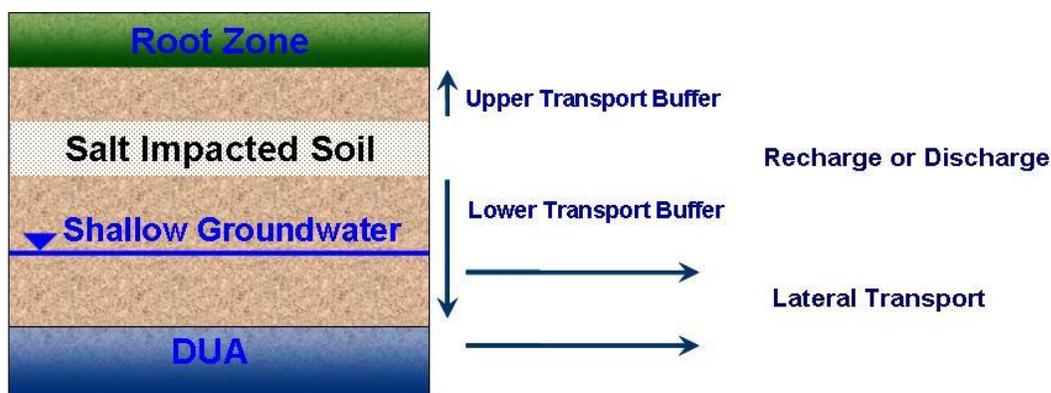
In some instances, an upper transport buffer may not be present as salinity impacts are present within, as well as immediately beneath, the root zone. The SST can still be utilized, although the guidelines will be more constrained since the root zone is already impacted, and there is an absence of an 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 sodium to background root zone SAR
  - 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 sodium to background SAR in shallow groundwater that discharges into a dugout potentially constructed in the future
  - Contribution of site-related chloride combined with background chloride in shallow groundwater at a discharge point into a water body that is an aquatic life receptor
  - Contribution of site-related chloride combined with 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 exceedance of AEP (2019a) 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. It also calculates the mass of sodium that can redistribute upward into the root zone from subsoil that on average does not increase SAR in the root-zone (1.0-1.5 m depth) above the corresponding Tier 1 SAR value.

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: AENV 2001 and AEP (2019a) 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, AEP 2019a).
▪ For sites where background EC and SAR values are greater than these commercial/industrial 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	Commercial/Industrial Guidelines
EC	4 dS/m
SAR	12

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

▪ For the protection of aquatic life, the Alberta (GoA, 2018) chloride surface water quality guideline of 120 mg/L is used. Due primarily to a greater transport potential for chloride relative to sodium, chloride is considered more risk-limiting than sodium for aquatic life and therefore sodium is not considered a risk driver for aquatic life;
▪ For the protection of livestock watering, thresholds are based on the AEP (GoA, 2018) livestock watering guideline of 3,000 mg/L TDS. Dugout water concentrations above this 3,000 mg/L TDS threshold due to background salts result in the livestock pathway being eliminated;
▪ A chloride concentration of 355 mg/L (or approximately 1 dS/m) is considered sufficiently protective of foliar damage to most Alberta-relevant crop species (GoA, 2018) and is used as the irrigation threshold. To determine the influence of background salinity on dugout water irrigation suitability, 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" (GoA, 2018). 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" (GoA, 2018). Irrigation water with TDS concentration greater than 1,280 mg/L is considered "hazardous" or "unusable" for this purpose. Similarly, SAR values of 5 or less in irrigation water are considered 'Safe', values of 5 to 10 are considered "possibly safe" (generally as a function of EC), and SAR values in irrigation water above 10 are considered "'hazardous" or unusable. Dugout water that falls into the "hazardous" category due to background salinity results in elimination of the irrigation pathway.

	Safe	Possibly Safe	Hazardous
EC (dS/m)	≤ 1.0	> 1.0 to < 2.0	≥ 2.0
TDS (mg/L)	640	1,280	>1,280
SAR	≤ 5	> 5 to < 10	≥ 10

For the protection of a DUA:
- The human aesthetic Tier 1 chloride water quality guideline of 250 mg/L is used. Due to the greater transport potential of chloride relative to sodium, chloride is considered more risk-limiting than sodium for the DUA pathway and therefore sodium is not considered a risk driver for the DUA pathway. This Tier 1 chloride guideline of 250 mg/L is also more constraining on an equimolar basis than the comparable Tier 1 human drinking water sodium guideline of 200 mg/L, with the chloride guideline thus considered also sufficiently protective of sodium.

For the soil structure pathway:
- The soil structure thresholds for subsoil SAR are not associated with specific pre-existing Tier 1 guidelines, but are based on empirical SAR, EC, and hydraulic conductivity relationships from literature and from a range of Alberta soils. While a change in vertical (saturated) hydraulic conductivity is not necessarily considered an adverse effect on its own, excessive losses in saturated hydraulic conductivity can potentially result in root-zone water logging, water table perching, or other adverse alterations in water infiltration capabilities. As will be discussed in more detail in later sections, elevated levels of EC can be protective of these potential adverse effects on soil structure from elevated soil SAR levels.

While Tier 1 guidelines for EC and SAR are generally applied to the root-zone, salinity-impacted sites can use a combination of Tier 1 guidelines and/or Tier 2 (SST) guidelines in subsoil depending on what is most suitable for the particular combination of chloride/SAR/sodium impacts. For the pathways described above, the SST Version 3.0 allows generation of Tier 2 guidelines for subsoil chloride alone, generation of Tier 2 guidelines for subsoil SAR/sodium alone, or generation of Tier 2 guidelines for subsoil chloride in combination with subsoil SAR and sodium.

1.4.2 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 site conditions do not meet the default assumptions in the SST. 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 AEP (2019a):

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 200 m (40,000 m^2) for the aquatic life and DUA guidelines that are source dimension dependent;
   b. source length for entire site greater than 300 m as measured in the longest impacted length across the site;
   c. soil depth profiles composed primarily of sands and gravels (that would meet the definition of a DUA) with negligible overlying till,
   d. 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,
   e. shallow groundwater velocities greater than 25 m/year,
   f. impact depths greater than 15 m,
   g. DUA depths greater than 25 m (treated as a maximum of 25 m in the SST);
   h. close proximity (see Section 4.5) to a surface water body that has a functional aquatic ecosystem;
   i. DUA or aquatic life receptors which have impact-related or background chloride concentrations within 10% of the relevant drinking water or aquatic life guidelines at the receptor;
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.

Assessors should also be aware that there is the potential for other site-specific concerns that the SST does not cover and for which a Tier 2C approach should be considered. Examples of such scenarios include cases where groundwater may come to surface (such as surfacing downslope as a spring) at locations not already considered aquatic life receptors, impacted shallow groundwater in a residential area potentially being pumped to surface by a sump pump, and other possible examples with pathways or receptors outside the SST assumptions. Professional judgement should be used in such cases on if or how a Tier 2C assessment is performed.

There may also be cases where a site has complex layered lithology (such as more than two layers) which cannot be adequately described for all receptors simultaneously with the input parameters available within the SST. Examples of such cases are described throughout this document, and may in some cases also require a Tier 2C approach.

⚠️ ***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 AEP/AER representative for further details. Tier 2C assessments must be submitted to AEP/AER for review prior to remediation and reclamation work for sites applying for a reclamation and/or remediation certificate.***

⚠️ ***The report describing the SST input parameters and assumptions must clearly state if the assessment as a whole is considered a Tier 2C approach or a standard Tier 2A/Tier 2B approach.***

1.5   Reporting Requirements

The SST software allows generation of a report detailing all input parameters, supporting calculations, and resulting guidelines for all relevant pathways. A separate written report must also 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 a range of information, including but not limited to, 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. Clear statement of whether the assessment as a whole is considered a Tier 2C approach or a standard Tier 2A / Tier 2B approach.

A list of information which must be included in this report is provided in the "Subsoil Salinity Tool Checklist" (AER, 2016), which must be submitted along with the report, the SST guideline outputs, and the SST checklist itself. Examples of information which must be included in the report are provided throughout this manual. Key information points as well as requirements for clear presentation of additional key tables and figures that support the calculated guidelines are identified in this manual with the following symbol. ⚠️

⚠️ These reporting requirements are designed to help ensure that all important site information is collected, analyzed, and reported in a manner consistent with the protocols described in this manual. The reliable use of the SST is dependent on the reliable and accurate collection and entry of data by the proponent, and it is the responsibility of the proponent to ensure that the data entered into the SST is logical and consistent with these protocols. Guidelines generated from inaccurate input parameters will also be inaccurate, and may result in inappropriate remediation activities (either over-remediation or under-remediation) which could potentially need to be addressed.

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2   SST PROGRAM BASIS

2.1   Introduction

The SST program is essentially a chloride and sodium mass balance-based fate and transport guideline calculator. It estimates the redistribution of a chloride and/or sodium impact over time to determine present-day chloride and/or sodium 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 exceedances of AEP (2019a) 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 and Parks 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.
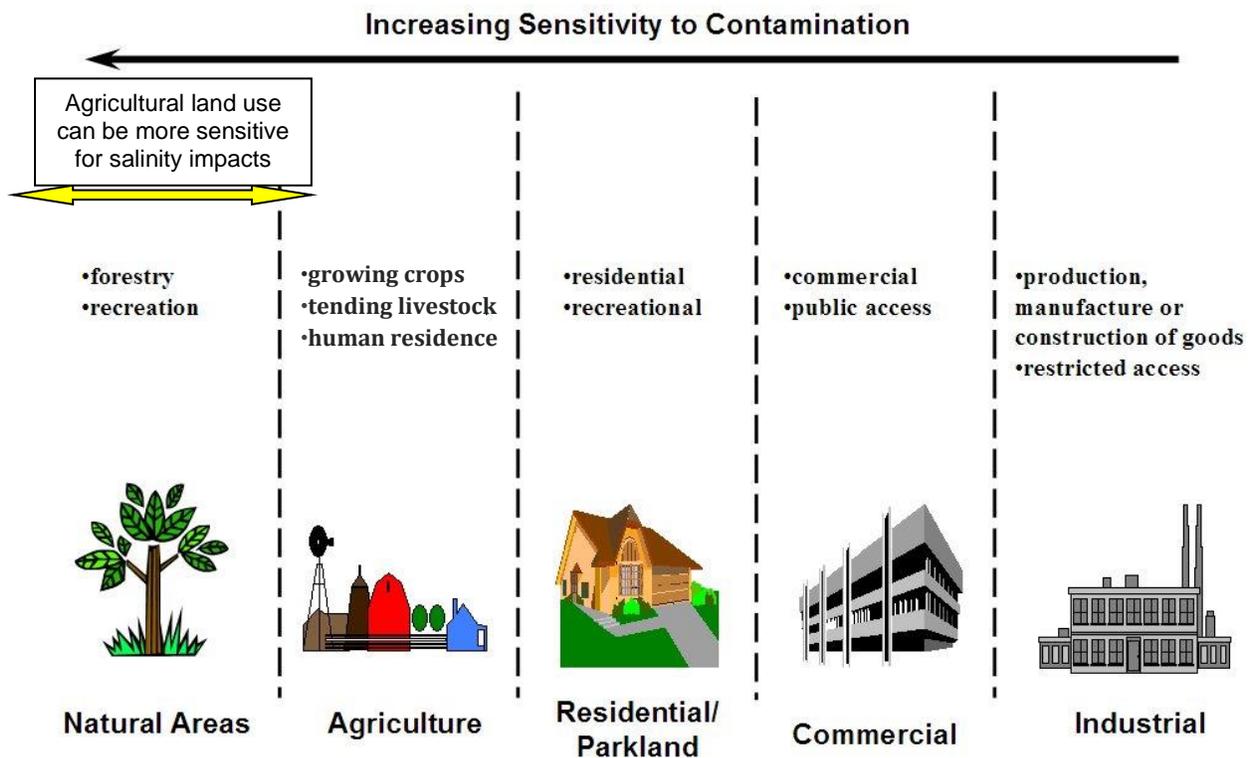
Potential receptors of concern and relevant exposure pathways include

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

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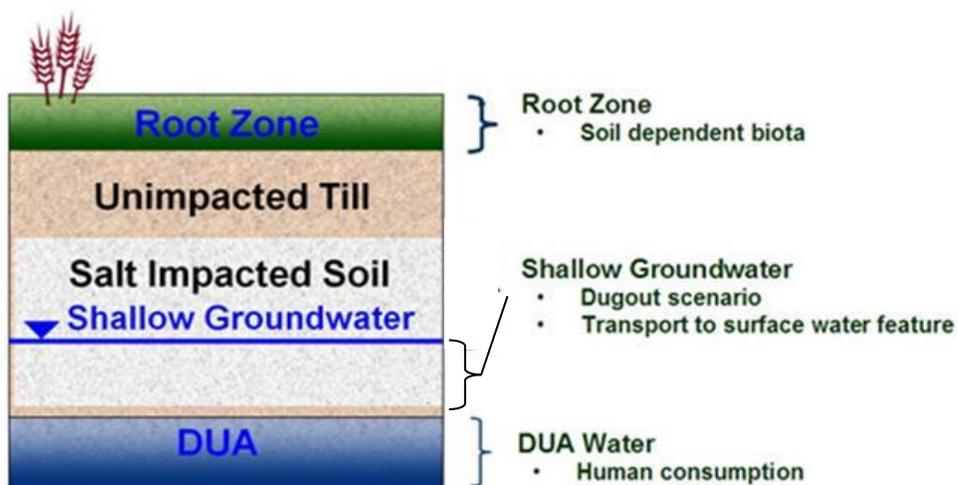
2.2.1 Agricultural Land Use

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 use for livestock watering and irrigation purposes;
- Aquatic life in a nearby surface water receptor;
- Humans via consumption of water in a DUA; and
- Soil structure via elevated soil SAR.

⚠ *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.*
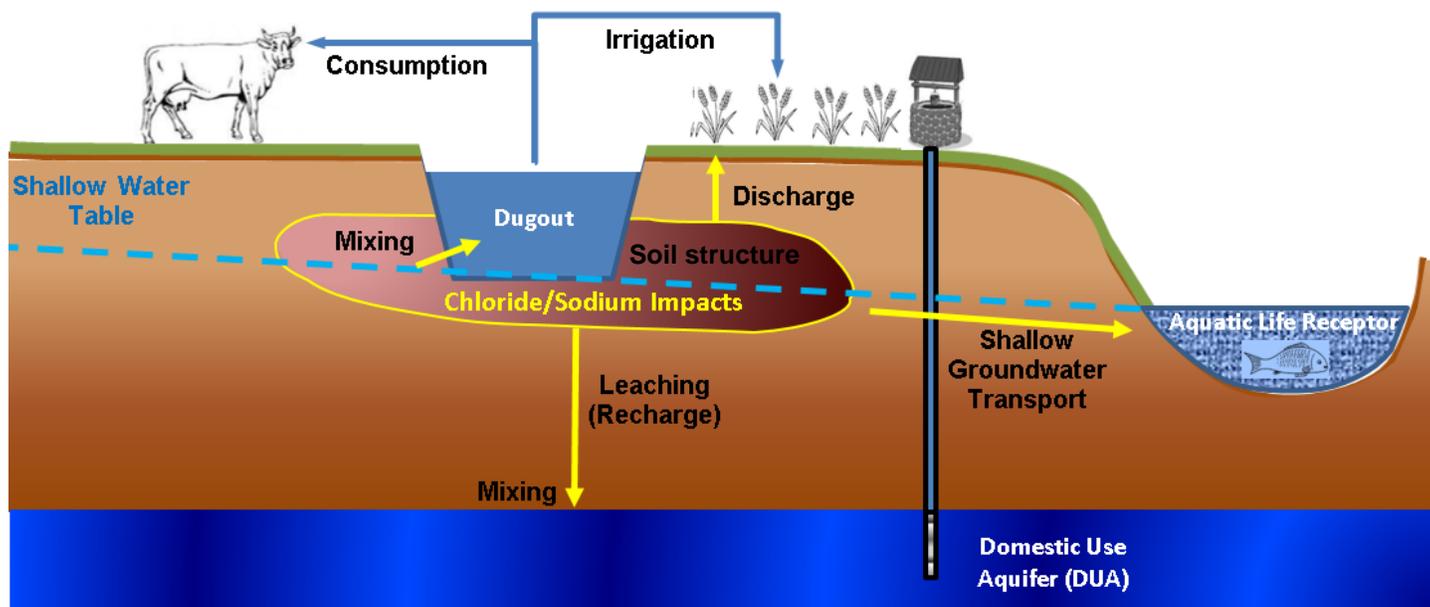
2.2.2 Natural Areas and Residential/Parkland Land Use

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;
- Humans via consumption of water in a DUA; and,
- Soil structure via elevated soil SAR.

⚠️ *Note, for non-Agricultural 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 non-Agricultural land use. Under Tier 2A, adjacent Agricultural land use is considered in any direction from the non-Agricultural 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;
- Humans via consumption of water in a DUA; and,
- Soil structure via elevated soil SAR.

⚠️ *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 and/or sodium 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 and/or sodium impacts currently within the deeper root zone interval (1.0 to 1.5 m);
- Estimation of future peak chloride and/or sodium concentrations at the base of the root zone (1.5 m) and contribution to deep root zone (1.0 to 1.5 m) EC or SAR;
- Background root zone EC and/or SAR (or backfill EC and/or SAR) and determining the upper bound of an appropriate Tier 1 root zone rating category for EC and/or SAR (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 subsoil chloride 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 chloride 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 AEP (2019a) 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 saturated 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 subsoil 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 Alberta Tier 1 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 subsoil chloride and/or sodium 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 and/or sodium concentrations in groundwater from 1.5 to 6 m;
- Contribution of chloride and sodium towards TDS in dugout water for livestock watering;
- Contribution of chloride to dugout water for irrigation water;
- Chloride and SAR guidelines for irrigation water, and the 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 from non-agricultural land to adjacent agricultural land; and,
- Application of an adjustment factor to account for dilution as groundwater mixes with water and precipitation/runoff in the dugout. This adjustment factor is influenced by several parameters including soil texture, shallow groundwater velocity, water table depth, and climate.

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: the LEACHM software suite (Hutson and Wagenet 1992, Hutson 2000) ; and, 3DADE (Leij and Bradford, 1994). The manner in which the models were used is shown below. LEACHM was used for modeling the vertical transport of chloride and estimation of breakthough curves at various vertical soil depth intervals, including additional modeling of sodium transport including cation exchange reactions using the LEACHC module for the root-zone pathway. 3DADE was used for lateral transport of chloride towards an 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.

For each of these horizontal and vertical modeling aspects, a 1,000 year time-horizon is used in the SST due to the non-biodegrading nature of salinity impacts, and in order to allow the majority of scenarios (but not all) to reach peak breakthrough concentrations.
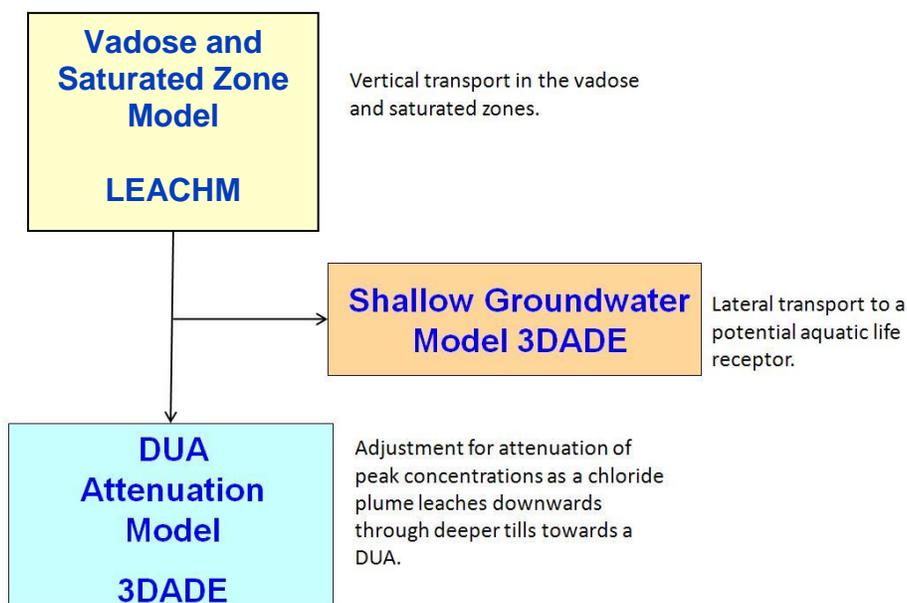
2.6 Delineation Criteria and Management Limits

The software models discussed at a high-level in the previous section and in more detail in subsequent sections are generally based on modeling the fate and transport of chloride concentrations which are above typical background concentrations. True background chloride concentrations vary between different regions and soil types, but are generally below 100 mg/kg in the large majority of cases. Consequently, 100 mg chloride/kg soil is the primary delineation criterion within the SST. This is the concentration used to determine the extent of anthropogenic chloride impacts (>100 mg/kg) that must be included when modelling chloride transport to the various receptors. This 100 mg/kg delineation criterion applies both vertically and laterally, and thus can be used to guide the depth and spatial extent of site investigations. Note that the use of the SST is a Tier 2 guideline option that automatically involves detailed examination of groundwater receptors. When assessing a salt-contaminated site for the application of Tier 1 soil guidelines, a more stringent delineation criterion (the lowest groundwater chloride guideline on a mg/L saturated paste basis as per AEP 2019a) is required along with consideration of groundwater pathways (if appropriate). This is because Tier 1 EC / SAR soil guidelines do not directly address potential chloride risk to groundwater receptors.

Note that in some cases, chloride concentrations above 100 mg/kg may potentially be considered to represent background conditions (or sufficiently close to background) or sufficiently complete delineation. Such cases require professional judgement on a case-by-case basis, and may occur in situations involving (for instance) naturally-occurring elevated chloride concentrations, low-level widespread chloride impacts from other industries or sources (such as agricultural effects, road salt use, industrial urban environments, etc), or soils with lower bulk densities and higher saturation percentages than typical mineral soils (e.g., peat or other highly organic soils, some heavy clays).

For sodium, there is no numerical equivalent to the 100 mg/kg delineation criteria for chloride since background sodium concentrations vary widely due to naturally occurring sodium salts such as sodium sulphate and sodium bicarbonate. For this reason, delineation of SAR/sodium impacts is based on delineating to the relevant Tier 1 SAR guideline, which is itself a function of background SAR.

At the high end of the concentration range, chloride concentrations which are above certain thresholds are considered to be outside the range of model tolerances and reduced modeling accuracy may occur. These upper concentration limits for chloride are referred to as 'Management Limits', and are based on saturated pore water chloride concentrations approximately 1.5-fold above typical sea-water chloride concentrations of 20,000 mg/L. Above this threshold, density-driven flow may become a more prominent factor and modelling accuracy thus reduced. Based on bulk-density and porosity assumptions within SST (consistent with Tier 1 defaults as discussed in Section 2.7.4), this corresponds to chloride management limits of 10,000 mg/kg for fine soils and 7,000 mg/kg for coarse soils in Version 3.0. Remediation guidelines generated by the SST thus have an upper bound of these management limits, thus indicating that chloride impacts above management limits will generally require remediation unless considered on a Tier 2C basis.

Sodium management limits of 6,500 mg/kg for fine soils and 4,500 mg/kg for coarse soils are utilized by the SST in a similar manner, and derived from the chloride management limits combined with the atomic weight ratios of sodium to chloride. Since SAR is a calculated value involving ratios, SAR does not have a specific numerical management limit but does have an upper limit of 100 implemented for guideline display purposes. Laboratory SAR measurements and calculations at those levels tend to involve increased uncertainty since they generally involve calcium and/or magnesium concentrations at or near laboratory detection limits.

For both chloride and sodium, calculated guidelines which are above management limits are displayed as "ML", with the numerical guideline value shown in parentheses after the "ML" shown solely for context and not for remediation purposes. These displayed values in parentheses also have upper limits based on solubility limits for typical chloride salts (approximately 160,000 mg/L). These upper limits on displayed numerical values are 54,000 mg/kg chloride for fine soil and 34,000 mg/kg chloride for coarse soil, and 35,000 mg/kg sodium for fine soil and 22,000 mg/kg sodium for coarse soils. Since these values are all above the respective management limits, they are displayed solely for context and not for remediation purposes.

As discussed in later sections, groundwater guidelines for chloride are also generated in Tier 2B scenarios to correspond to soil guidelines, with management limits for groundwater chloride guidelines implemented to be consistent with the soil management limits.

2.7   Vertical Salt Ion Transport

Chloride is a conservative substance in terms of fate and transport because it does not adsorb to soil, readily form precipitates, or undergo breakdown by chemical, biological, or radioactive processes. Sodium in comparison will exchange with other cations on the cation exchange complex which can influence the rate of transport.

Salt transport is governed by the net movement of 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. Other than in cases of slow groundwater movement, 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. Diffusion effects are most prominent when there are large concentration gradients, such as when the root-zone has been excavated and backfilled and substantial chloride or sodium concentrations remain in subsoil directly below the root-zone which may then redistribute upwards into the backfill / root-zone. Diffusion is generally slower through unsaturated soils than through saturated soils. This aspect is addressed in detail in Version 3.0 as discussed in later sections.

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 generally parallel the advective flow of water in soil and groundwater, though in some cases diffusive flow can cause salt ions to migrate in the opposite direction of advective flow, particularly if this advective flow is slow (such as during slow downward leaching). 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.

2.7.1 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.*, 2013). 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).

Classification: Public
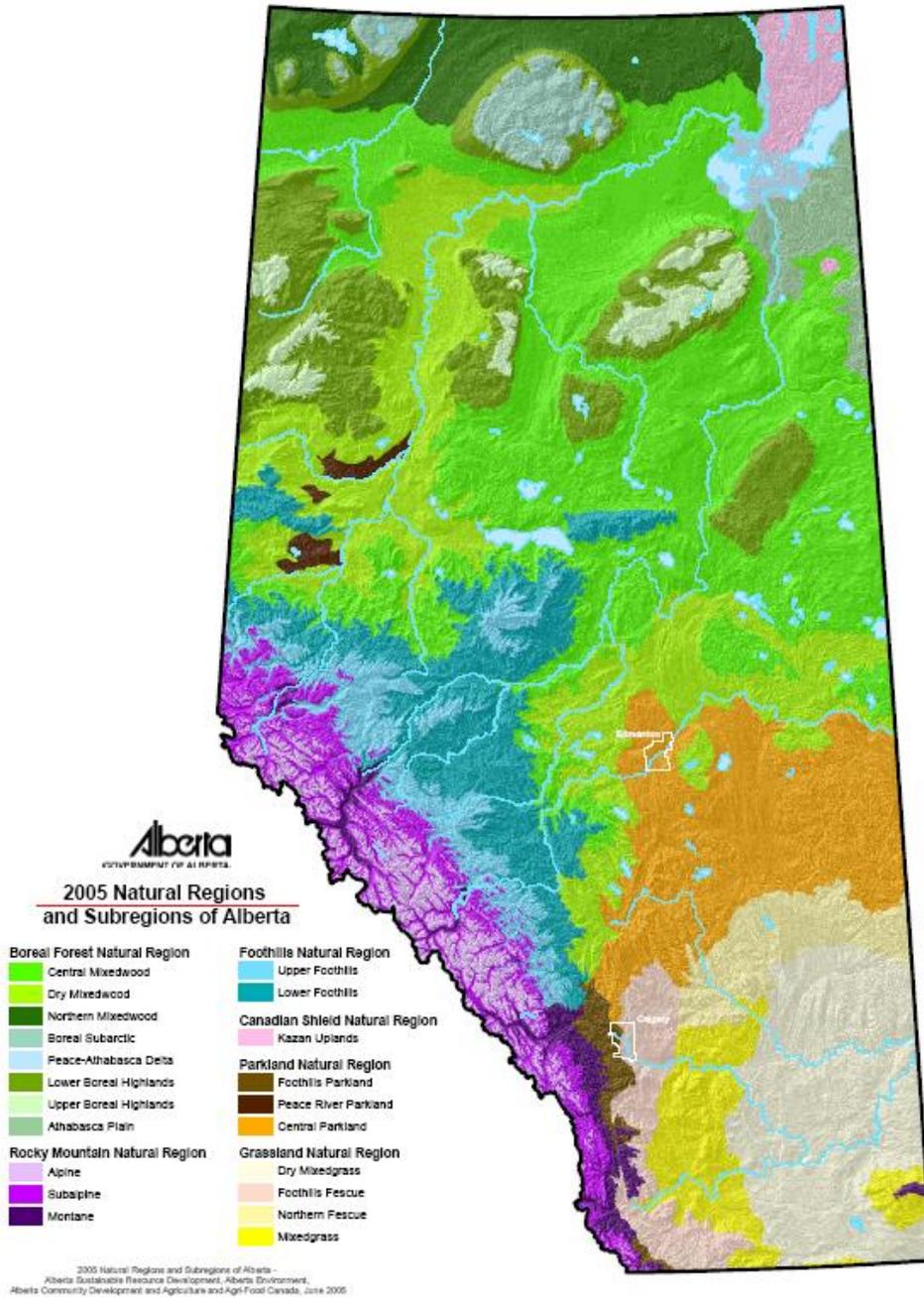
2.7.2 Climate, Water Balance, and Soil Moisture Surplus/Deficit

Climate has a strong influence on water balance and the net fluxes of water into and out of the root zone. The likelihood of infiltrating precipitation draining below the root zone depends on the balance between precipitation and evapotranspiration. 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). Various studies have been performed analyzing trends in precipitation (P) and potential evapotranspiration (PET) across the various natural regions of the province. Further details are provided in the Technical Manual, including various assumptions, calculations, diagrams, and tables related to the topic of water balance and moisture surplus/deficit.

One useful way of analyzing P and PET values is by using them to calculate Climate Moisture Index (CMI) values (details in the Technical Manual). The figure below shows calculated CMI as a function of natural subregion, with a positive CMI indicating potential recharge and a negative value indicating potential discharge.   None of Alberta's Subregions were within the Very Dry/Very Arid, Wet/Humid, or Very Wet/Very Humid categories.
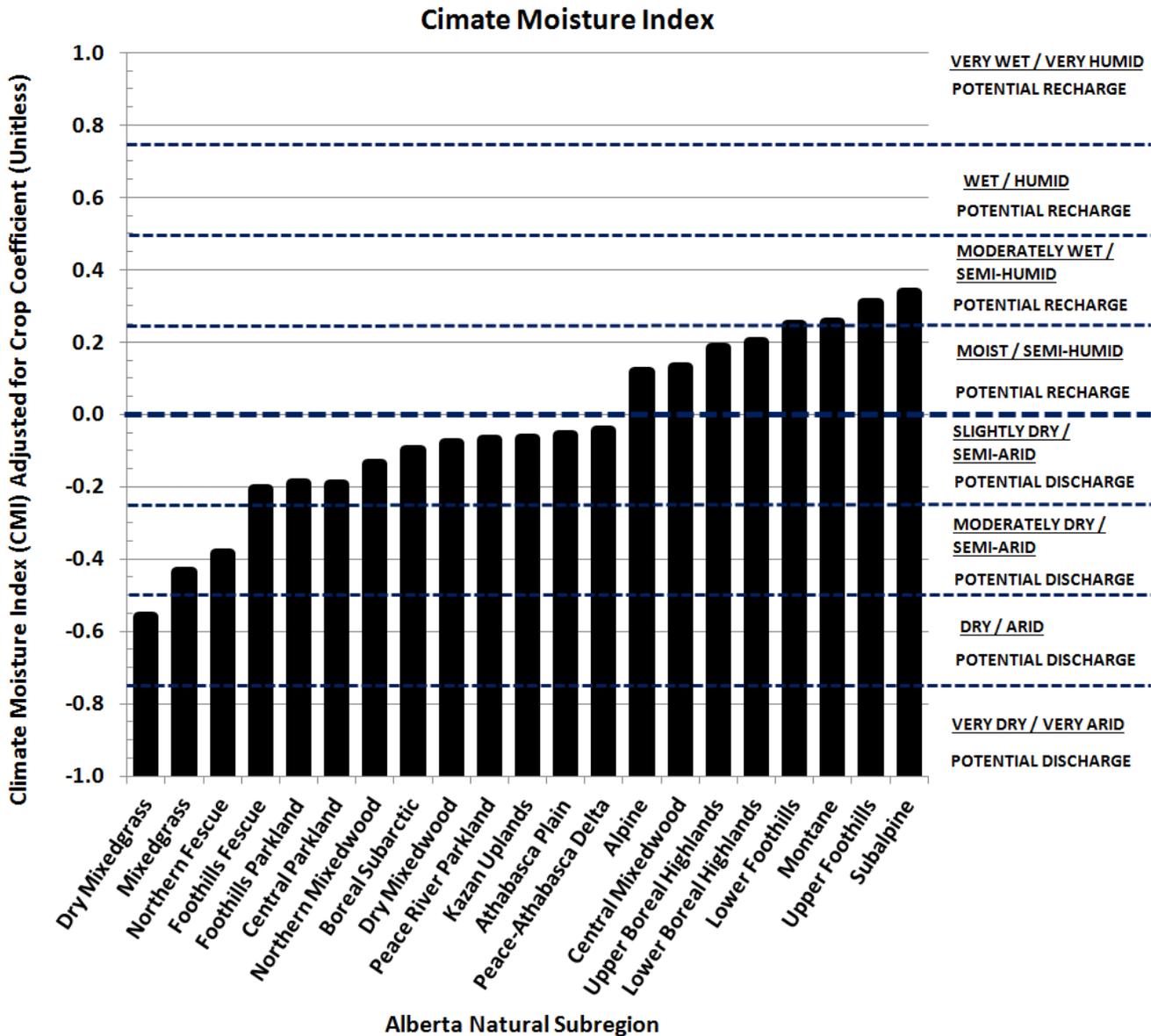
⚠️ *Local variations in climate associated with micro-climates or distinct vegetation type are not accounted for in the SST program. Climate conditions are assumed to be uniform within each Natural Subregion. A more refined estimate of drainage conditions may be obtained by installing nested wells, and incorporating a measured vertical gradient into the SST.*

2.7.3 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.

Root Density kg/m³

Cover Type	% Root Biomass in Upper 30 cm
Boreal Forest	83
Temperate Grassland	83
Crops	70
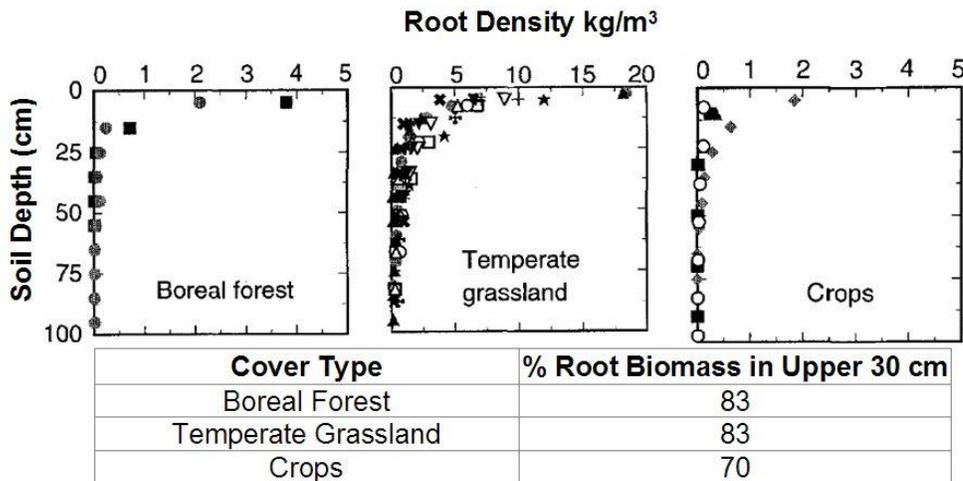
Source: Jackson et al., 1996.

2.7.4 Soil Lithology and Properties

Two generalized soil lithology groupings are used to categorize soil texture at sites across Alberta (coarse and fine) in a manner consistent with Tier 1 guidelines. For subsoil (> 1.5 m), the predominant soil texture governing vertical transport is selected for entry into the SST for overall subsoil lithology. For example, if soils are primarily fine soils with occasional sand lenses, and fine soils are primarily governing vertical 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. This overall subsoil lithology is one of the primary determinants of drainage rate, and also determines the pore water conversion performed internally by the SST using bulk density and porosity.

Version 3.0 of the SST follows the Tier 1 protocol (AEP, 2019a) for defining coarse and fine soils. Unlike previous versions of the SST, which determined clay percentage by hydrometer, Version 3.0 uses the sieve method for distinguishing coarse and fine soils. After removing particles >2mm, the texture category is determined by the proportion of the remaining sample passing a 75 μm (200 mesh) sieve. Statistics are calculated to determine the overall site texture (calculated separately outside of the SST such as in Microsoft Excel) which can be used to select the appropriate soil lithology in the SST. Soils with 50% or less retained (median particle size of less than 75 μm) are treated as fine texture soils, and soils with more than 50% retained (median particle size of more than 75 μm) are treated as coarse texture soils.

Though sieve data is used for overall lithology for both chloride and SAR/sodium assessments, useful textural context is still provided by hydrometer data, and is required in addition to the sieve data when performing a SAR/sodium assessment in the SST. If obtaining both sieve and hydrometer data, note that the Tier 1 definition of 'coarse' (>75 μm) as measured by sieve does not directly correspond to the definition of 'sand' (2 mm - 50 μm) in the Canadian System of Soil Classification (CSSC) (Agriculture and Agri-Food Canada, 2013). Particle size fractions obtained from hydrometer are typically based on the

CSSC. Regardless of these differences, some general trends can frequently be observed if comparing texture by sieve to texture by hydrometer as shown below:

1. 'Fine' by sieve (50% or less retained on 75 µm sieve)
   - Generally includes heavy clay, clay, clay loam, silty clay, silty clay loam, silt, silt loam, most loams

2. 'Coarse' by sieve (more than 50% retained on 75 µm sieve)
   - Generally includes sandy soils with sand content >50% such as sand, loamy sand, sandy loam, and potentially sandy clay loam or sandy clay
   - 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 does not represent a DUA.
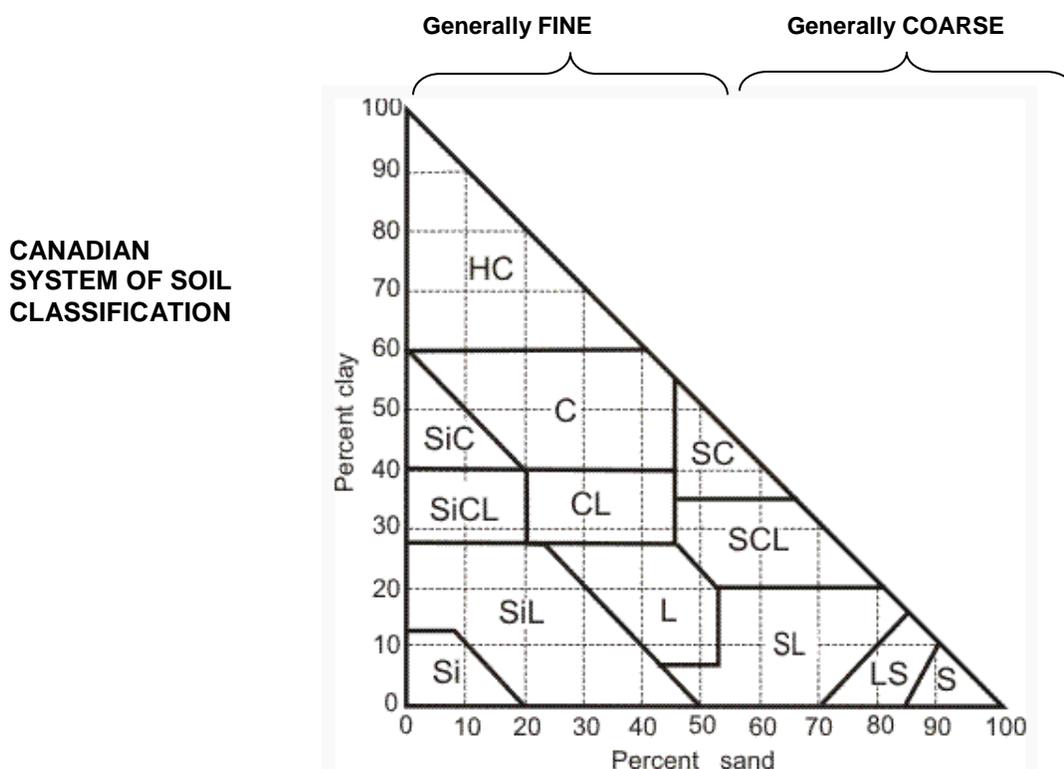
Generally FINE   **Generally COARSE**

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

Note that if soils are dominated by very coarse particles (more than 70% in the >2 mm range as per AEP 2019a) then at a minimum a Tier 2B (or potentially Tier 2C) approach is required so that the hydraulic properties of the very coarse materials can be characterized. Borehole log observations are the likely first place to identify the potential for a significant content of very coarse (>2 mm) content, and where this is observed, it will flag the need to closely examine the soil texture methodology and data.

In addition to using sieve data to define overall subsoil lithology and vertical transport, sieve data can also be used to refine lateral transport properties via the 'shallow' and 'deep' groundwater parameters (discussed further in Section 2.10). Shallow and deep groundwater lithology generally match the overall subsoil lithology in cases of uniform soil texture throughout the soil profile. In cases of non-uniform or layered subsoil lithology, adjusting shallow and/or deep groundwater texture independently of overall subsoil lithology allows improved description of soil layering and lateral flow. In particular, altering

these parameters influences the default hydraulic properties of these intervals, along with the porosity used for groundwater velocity calculations.

The SST is not intended to be applied to peat/muskeg deposits due to substantial differences in bulk density and transport properties compared to more typical mineral soils. 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. The SST is also not intended to be applied to soil depth profiles composed primarily of sands and gravels (that would meet the definition of a DUA) with negligible overlying till.

It is the responsibility of the proponent to represent the soil lithology of the site accurately. Particularly in cases with non-uniform soil lithology, judgment is required by the proponent to adequately identify the presence and thickness of important soil layers based on field borehole logs and soil textural information. These cases with non-uniform soil lithology generally require more professional judgement and an understanding of the underlying conceptual models in order to assign lithologies (overall, shallow, and deep) which accurately describe the physical site. In most cases, there is one set of parameters which can adequately describe the lithologies for all receptors at once. In some cases, however, there may not be one set of parameters which can adequately describe all receptors at once. This may occur (for instance) if an overall lithology of 'coarse' is most appropriate for drainage rates for the DUA pathway but an overall lithology of 'fine' is most appropriate for drainage rates for the root-zone. This could potentially occur in some instances of fine-grained soil overlaying coarse-grained soil, with detailed examples provided in Section 4.11. In such cases, the user may need to run the site twice, once with an overall fine-grained lithology and once with an overall coarse-grained lithology, and selecting the guideline most appropriate (or in some cases, most conservative) for each relevant pathway.

Parameters used in the SST for coarse soils and fine soils are summarized in the table below, with bulk density and porosity consistent with AEP Tier 1 defaults for fine and coarse soils. It also includes Campbell's Parameters for moisture tension and corresponding values from the moisture retention curves which describe how much moisture is retained in soil for a given matric potential (suction).

Parameters	Fine Texture (median < 75 μm)	Coarse Texture (median > 75 μm)
Bulk Density (g/cm^3)	1.4	1.7
Total Porosity	0.47	0.36
Ksat (mm/d)	0.88	8.8
Dispersivity (mm)	125	125
Campbell's Parameter α	-3.47	-0.938
Campbell's Parameter β	7.54	5.058
Moisture Retention -3 kPa	0.463	0.285
Moisture Retention -10 kPa	0.410	0.225
Moisture Retention -30 kPa	0.354	0.181
Moisture Retention -100 kPa	0.302	0.142
Moisture Retention -1500 kPa	0.211	0.083

Note: *α* and *β* are coefficients of moisture tension.

Hydrometer data and clay content

When a SAR/sodium assessment is performed, texture by hydrometer (particularly clay content) is required in addition to sieve data. This is required due to the strong influence of clay content on cation exchange and the relative transport of sodium and calcium/magnesium. Average clay content is required for the root-zone (<1.5 m), subsoil (1.5 m to approximately 6 m), and (if relevant) backfill. Each interval is classified as to whether clay content is "low" (<18%), "medium" (18-36%), or "high" (>36%) for SAR/sodium guideline development based on the arithmetic average clay content for each interval.

2.7.5 Soil Drainage Rate

The site water balance and drainage rate are factors involved in determining whether a chloride (or sodium) 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 or irrigation, 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:

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

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). AEP (2019a) determined maximum drainage rates based on precipitation data from Edson (surrounded by the Lower Foothills Subregion, mean annual precipitation of approximately 568 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 12 mm/year, equivalent to the Tier 1 infiltration rate for fine soils. For coarse soils, the maximum rate was set at 60 mm/year which is also consistent with the Tier 1 infiltration rate for coarse soil. 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 natural subregion that has approximately 100 mm less precipitation per year, the maximum downward drainage rates are set at 9 and 30 mm/year for fine and coarse textured soils, respectively, compared to 12 and 60 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 and be associated with recharge conditions. Because of potential variable rates of downward drainage, a different drainage rate is used in the SST model for shallower receptors than the DUA to ensure all receptors are protected. A lower downward drainage rate is used to develop guidelines for receptors located in closer proximity to the soil surface (*e.g.*, root zone). Conversely, a higher downward drainage rate is used to develop guidelines for 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 protecting the root zone (discharge condition) and a downward drainage category is considered for the DUA. While this implies that salts are simultaneously moving upward and downward, the assumption is made to account for variability in drainage rate estimates and to ensure that modelled results protect against potential changes in plant cover or land use that could affect moisture balance. This includes situations such as fallow land, or conversion between native grassland and agricultural crops as described in the Technical Document. For the aquatic life and dugout pathways, whichever of the two drainage rates results in a more conservative guideline is used regardless of whether the root-zone is a discharge or recharge scenario.

Default drainage categories in the SST are shown below as a function of CMI and soil texture (in the absence of vertical gradient or hydraulic conductivity data relevant to drainage). 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 combination was used. The downward default drainage rate for these Subregions is higher than Subregions within the Grassland Natural Region due to greater precipitation rates and lower potential evapotranspiration.

Climate Moisture Index and Drainage Rates

VERY WET / VERY HUMID

WET / HUMID

MODERATELY WET/SEMI-HUMID

FINE:	1 DOWN; 12 DOWN
COARSE:	2 DOWN; 60 DOWN

MOIST / SEMI-HUMID

FINE:	1 DOWN; 9 DOWN
COARSE:	2 DOWN; 30 DOWN

SLIGHTLY DRY / SEMI-ARID

FINE:	1 UP; 6 DOWN
COARSE:	1 UP; 15 DOWN

MODERATELY DRY / SEMI-ARID

FINE:	1 UP; 3 DOWN
COARSE:	1 UP; 7 DOWN

DRY / ARID

FINE:	1 UP; 1 DOWN
COARSE:	1 UP; 2 DOWN

VERY DRY / VERY ARID

- The first (lower) drainage rate for a given texture/subregion combination is for the root-zone pathway, and the second (higher) drainage rate is for the DUA.
- For the aquatic life and dugout pathways, whichever of the lower and higher drainage rate results in more conservative guidelines is used.

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

Vertical Gradient and Hydraulic Conductivity Relevant to Drainage

As discussed above, default drainage categories are determined in the SST based on soil texture and CMI (as determined by natural subregion). In addition, drainage categories in Tier 2B assessments may be further modified from these baselines based on supplementary data including vertical hydraulic gradient (from nested wells) and potentially hydraulic conductivity. Modified inputs for vertical hydraulic gradient and conductivity will apply to the entire depth from root zone to DUA. At sites with layered lithology, it may be appropriate to use different gradient and conductivity data for deep versus shallow pathways. For these sites, separate runs will be needed for shallow and deep pathways, as discussed in Section 4.11. There are specific requirements for installing and collecting data from the nested wells (discussed in Section 4.10), as well as specific requirements for selecting and analyzing hydraulic conductivity data relevant to drainage from wells or potentially soil cores (discussed in Section 4.11).

Vertical gradient data can be used to allow limited adjustments to drainage rates (to both lower and higher drainage rates), primarily as a function of the direction of the vertical gradient (discharge or recharge). This vertical gradient information can be used regardless of whether sufficient hydraulic conductivity data relevant to drainage is available. Note that the converse is not permitted, as the use of hydraulic conductivity relevant to drainage also requires the simultaneous use of vertical gradient information. Additional adjustments to drainage rates are possible when both vertical gradient and hydraulic conductivity data relevant to drainage are available. These potential adjustments to drainage rates based on nested wells or hydraulic conductivity relevant to drainage allow better representation of situations where the default drainage categories may not be appropriate for a particular site due to local conditions such as site-specific soil and groundwater conditions, topography, micro-climate, *etc.*

While hydraulic conductivity relevant to drainage is preferably derived from monitoring well data (*i.e.*, slug tests), the use of soil core data (*i.e.*, Shelby tubes) is also allowable in conjunction with monitoring well data provided the intervals they are taken from are relevant to the drainage category (shallow vs deep) being modified. For both wells and soil cores, data is considered relevant to drainage if it is from subsoil (>1.5 m), characterizes an interval which is reasonably wide-spread, and sufficiently representative of typical intervals groundwater will need to recharge through to eventually reach the DUA. More complex lithologies will require more wells and/or soil cores to be considered sufficiently representative for this parameter, as discussed in more detail in Section 4.11. The vertical gradient information obtained from wells must also be from generally similar lithologies as the hydraulic conductivity data relevant to drainage.

In cases where soil core data is used on its own or as a supplement to well data, the hydraulic conductivity data (vertical) from soil cores must first be multiplied by 10 prior to entering the data in the SST in order to compensate for sample-size effects. This sample-size correction for soil cores is consistent with Tier 1 / Tier 2 protocols for DUA exclusion for hydrocarbons, where the limited sample size tested within a soil core via leaching column is substantially less than the effective radius of influence evaluated during a slug test on a monitoring well. Since smaller samples are less likely to exhibit larger fractures or preferential flow pathways through coarser intervals, a 10-fold upward correction for soil cores is considered appropriate to make their values comparable to slug test results from monitoring wells.

For example, a soil core with a tested vertical hydraulic conductivity of 1×10^{-8} m/s would be considered equivalent to a well with a hydraulic conductivity measured by slug test of 1×10^{-7} m/s. This 10-fold upward correction of soil core data to make comparable to well data must be done outside the tool, with the final effective hydraulic conductivity relevant to drainage (from a combination of wells and potentially corrected soil cores) entered into the tool by the user. Additional details on minimum data requirements and statistical methods for this analysis is considered in the Section 4.11.

If data for both vertical gradient and hydraulic conductivity relevant to drainage are entered into the tool during a Tier 2B assessment, the tool internally multiplies the two values as an initial proxy value relevant to vertical flux (drainage rate). Recharge categories ('low', 'mid', or 'high') are then estimated from this calculation based on typical broad ranges of vertical gradient and hydraulic conductivity combinations which take into account typical variability of texture, conductivity, gradient, and other factors. These recharge categories are then used to derive drainage rates as discussed in more detail below.

Based on the vertical gradient and/or hydraulic conductivity data relevant to drainage entered into the tool, numerical drainage rates are assigned by the SST based on the site-specific soil texture, CMI, vertical gradient (if available), and hydraulic conductivity relevant to drainage (if available). A summary of these numerical drainage rates are shown in the tables below, first for the case with vertical gradient only, and then for the case with both vertical gradient and hydraulic conductivity relevant to drainage data.

The table below shows how site-specific drainage rates are derived in the SST on a Tier 2B basis when sufficient vertical gradient data is available and entered into the SST, and how these drainage rates compare to the default values (with no vertical gradient data). Lower (root-zone) and higher (DUA) drainage rates are shown below as a function of the direction of the vertical gradient, with gradients <0 indicating 'discharge' scenarios and gradients ≥0 indicating recharge scenarios. Root-zone drainage rates in some cases change from discharge to recharge (or vice versa) compared to the default case depending on vertical gradient. Similarly, DUA drainage rates may in some cases be reduced from the conservative defaults if a discharge condition is observed. Intermediate changes in DUA drainage rates are also possible when both vertical gradient and hydraulic conductivity relevant to drainage are available as discussed further below.

Fine soils

Lower Drainage Rate (Root Zone Protection)

CMI	No Vertical Gradient (Default)	Vertical Gradient Direction	
		Discharge	Recharge
Moderately wet / semi-humid	1	-1	1
Moist / semi-humid	1	-1	1
Slightly dry / semi-arid	-1	-1	1
Moderately dry / semi-arid	-1	-1	1
Dry/arid	-1	-1	1

Higher Drainage Rate (DUA Protection)

CMI	No Vertical Gradient (Default)	Vertical Gradient Direction	
		Discharge	Recharge
Moderately wet / semi-humid	12	6	12
Moist / semi-humid	9	3	9
Slightly dry / semi-arid	6	1	6
Moderately dry / semi-arid	3	1	3
Dry/arid	1	1	1

Coarse soils

Lower Drainage Rate (Root Zone Protection)

CMI	No Vertical Gradient (Default)	Vertical Gradient Direction	
		Discharge	Recharge
Moderately wet / semi-humid	2	-1	2
Moist / semi-humid	2	-1	2
Slightly dry / semi-arid	-1	-1	2
Moderately dry / semi-arid	-1	-1	2
Dry/arid	-1	-1	2

Higher Drainage Rates (DUA Protection)

CMI	No Vertical Gradient (Default)	Vertical Gradient Direction	
		Discharge	Recharge
Moderately wet / semi-humid	60	15	60
Moist / semi-humid	30	7	30
Slightly dry / semi-arid	15	2	15
Moderately dry / semi-arid	7	2	7
Dry/arid	2	2	2

-Vertical gradient direction is categorized as 'discharge' (gradient <0) or 'recharge' (gradient ≥0)
-Drainage rates are in mm/year
-Negative drainage rates indicate upward transport (discharge)
-Positive drainage rates indicate downward transport (recharge)

The table below shows how site-specific drainage rates can be further modified on a Tier 2B basis when both vertical gradient and hydraulic conductivity relevant to drainage are available and entered into the SST. Lower (root-zone) and higher (DUA) drainage rates are shown below as a function of drainage category, with drainage category ('discharge', 'low recharge', 'mid recharge', and 'high recharge') determined as previously discussed based on vertical gradient and hydraulic conductivity relevant to drainage.

Fine soils

Lower Drainage Rate (Root Zone Protection)

CMI	Drainage Category			
	Discharge	Low recharge	Mid recharge	High recharge
Moderately wet / semi-humid	-1	1	3	6
Moist / semi-humid	-1	1	3	3
Slightly dry / semi-arid	-1	1	3	3
Moderately dry / semi-arid	-1	1	1	3
Dry/arid	-1	1	1	1

Higher Drainage Rate (DUA Protection)

CMI	Drainage Category			
	Discharge	Low recharge	Mid recharge	High recharge
Moderately wet / semi-humid	6	6	9	12
Moist / semi-humid	3	3	6	9
Slightly dry / semi-arid	1	1	3	6
Moderately dry / semi-arid	1	1	1	3
Dry/arid	1	1	1	1

Coarse soils

Lower Drainage Rate (Root Zone Protection)

CMI	Drainage Category			
	Discharge	Low recharge	Mid recharge	High recharge
Moderately wet / semi-humid	-1	2	7	15
Moist / semi-humid	-1	2	7	7
Slightly dry / semi-arid	-1	2	7	7
Moderately dry / semi-arid	-1	2	2	7
Dry/arid	-1	2	2	2

Higher Drainage Rates (DUA Protection)

CMI	Drainage Category			
	Discharge	Low recharge	Mid recharge	High recharge
Moderately wet / semi-humid	15	15	30	60
Moist / semi-humid	7	7	15	30
Slightly dry / semi-arid	2	2	7	15
Moderately dry / semi-arid	2	2	2	7
Dry/arid	2	2	2	2

-Drainage categories ('discharge', 'low recharge', 'mid recharge', high recharge') are based on vertical gradient and hydraulic conductivity relevant to drainage
-Drainage rates are in mm/year
-Negative drainage rates indicate upward transport (discharge)
-Positive drainage rates indicate downward transport (recharge)

2.7.6 Influence of Sulphate and Water Table on Drainage Rate

The previous section described the methods the SST uses to derive drainage rates for the root-zone and DUA pathways using properties such as climate and soil texture, and potentially further refined with vertical gradient and hydraulic conductivity relevant to drainage. As discussed in the Native Prairie Protocol (AEP, 2019c), additional factors such as natural sulphate profiles and water table depth can also be relevant to drainage rate, particularly in the context of diagnosing or predicting potential discharge vs recharge conditions. The Native Prairie Protocol is based on recognizing that native prairie ecosystems can take decades to recover after disturbance, and in cases where current-day and future adverse effects are not observed or predicted for the root-zone, that the root-zone can in some cases be left undisturbed provided other receptors are acceptably protected using tools such as the SST. This prediction of future vegetation health in native prairie ecosystems is based in part on identifying potential moisture discharge vs recharge scenarios, and thus has potential relevance to other SST assessments regardless of ecosystem.

This native prairie protocol and the accompanying technical supporting document (Millenium, 2018) describe the relationship between water table depth and potential discharge conditions, with water tables deeper than approximately 2 m considered to be unlikely to discharge substantially to the surface under the majority of vegetation, hydrogeological, and climatic conditions. In the specific context of the Native Prairie Protocol (which frequently involves leaving root-zone soils undisturbed in native prairie ecosystems), upward chloride migration is primarily associated with moisture discharge conditions since upward chloride diffusion is likely minimal with long-established historical chloride impacts in the absence of further soil disturbance. Application of this protocol specifically to native prairies is described later in this sectio n. In the context of the SST in other ecosystems where the root-zone generally needs to be remediated to Tier 1 salinity guidelines, upward chloride migration due to diffusion can still occur under recharge conditions due to the large chloride concentration gradients present after replacing impacted root-zone soils with low-chloride backfill. Since the moisture balance of the root-zone (discharge vs recharge) also has a strong influence on upward chloride transport in such situations, the protocols described in the Native Prairie Protocol can also be used within the SST to identify likely recharge scenarios and thus potentially refine the SST root-zone drainage rate from discharge to recharge in such conditions.

The interaction between sulphate profiles and water table depth is shown in the 'Step 3 Decision Tree' below from AEP 2019c. Here, Step 3a uses naturally-occurring sulphate depth profiles as an indicator of upward or downward water movement, with ambiguous cases resolved using water table depth as an additional indicator in Step 3b.
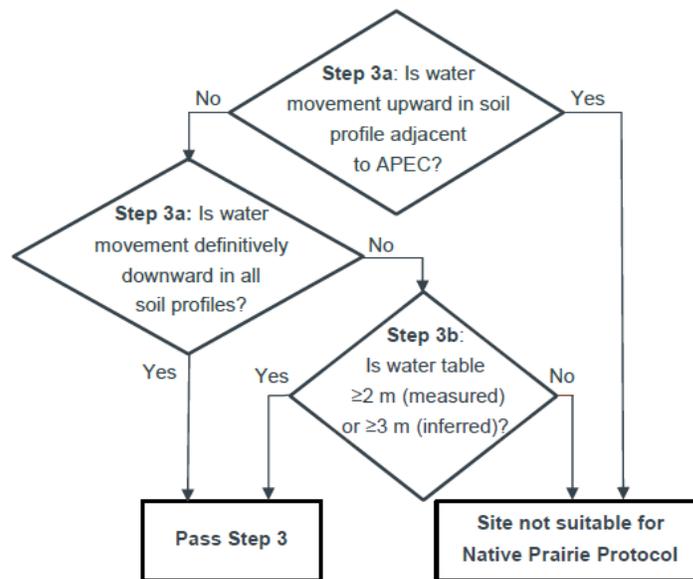
Source: AEP, 2019c
(Native Prairie Protocol)

Data requirements for the sulphate profiles are described in AEP 2019c, and include a requirement for profiles from background locations (at least three) and locations near impact areas (at least one per area). In general, a total of 8 sampling depths are recommended within the top 4.5 m for these sulphate profiles, typically involving 4 or 5 samples from the top 1.5 m and samples with greater spacing intervals below that. Soil profiles for this analysis must be undisturbed so that the sulphate depth profiles provide a reliable indicator of typical historical salt (and hence moisture) movement.

Two examples of such sulphate depth profiles from AEP 2019c are shown below, including 'definitive downward' moisture transport on the left, and 'upward' (discharge) moisture transport on the right (AEP 2019c). Other examples of sulphate profiles are also provided in Appendix A of AEP 2019c, including 'probable downward' and 'ambiguous' sulphate profiles. Additional details on interpretation of sulphate profiles is also provided in AEP 2019c.

Figure A-1. Definitive Downward Sulphate Profile

Figure A-3. Upward Sulphate Profile
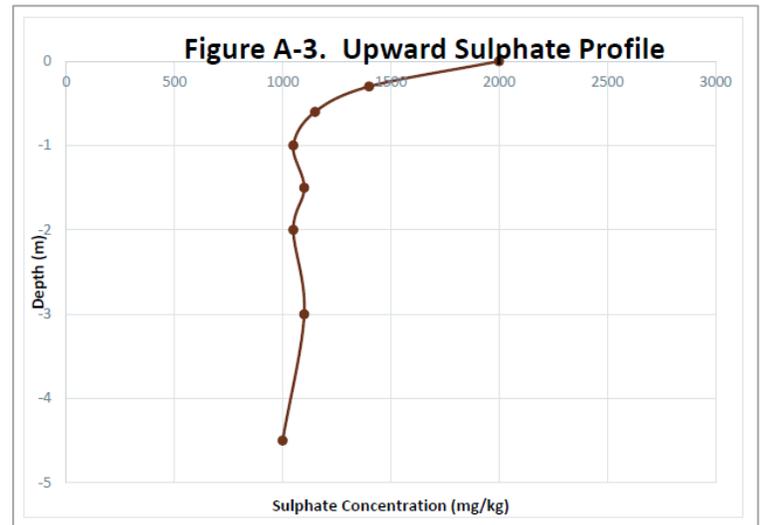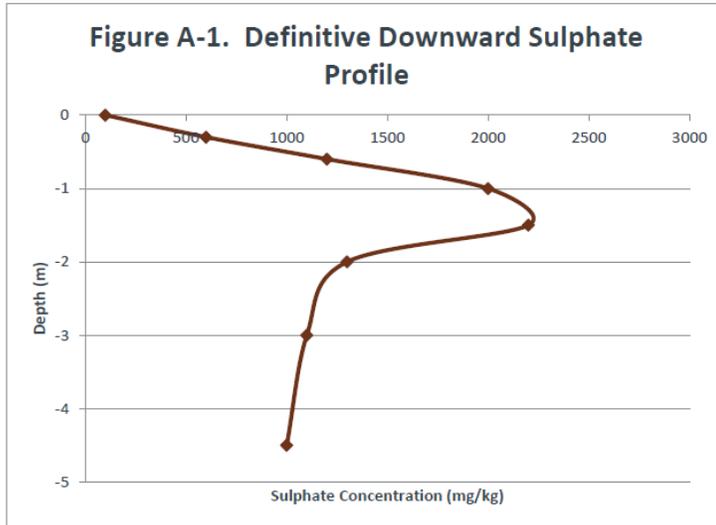
If the sulphate depth profiles are categorized as 'definitive downward', it is concluded that net moisture transport through the root-zone is downward rather than upward. If the sulphate depth profiles are either 'probable downward' or 'ambiguous', then water table depth is used as an additional indicator as shown in the Step 3 Decision Tree. If the water table is 2 m or deeper (as measured by monitoring wells), or 3 m or deeper (as inferred by less-precise field observations and borehole logs), then it is also concluded that net moisture transport through the root-zone is downward (or unlikely to be upward). If sulphate profiles are 'upward', or profiles are not 'definitively downward' and the water table is shallow, there is insufficient evidence to conclude that moisture transport is downward and thus the potential for discharge in the root-zone must be considered.

To implement this protocol within the SST, any site (regardless of ecosystem) which otherwise would show a 'discharge' default for the root-zone pathway can be evaluated using this protocol for sulphate depth profiles and water table depth. This is potentially relevant to natural subregions with CMI in the "slightly dry / semi-arid", "moderately dry / semi-arid", and "dry / arid" categories. If application of the sulphate and water table protocols result in likely net downward moisture transport through the root-zone ('Passing' Step 3), then the user may enter a vertical gradient of 0 (indicating slight recharge conditions) into the SST regardless of whether or not monitoring wells (or nested pairs) are present. As shown in Section 2.7.5, this change will have no influence on the DUA drainage rate, but would change sites with a 'discharge' default drainage rate for the root-zone (1 mm/year up) to minimal recharge instead (1 mm/year down for fine soils, or 2 mm/year down for coarse soils). While this does not necessarily imply negligible risk to the root-zone (since some upward chloride diffusion will still occur), it does reduce the amount of chloride breakthrough modelled in the root-zone during subsoil chloride guideline calculations. As always, sites outside native prairie ecosystems generally require remediation of the root-zone to Tier 1 guidelines, plus meeting the Tier 2A/B subsoil chloride guidelines for all pathways, including the root-zone.

When implementing this technique in the SST, it involves using the Tier 2B assessment option regardless of whether monitoring wells are present or not to allow access to the vertical gradient option (which must be entered as '0'). If physical monitoring wells are not present, all other groundwater parameters would be left as defaults for consistency with a Tier 2A assessment, with the exception of background TDS. Assuming wells are not present, background TDS may be first calculated separately in a preliminary Tier 2A SST calculation based on background soil sulphate (and potentially carbonate / bicarbonate) concentrations. The resulting calculated TDS can then be directly transferred to the Tier 2B assessment. Note that hydraulic conductivity relevant to drainage cannot be used when vertical gradient is inferred in this manner from sulphate profiles and water table depth rather than directly measured from nested pairs.

Native Prairie sites
While the above discussion applies generally to any site with potentially discharge conditions, the Native Prairie Protocol can also be fully implemented as described in AEP 2019c for sites specifically within a native prairie ecosystem. Details are provided in AEP 2019c, and involve potentially using the SST for all pathways other than the root-zone when both current-day and future adverse effects on the root-zone are not observed or predicted.

2.7.7 Key Breakthrough Curve Depths

The LEACHM 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 1.5 to 15 m);
3. 1.5 to 6 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 25 m).

Note that water table depths entered as "<2 m" into the tool for either a Tier 2A or Tier 2B assessment is treated as 1.5 m within the tool for modeling purposes. The root-zone (0-1.5 m interval) is thus considered to remain unsaturated (above the water table) for SST purposes.

Classification: Public
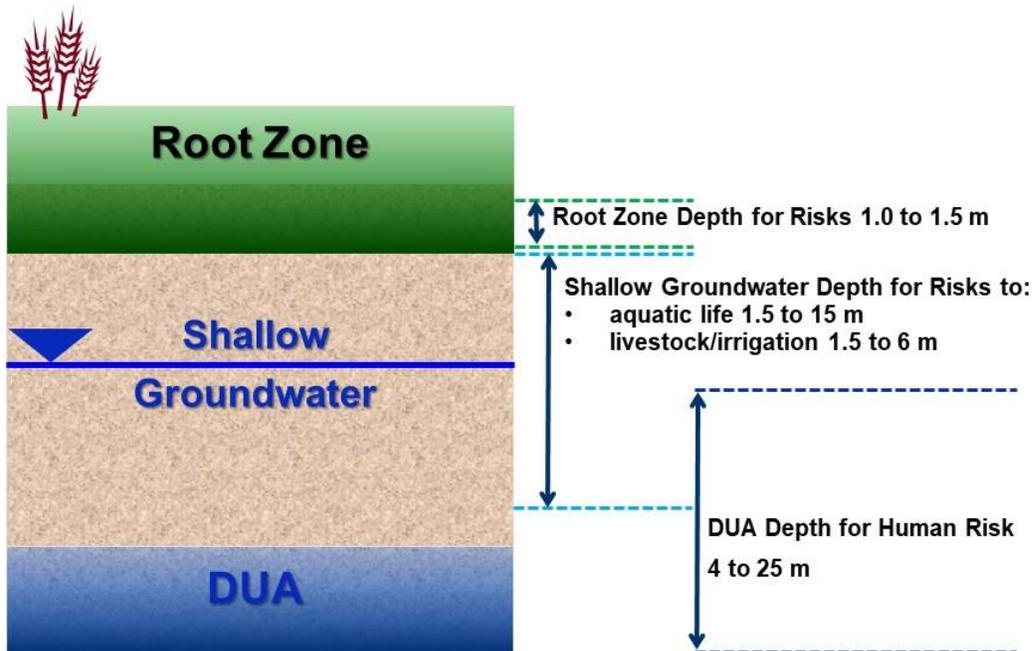
2.7.8 Shallow Groundwater Table Depth

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 1.5 to 6 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 and the dropdown box for water table depth is in 1 meter increments.

2.7.9 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 AERP (2019a) Tier 1 root zone salinity rating categories (*i.e.*, Good, Fair, Poor, Unsuitable) for EC or SAR 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 guidelines are used. A buffer is calculated using background information for determining the allowable contribution of chloride or sodium towards root zone salinity or sodicity. Buffers for both EC and SAR are calculated based on the relevant Tier 1 guidelines and current-day conditions in the root-zone, with some details of (and differences between) the EC and SAR buffer calculations shown below.

EC buffer for subsoil chloride guidelines
The EC buffer for protection of the root zone from excess salinization is calculated from the 95th percentile EC value of background locations at depths from 1.0 to 1.5 m below ground surface. This data is used to determine the AEP (2019a) 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) minus 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 used to determine the acceptable contributions of chloride that will not lead to an exceedance of the AEP soil quality category is calculated according to the following equation built into the SST:

$$EC_{BUF} = EC_{Tier\ 1} - EC_{AVG\ BACK}$$

Where:
EC_BUF	=	EC buffer (dS/m) allocated to avoid an exceedance of Tier 1 across the deeper portion of the root zone (1.0 to 1.5 m) due to upward transport of subsoils impacted by chloride
EC_TIER 1	=	EC Tier 1 guideline for the root zone (upper boundary of the appropriate subsoil (1.0 to 1.5 m) Tier 1 category based on background statistics)
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:

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

Where:
EC_BUF	=	EC buffer (dS/m) allocated to avoid an exceedance 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 (95th percentile of background subsoil (1.0 to 1.5 m))
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, a 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 can be run separately for different subareas 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.*
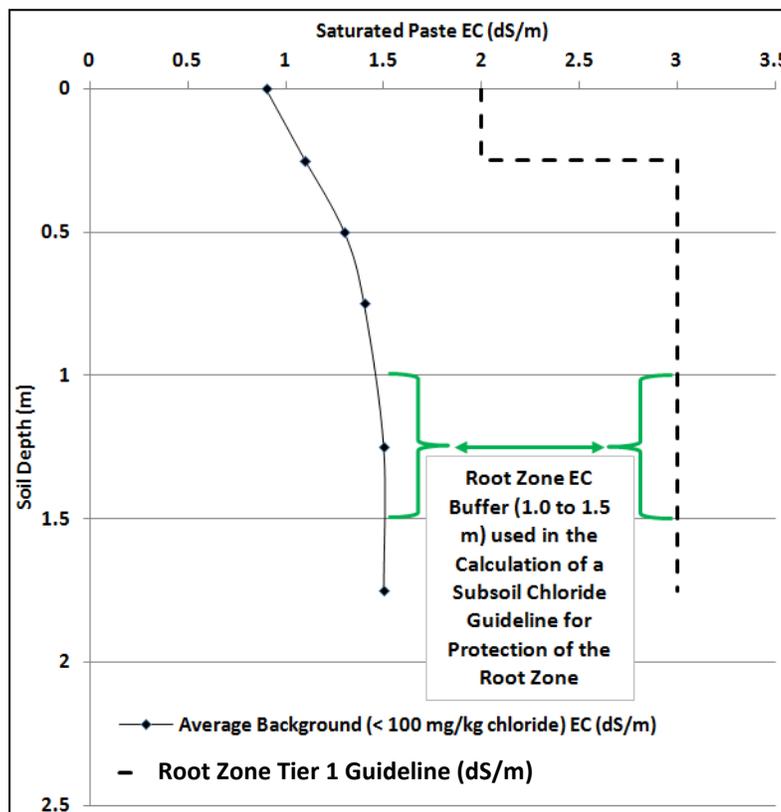
Outlier Analysis

Outliers can contribute to the misrepresentation of data for guideline calculation purposes. An outlier analysis for EC is required prior to the data being entered in the SST (identifies EC values which are greater than 2 x Standard Deviation + Arithmetic Mean). EC 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 EC data for BH10-1 was identified as an outlier, and the borehole removed from the dataset. The last (second) outlier iteration was conducted and BH10-14 was identified as an EC 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.*

This type of outlier analysis can also help address situations where background average and 95th percentile EC values stretch across three categories, such as average of 'Good' and 95th percentile of 'Poor', or average of 'Fair' and 95th percentile of 'Unsuitable'. Such background data should generally not be entered into the SST without first reducing the background range by removing outliers, or potentially collecting additional data or using SubAreas as described in Section 2.13.1,

Note that EC data is used to identify outlier samples for both chloride and SAR/sodium guideline calculations, and thus a separate outlier check specifically for SAR values is not required.

SAR buffer for subsoil sodium guidelines

Calculation of a root-zone SAR buffer is similar to, but somewhat different from, the root-zone EC buffer calculated for subsoil chloride assessments. The root-zone SAR buffer is calculated as the underlined ratio between the derived Tier 1 SAR guideline for the root-zone (specifically for 1-1.5 m) and the current-day SAR in the root-zone. This SAR buffer is calculated as a ratio rather than a difference (as done for EC) since SAR values themselves are inherently ratios and using a ratio is more relevant for subsequent calculations. This root-zone SAR buffer calculation shown below will always be greater than 1 (otherwise excavation of the root-zone is required for Tier 1 SAR exceedances), and is used for subsequent sodium transport and guideline calculations.

$$SAR\ buffer = \frac{Tier\ 1\ SAR\ guideline}{current\ day\ SAR}$$

Classification: Public

2.7.10 Pore Water and Saturated Paste Conversions

Any salt transport (vertical or horizontal) modelled within the SST involves concentrations expressed on a mg/L pore water basis in conjunction with subsoil guidelines generated on a mg/kg soil basis. Conversions between mg/L pore water and mg/kg soil are performed automatically within the SST using parameters such as porosity and bulk density, and thus vary depending on soil texture. It is important to note that the mg/L saturated paste concentrations frequently reported on laboratory sheets are different from mg/L pore water concentrations since they are evaluated at different water contents, with mg/L saturated paste concentrations converted to mg/kg soil using saturation percentages rather than porosity and bulk density.

2.7.11 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) by using copy/paste functions (Ctrl-C and Ctrl-V as keyboard shortcuts). 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 in meters as a single value (*e.g.*, 1.25) rather than a range (*e.g.*, 1.1 – 1.25).

2.8   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 or sodium 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 and/or SAR/sodium impacts.

2.8.1 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 and SAR values both lower than the applicable Tier 1 guideline for the site.

When performing an SST chloride assessment, 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:

$$EC_{AVG\ BACK} + EC_{FUTURE\ Cl} \leq EC_{Tier\ 1}$$

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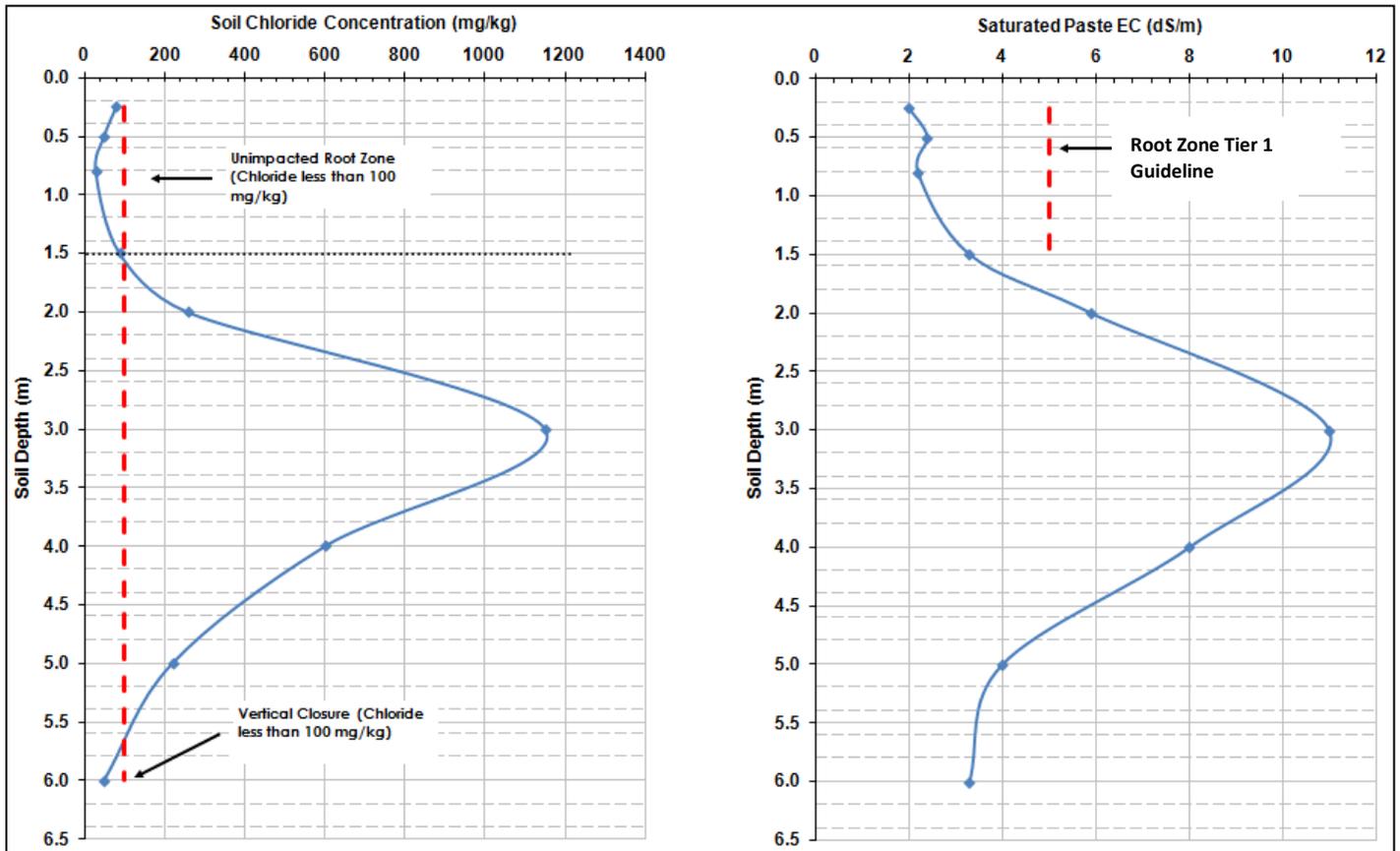
⚠️ *Vertical graphical profiles of chloride and EC data should be included in guideline calculation supporting documentation to facilitate the regulatory review process.*

If performing a subsoil SAR/sodium assessment, the calculations are performed similar to EC but instead ensuring that the future SAR level in the root-zone (background SAR multiplied by the relative increase in SAR from future upward sodium migration) remains below the Tier 1 SAR guideline. The following equation is used to express an unimpacted root zone scenario for SAR:

$$SAR_{AVG\ BACK} * SAR_{FUTURE\ Na} \leq SAR_{Tier\ 1}$$

Where,

$SAR_{AVG\ BACK}$	=	average background SAR from 1.0 to 1.5 m based on background borehole data
$SAR_{FUTURE\ Na}$	=	proportional increase in SAR due to subsoil (> 1.5 m) sodium discharge into the deeper root zone (1.0 to 1.5 m) within the impacted area
$SAR_{Tier\ 1}$	=	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))

An example of an impacted root zone from SAR/sodium is shown below.
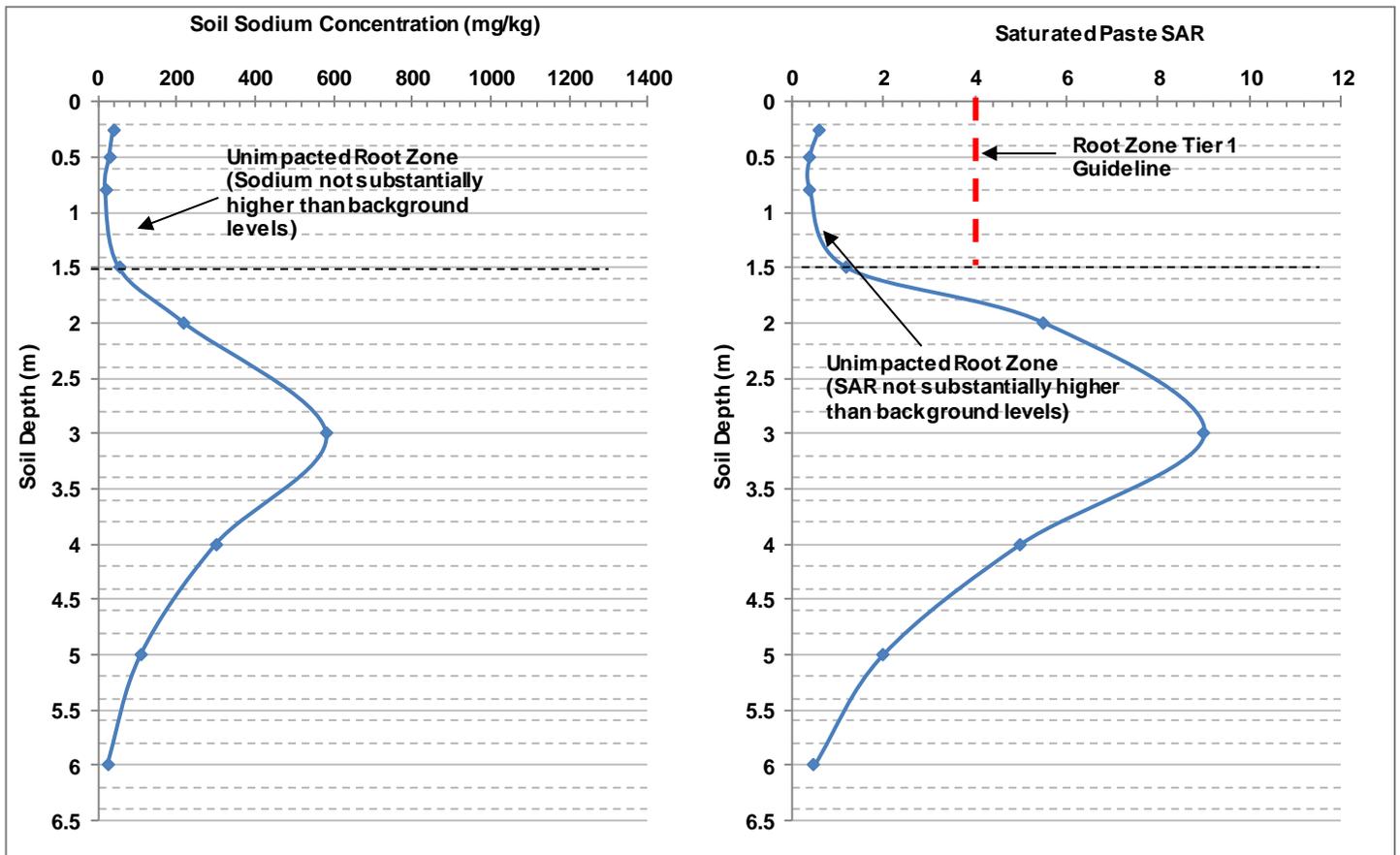
Note that in this example, elevated SAR values are shown to generally correspond to elevated sodium values. While this is frequently the case, there are also common instances where SAR values may be elevated above Tier 1 guidelines but not have sodium levels appreciably above background. In such cases, the elevated calculated SAR value is typically due to calcium and magnesium levels being lower than background levels rather than sodium being particularly elevated. This is a common occurrence in salinity-impacted areas, where historical produced water impacts have displaced calcium and magnesium from soils and much of the residual soluble sodium, calcium, and magnesium have already leached from the root-zone (particularly in coarse soils). Since such cases also pose potential risks to soil structure, they are not generally considered differently from other situations where the elevated SAR is due directly to elevated sodium.

2.8.2 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) or marginally-elevated root-zone SAR, but the root zone EC and SAR do not exceed the Tier 1 SCARG salinity guidelines, and some buffer remains for the future contribution from subsoil chloride or sodium (below 1.5 m) discharging into the root zone.

When performing an SST chloride assessment, 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:

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

Where,

$EC_{AVG\ BACK}$	=	average background EC from 1.0 to 1.5 m based on background borehole data
$EC_{CURRENT\ Cl}$	=	EC due to current chloride impacts (> 100 mg/kg) in the root zone from 1.0 to 1.5 m
$EC_{FUTURE\ Cl}$	=	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 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 from chloride is shown below.

Classification: Public
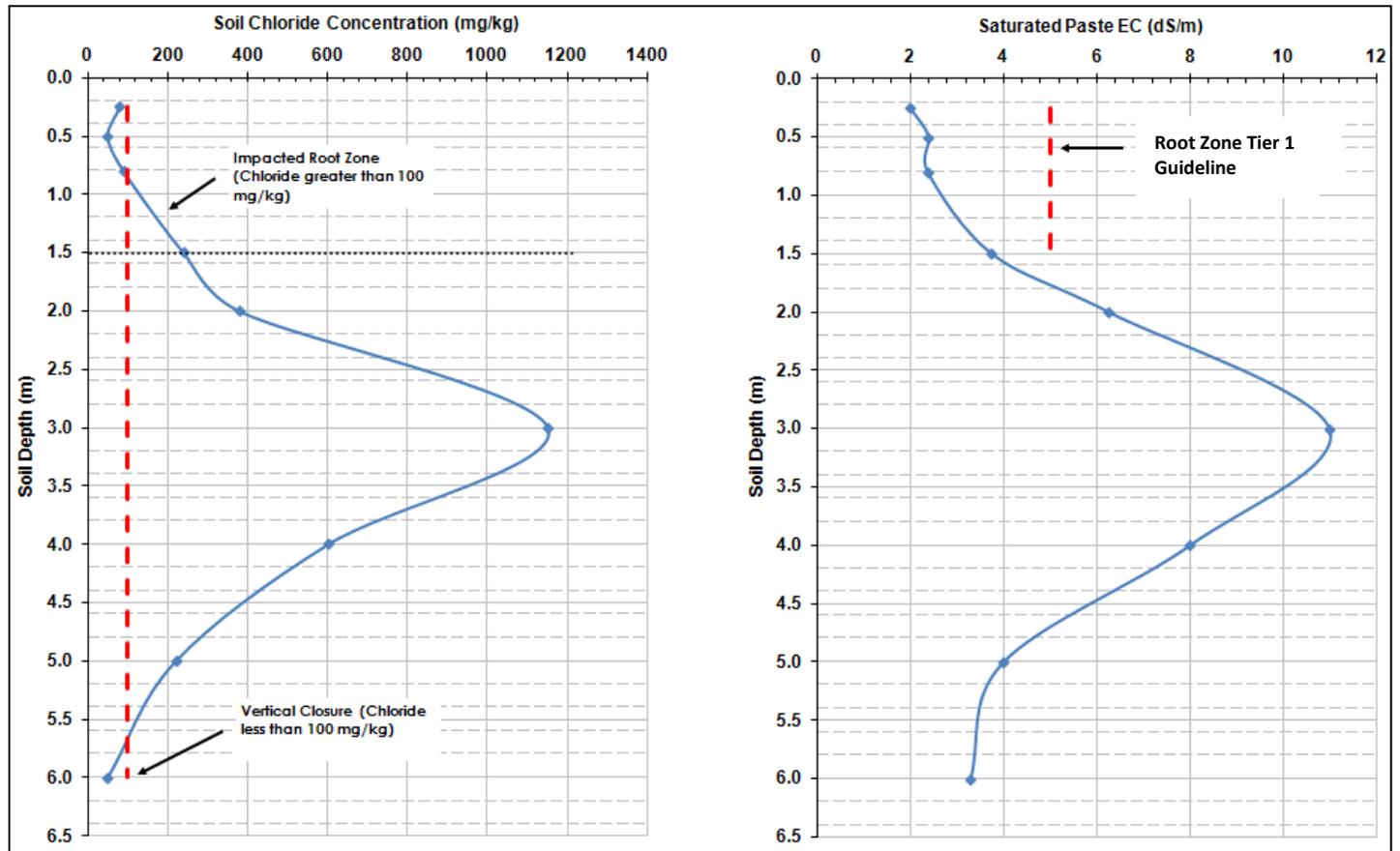
Subsoil chloride guidelines generated with an 'impacted' root-zone scenario will in all cases be less than those generated with a comparable 'unimpacted' root-zone scenario due to the reduced EC buffer to accommodate future upward migration of chloride into the root zone. In the SST Version 3.0, this reduction in guideline is less than what would have been calculated in previous versions due to more detailed chloride transport modeling which takes into account the reduced chloride diffusive gradient between the subsoil and root-zone when marginally elevated levels of chloride are already present in the root-zone.

If performing a subsoil SAR/sodium assessment, the calculations are similar to the unimpacted root-zone scenario but in this case there will be less buffer for the proportional future SAR increase due to the marginally-elevated (but still below Tier 1) SAR levels in the root-zone. The following equation is used to express an impacted root zone scenario for SAR:

$$SAR_{CURRENT} * SAR_{FUTURE\ Na} \leq SAR_{Tier\ 1}$$

Where,

$SAR_{CURRENT}$ = current-day marginally-impacted SAR level from 1.0 to 1.5 m (below Tier 1)

$SAR_{FUTURE\ Na}$ = proportional increase in SAR due to subsoil (> 1.5 m) sodium discharge into the deeper root zone (1.0 to 1.5 m) within the impacted area

$SAR_{Tier\ 1}$ = 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))

An example of a SAR/sodium impacted root zone is shown below, whereby soil sodium and SAR are both elevated above background levels but SAR levels in the root-zone remain below the Tier 1 root-zone SAR guideline.
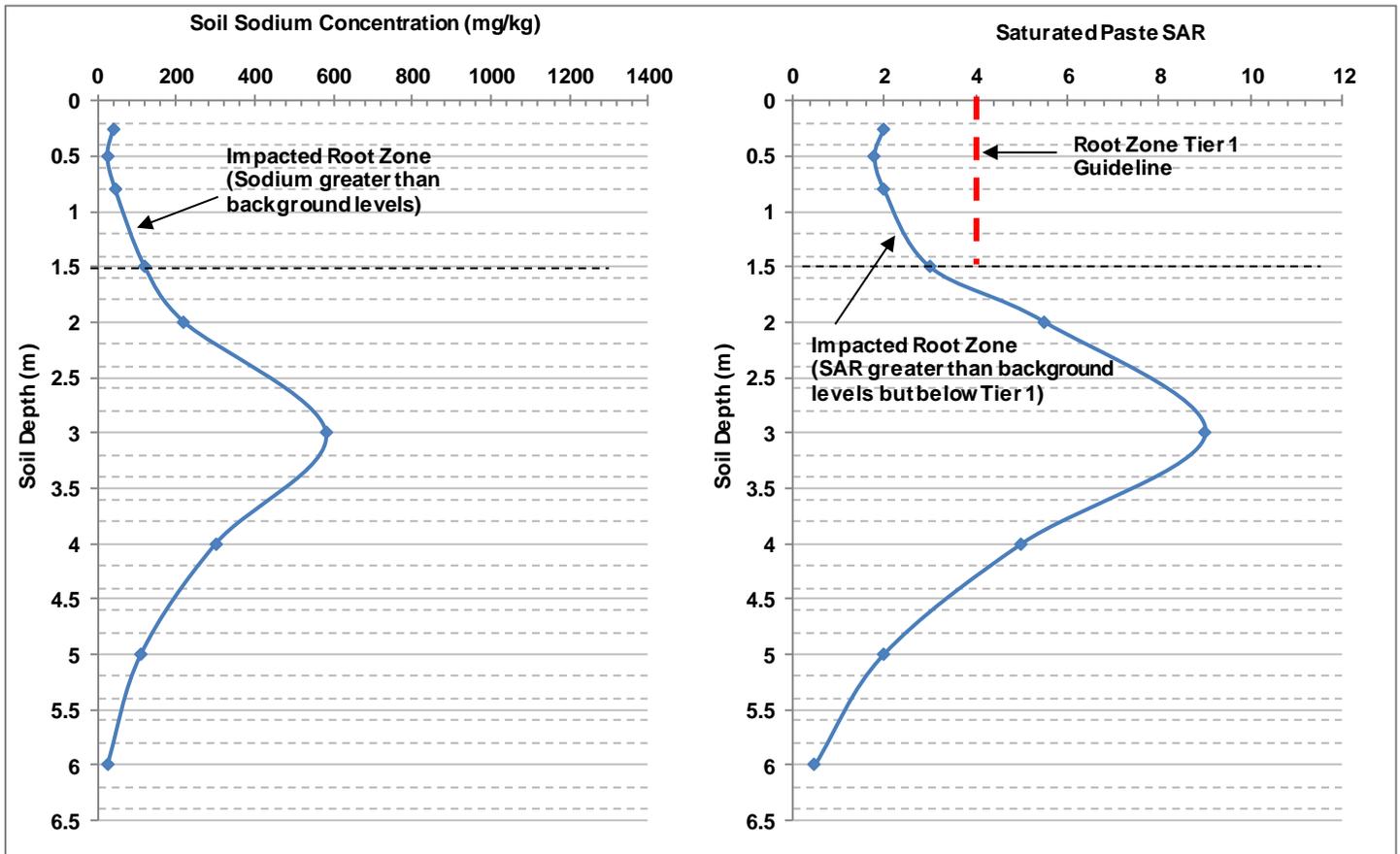
2.8.3 Excavation and Backfill of Root Zone

The excavation and backfill scenario is used for situations where chloride or sodium impacts in the root zone exceed the Tier 1 root zone EC or SAR guidelines (from 1.0 to 1.5 m) and the soil must be excavated. Excavation and backfill may also be considered if root zone EC or SAR are at or near the Tier 1 guidelines leaving no remaining buffer for future EC or SAR increases due to subsoil chloride or sodium discharging into the root zone.

If performing a subsoil chloride assessment, 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:

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

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 exceedances 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.
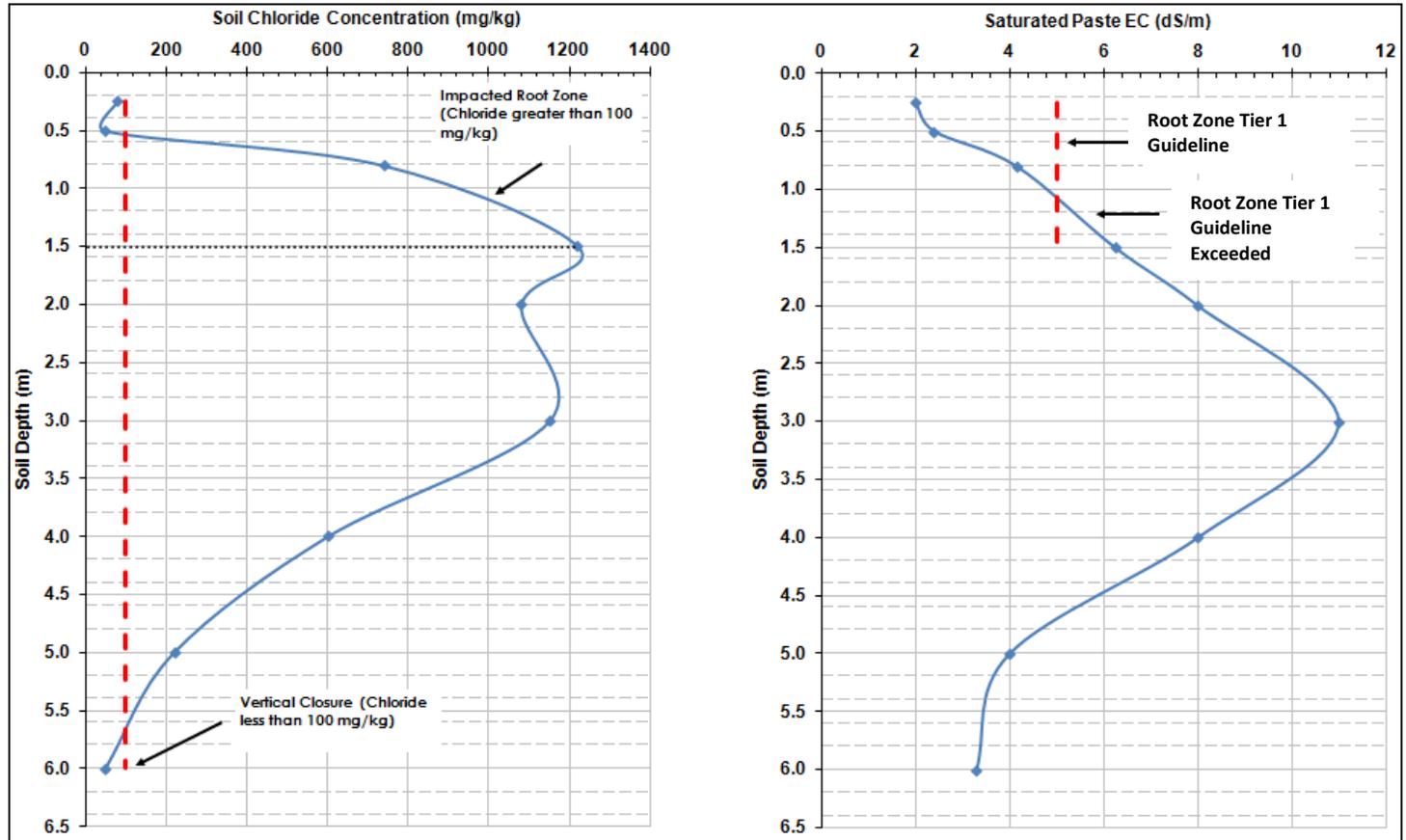
If performing a subsoil sodium assessment, the SAR of backfill material will influence the subsoil sodium SRG produced by the SST for protection of the root zone, where a lower backfill SAR results in a greater subsoil sodium SRG due to a greater SAR buffer within the root zone. The SST will calculate automatically a subsoil sodium SRG using the average SAR 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:

$$SAR_{AVG\ FILL} * SAR_{FUTURE\ Na} \leq SAR_{Tier\ 1}$$

Where,

EC$_{AVG\ FILL}$	=	average backfill material SAR placed from 1.0 to 1.5 m based on backfill chemistry sampling
SAR$_{FUTURE\ Na}$	=	proportional increase in SAR due to subsoil (> 1.5 m) sodium discharge into the deeper root zone (1.0 to 1.5 m) within the impacted area
SAR $_{Tier\ 1}$	=	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))

An example of an excavation and backfill scenario for SAR/sodium is provided below. The charts show root zone SAR exceedances above the Tier 1 guideline 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 sodium transported upward from subsoil.
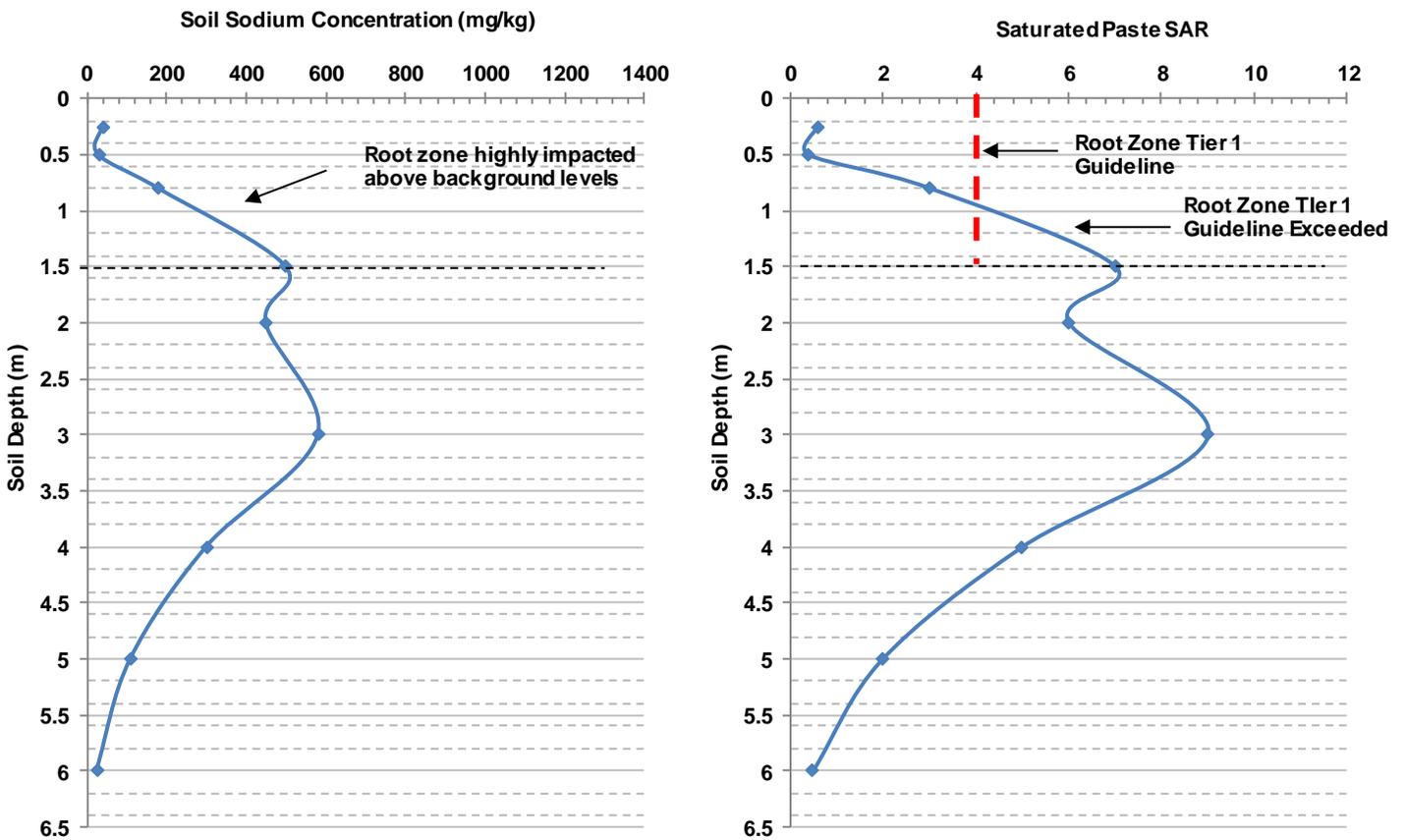
⚠️ *Regardless of whether a chloride or SAR/sodium assessment is being performed in the SST, samples must be collected from backfill material and analyzed for salinity and texture parameters. Backfill chemistry and texture must be documented. The texture and chemistry of the backfill should be similar to native background material at an equivalent depth. For example, if the average background texture is coarse 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 and/or SAR. Contact AER/AEP or review appropriate AER/AEP guidance regarding reclamation requirements for the 0 to 1.5 m depth interval.*

2.8.4 Contribution from Subsoil Sulphate Toward Future Root Zone Salinity

For protecting future root-zone EC, 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.

2.8.5 Role of Cation Exchange in Sodium Transport into Root Zone

When performing the vertical chloride transport modelling to evaluate future root-zone salinity risk from chloride, cation exchange reactions do not need to be considered since chloride is considered a 'conservative tracer' which does not interact with other soil constituents. In that scenario, an equivalent amount of cations are transported along with the chloride to maintain charge balance, though the details of which cations are being transported (*i.e.*, the particular mixture of primarily sodium, calcium, and magnesium) is not of concern since they all contribute to EC in a similar manner.

In contrast, when performing a subsoil SAR assessment, the risk to the root zone is influenced by not only by direct sodium transport but also by the cation exchange reactions which accompany it. These cation exchange reactions are influenced by the initial EC and SAR conditions in the root zone, and thus influenced by the particular root zone scenario selected and properties entered for background, backfill, or initial root zone impacts. These cation exchange reactions also result in some 'buffering' of changes in SAR due to the release of calcium and magnesium as sodium enters initially unimpacted soil. A schematic showing cations exchanged on the surface of a clay particle is shown below, along with the corresponding dissolved cations present in pore water which are measured on a saturated paste basis.

Schematic showing cations exchanged onto clay particle
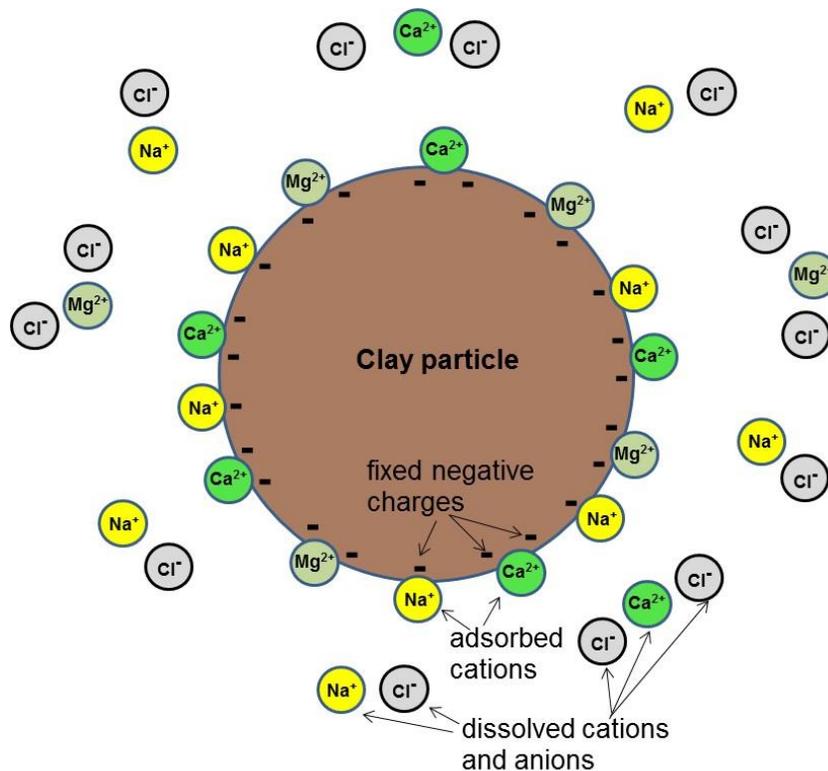
As an example of these cation exchange reactions, an 'excavation and backfill' scenario can be visualized whereby a root zone with initial Tier 1 EC or SAR exceedances is excavated and replaced with backfill in the 'Good' category for both EC and SAR. Elevated sodium in subsoil is then modelled to transport upward into the backfill from a combination of advection, dispersion, and diffusion. As sodium cations move to the low-sodium root zone, they exchange with calcium and magnesium ions on the soil cation exchange complex. This results in a general 'slowing down' or attenuation of sodium transport relative to chloride, with SAR values thus also changing more slowly than chloride. Further details of these cation exchange transport effects are provided in the Technical Manual.

The attenuation and slowing of sodium transport in relation to chloride is a strongly related to clay content. The high surface area and negative surface charges of clay minerals influence the cation exchange capacity (CEC) of soils. Due to these cation exchange effects, clay content data (via hydrometer) is required in addition to the sieve data to generate subsoil SAR or sodium guidelines using the SST Version 3.0.

2.9   Vertical Impact Thickness (Top and Bottom of Impact)

The vertical thickness of chloride impacts and sodium impacts may be different, and each must be evaluated separately depending on whether subsoil chloride guidelines or subsoil sodium guidelines (or both) are being generated.

2.9.1   Chloride Impact Thickness

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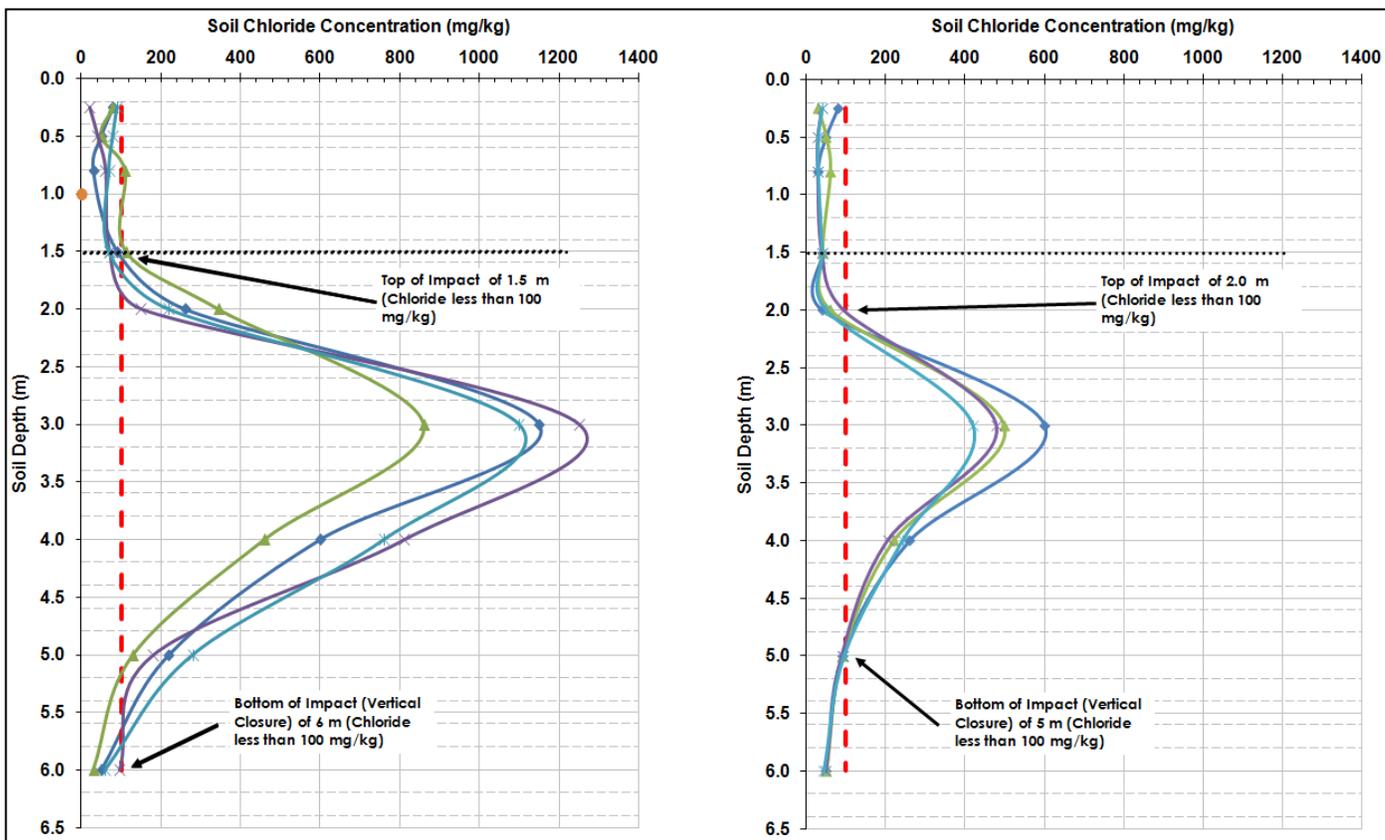
⚠️ *These charts provide suitable examples for the documentation of chloride chemistry in soil, highlighting vertical closure, grouped by unique areas of impact.*

⚠️ *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 Chloride Impact using 95% Vertical Mass Calculation

Estimates of the top and bottom of impact can be refined by determining 95% of the vertical mass, per SubArea, or for the entire site if only one SubArea is considered. *This approach is only available for vertical delineation; 95% lateral mass calculations are not accepted for Version 3.0 of the SST.* Four boreholes are required per SubArea when a 95% vertical

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mass calculation is to be conducted. 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.

The concept is illustrated below with an example calculation and supporting data. Four chloride profiles (boreholes) are shown for a SubArea, with chloride concentrations ranging up to 1,450 mg/kg. When using 100 mg/kg for vertical delineation, the top of subsoil impact is 1.5 m and the bottom of impact is 6.0 m (closure obtained at 6 m with chloride < 100 mg/kg for all boreholes/profiles). The bottom of impact is placed at 6 m because there are no data between 5.0 and 6.0 m to identify exactly where soil concentrations reach 100 mg/kg.

In order to refine the depth of vertical impact using the 95% vertical mass calculation, data from adjacent sample depths are averaged across the four boreholes to obtain an average concentration for that depth increment. For example, 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. This is represented in the diagram below by the dashed purple line with data and calculations shown in the following table. Data from the 0 to 1.0 m interval are not included in the calculation because any exceedance of Tier 1 will be dealt with separately. Data from 7 m and deeper depths are not included in the calculation because the concentrations are less than 100 mg/kg. Data from the base of the root zone (*e.g.*, 1.0 to 1.5 m) is combined with data from 2.0 m. Data not included in the calculation are shown as grey text in the table below – data used are shown in black text. Using the 95% mass concept, the 5.0 to 6.0 m depth interval represents 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).

Classification: Public
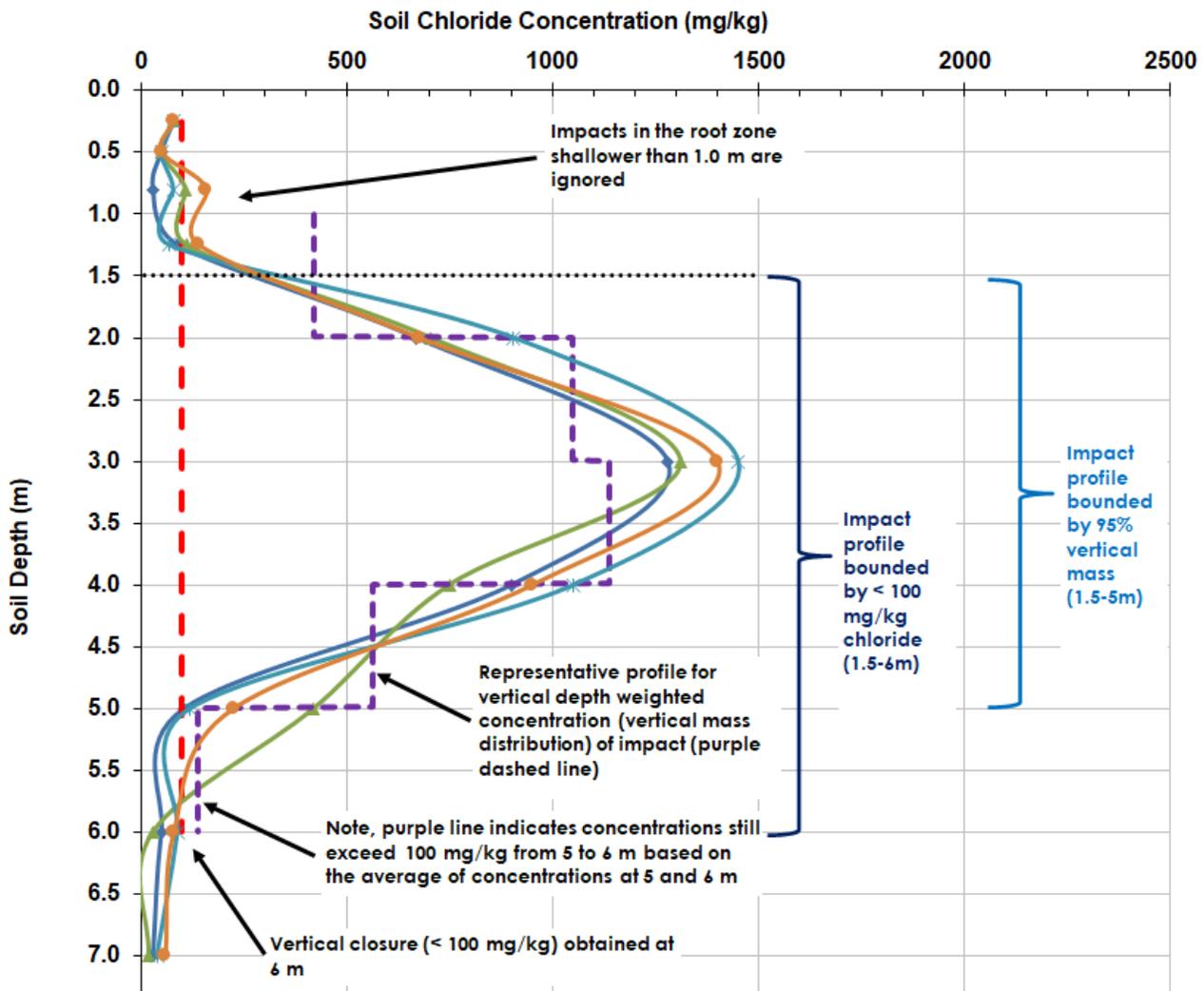
95% Vertical Chloride Mass Calculation

Sample Depth (m)	BH-01 Chloride (mg/kg)	BH-02 Chloride (mg/kg)	BH-03 Chloride (mg/kg)	BH-04 Chloride (mg/kg)	Average 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.*

Subsoil Depth Intervals with Minimal Chloride Impacts

There may occur situations where a subsoil depth interval has chloride concentrations less than 100 mg/kg but is bounded by impacted soils above and below. For example, this situation may occur if one area with shallow impacts overlies a deeper groundwater plume of chloride. Or, this situation could potentially occur when there are chloride impacts in fine soils located both above and below a coarse-grained interval, and any impacts formerly in this coarse-grained interval have been transported away either vertically or laterally. To distinguish between such cases, examining the impact data along with other relevant data such as textural layering is important to understanding the relevant transport mechanisms. If for instance soils are generally uniform in texture, then the presence of deeper impacts separated by a cleaner layer may be indicative of a second upgradient source which may not have been identified or fully characterized. Alternatively, in the scenario with fine/coarse/fine layering, there may be no additional chloride impacts either upgradient or downgradient. Ensuring all impact sources and areas have been identified and characterized is important for any SST assessment, and this determination when unusual impact patterns are present can be guided by additional considerations such as textural layering, sodium / chloride ratios in impact vs background areas, or the presence of elevated SAR as a potential indicator of historical source areas.

In cases where this interval with minimal impacts is consistent across the site and there are no unidentified sources, this minimally-impacted interval can in some cases be excluded from the vertical mass and a shallower bottom of impact can be input into the SST. An example is provided in the figure below. Chloride concentrations from 4.0 to 6.0 m are less than 100 mg/kg. 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, the same depth increment (2.0 m) must be subtracted from the DUA depth (*e.g.,* if the depth to a DUA has been determined to be $\geq$ 15 m, the DUA depth should be entered into the SST as 13 m (15 m minus 2.0 m) to ensure the appropriate buffer thickness is still incorporated). The applicability of this approach requires professional judgement, and should generally only be used when there is a single consistent SubArea at a site, or if multiple SubAreas are present, all SubAreas show the same pattern of an interval with minimal impacts. In cases where some SubAreas show this pattern and others do not, the DUA depth parameter cannot be selectively adjusted for some areas and thus the approach cannot be implemented within the SST (unless a Tier 2C approach is used).
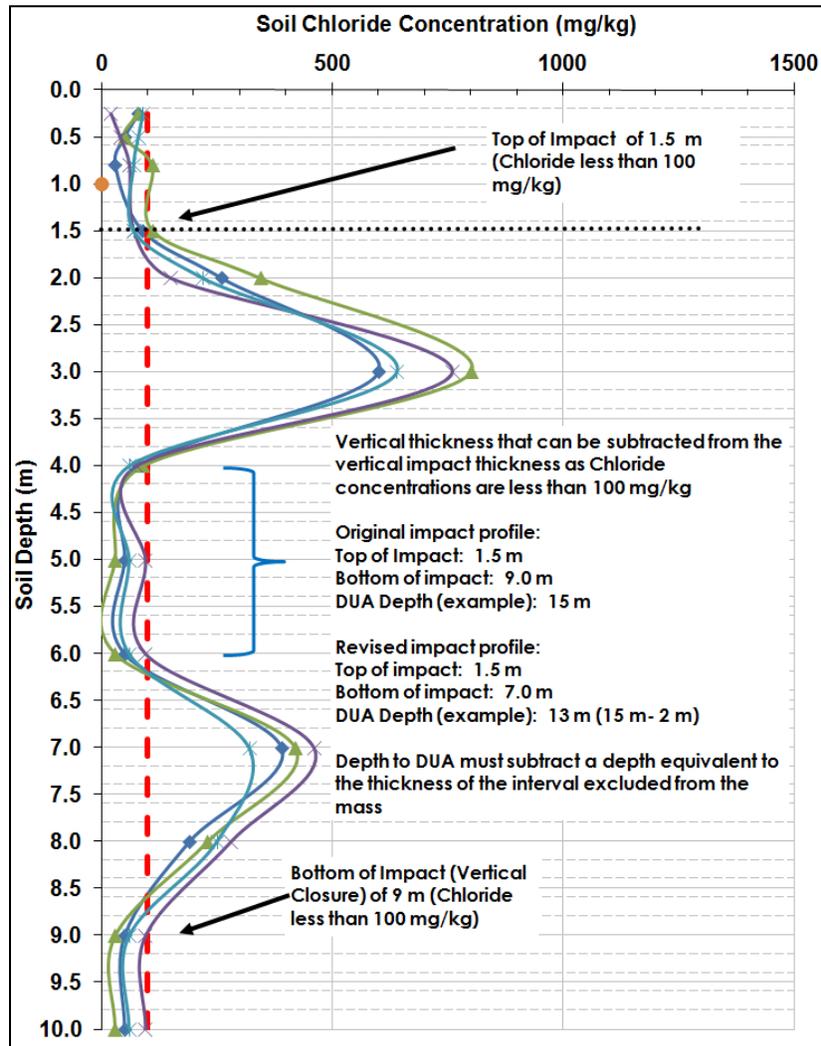
2.9.2 Sodium Impact Thickness

While sodium depth profiles may sometimes be of value in determining sodium impact thickness (analogous to chloride), there is typically no clear numerical boundary between 'impacted' and 'unimpacted' sodium concentrations. This is particularly since background sodium concentrations may vary substantially between sites, boreholes, and depth intervals, and there is thus no benchmark sodium concentration analogous to the 100 mg/kg benchmark for chloride which can be used to represent a typical sodium impact. Consequently, when performing a subsoil sodium assessment, it is important to characterize background subsoils as well as root-zone soils for SAR in order to have additional context for typical background subsoil SAR levels. The sodium impact thickness can then be based on the deepest depth interval where Tier 1 SAR exceedances are observed, with intervals which have SAR values below the corresponding subsoil Tier 1 SAR guideline considered to pose minimal risk of excessive upward sodium migration into the root-zone. Subsoil sodium/SAR impacts deeper than 6 m are also generally considered to pose minimal risk of upward sodium transport into the root-zone due to the slowed sodium transport relative to chloride.

2.10 Lateral Groundwater Transport

Within the SST, lateral transport of salt through groundwater is modelled for its potential influence on shallow groundwater (relevant to aquatic life) and deeper groundwater (relevant to the DUA). This is primarily relevant to chloride, as sodium will also undergo lateral transport but at slower rates than chloride (sodium thus not considered a primary risk driver for the aquatic life and DUA pathways). Both chloride and sodium also have the potential to enter a dugout through shallow groundwater, most typically an assumed future dugout installed within the impact area in agricultural land (relevant to both chloride and sodium). Chloride may also be transported laterally from non-agricultural land to adjacent agricultural land with a potential future dugout at the agricultural land boundary (this pathway considered negligible risk for sodium due to the slower transport relative to chloride). More details of lateral groundwater transport (primarily of chloride) are shown below.

Lateral chloride 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 porosity. This is represented by 'Darcy's Law' as per the equation below, where the calculated groundwater velocity is displayed by the SST for both shallow and deep groundwater based on the user-entered hydraulic values. Note that for DUA calculations (and drainage rates), a 'Darcy Velocity' (flux) is calculated instead of a linear groundwater velocity by using the same equation but without the total porosity.

Groundwater Velocity= (Hydraulic Conductivity x Hydraulic Gradient) / (Total 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.

2.10.1 Lateral Groundwater Bearing Zones and Parameters

Three lateral 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 brief description of these groundwater bearing zones is provided below:

Shallow groundwater
Describes the shallowest saturated intervals below the water table (as a rule of thumb, down to approximately 5 m below the water table). This interval is relevant to lateral chloride flow toward FAL receptors, and potentially relevant to chloride or sodium flow into a dugout assuming the water table isn't deeper than 6 m. Hydraulic conductivity and gradient data from wells which describe these intervals can thus be used for shallow groundwater in an SST Tier 2B assessment, or default values used in a Tier 2A assessment.

Deep groundwater
Describes the deeper saturated intervals below the impacts through which chloride impacts must travel as they leach downward toward the DUA. Relevant only to the DUA pathway, and influences only horizontal flow (horizontal smearing during vertical transport) and doesn't directly influence vertical flow. Hydraulic conductivity and gradient data from wells which describe these intervals can thus be used for deep groundwater in an SST Tier 2B assessment, or default values used in a Tier 2A assessment.

DUA
Describes a saturated interval (either identified or assumed) which meets the criteria of a Domestic Use Aquifer as defined in AEP 2019a (and summarized in Section 2.10.4). Parameters describing this water bearing zone are relevant only to the DUA pathway and do not influence other pathways. Hydraulic conductivity and gradient data from wells which describe the DUA can be used in an SST Tier 2B assessment, or default values used in a Tier 2A assessment or a Tier 2B assessment in which the DUA has not been identified or characterized.

A summary of SST input parameters for the DUA and shallow and deep groundwater bearing zones is shown below, including the relevant risk pathways for each zone:

Lateral Groundwater Bearing Zones and Parameters

Parameter	Shallow Groundwater Input	Deep Groundwater Input	DUA Input
Risk Pathway	Aquatic life or dugout risk	DUA risk	DUA risk
Depth of Water Bearing Zone	Tier 2A: estimated from soil lithology; Tier 2B: measured from monitoring well data (3 or more wells)	Same as shallow groundwater	Tier 2A/B: Maximum depth of drilling, or coarse saturated interval $\geq$ 0.5 m thick identified during drilling; or, Tier 2B: DUA depth confirmed by monitoring well data screening across potential DUA unit
Hydraulic Conductivity	Tier 2A: defaults of 1×10^{-6} m/s fine soils, 1×10^{-5} m/s coarse soils; Tier 2B: default, or maximum of measured values if 3 wells, or arithmetic mean of measured values if $\geq$ 4 wells	Tier 2A: defaults of 5×10^{-9} m/s fine, 5×10^{-8} m/s coarse; Tier 2B: default, or arithmetic average of measurements from $\geq$ 3 deep groundwater wells	Tier 2A: default of 1×10^{-6} m/s; Tier 2B: default, or arithmetic average of $\geq$ 3 wells screened across the DUA
Hydraulic Gradient	Tier 2A: default of 0.028 m/m; Tier 2B: default, or average of measured values from $\geq$ 3 wells on two or more distinct sampling events (e.g., July, November)	Tier 2A: default of 0.028; Tier 2B: default, or average of measured values from $\geq$ 3 wells on two or more distinct sampling events (e.g. July, November)	Tier 2A: default of 0.028 m/m; Tier 2B: default, or average of measured values from $\geq$ 3 wells on two or more distinct sampling events (e.g., July, November)
SubArea Source Dimensions	5x5 m up to 100x100 m (some modeling performed on 15x15, 25x25, 35x35, 50x50, 75x75, or 100x100 m dimensions)		
Lateral Distance to Aquatic Life	100 to 1,000 m for >50x50 m total area / 50 to 1,000 m for 25x25 to 50x50 total area / 25 to 1,000 m for ≤25x25 m total area	NA	NA
Lateral Distance to Dugout	0 m; > 0 m for non-agricultural land 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
Background 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; irrigation pathway eliminated if >1,280 diluted background TDS in dugout water; livestock pathway eliminated if >3,000 diluted background TDS in dugout water.	NA	If > 4,000 mg/L, pathway is eliminated for that interval. Consider next deeper potential DUA interval.

Classification: Public

2.10.2 Shallow Groundwater Model (Aquatic Life Risk)

Shallow groundwater represents the water bearing zone involved with the transport of salt ions (primarily chloride) towards an aquatic life receptor (potentially a highly permeable layer such as a sand lens, 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 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 exceedance 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.
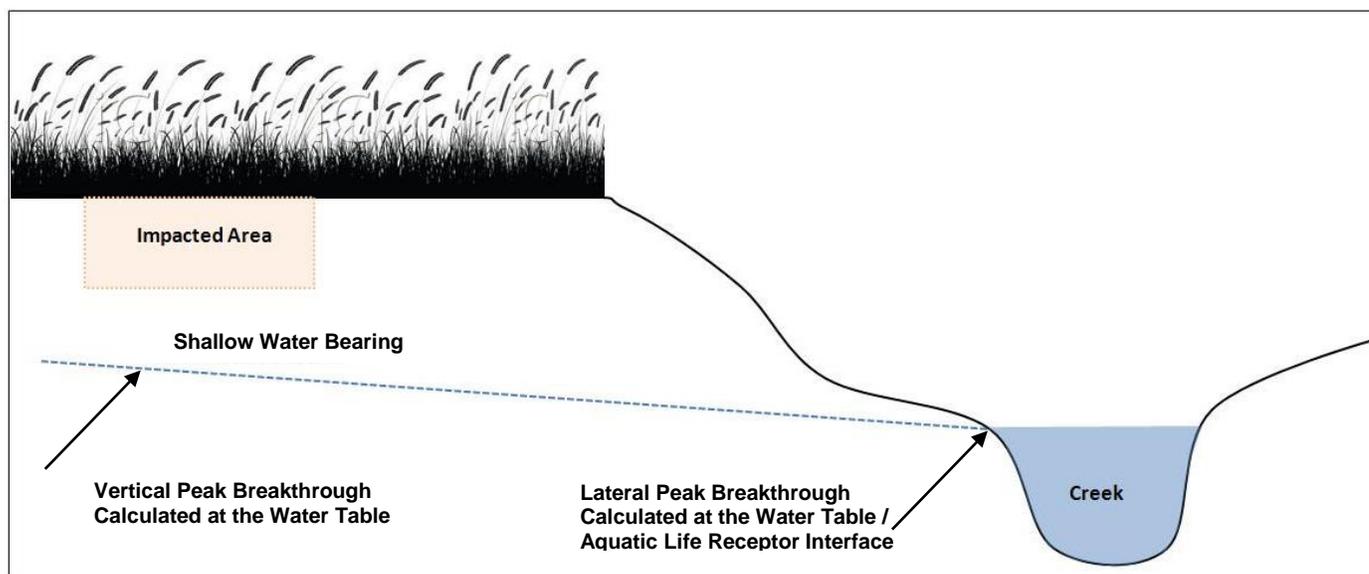
- The SST considers diffusion and dispersion in three dimensions (capped or limited in the Z-direction) as a chloride plume is transported laterally towards an aquatic life receptor via shallow groundwater flow; and,
- The 3DADE model was used to simulate peak chloride concentrations at a potential aquatic 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.
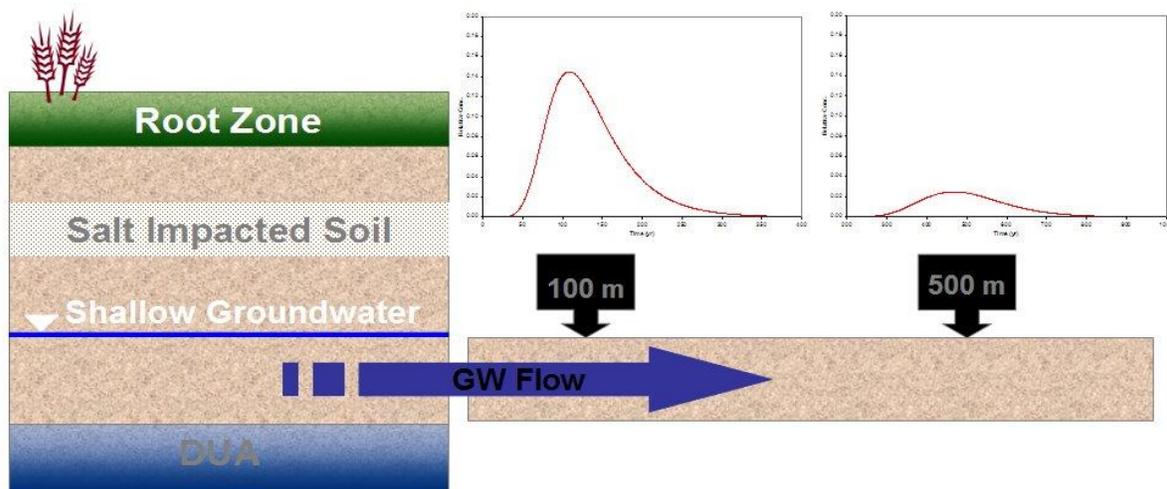
Note that for the generation of these shallow groundwater breakthrough curves, the shallow groundwater velocity calculated by the SST is conservatively rounded upward to the next highest of a specific set of values (0.1, 0.25, 0.5, 1.0, 1.9, 2.5, 5.0, 10.0, 15.0, 20.0, and 25.0 m/year). If for a given scenario the modeled peak breakthrough concentration occurs after 1,000 years (maximum time horizon for the SST), then the concentration at 1,000 years is used as the peak.

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.

For cases where multiple subareas are modelled to be loading onto the same aquatic life receptor, 'Buffer Allocation Factors' are also incorporated into the shallow groundwater model to ensure adequate receptor protection. Additional details about subareas and Buffer Allocation Factors are provided starting in Section 2.13.

For cases with multiple subareas, the shallow groundwater model also incorporates a neural network adjustment to the Buffer Allocation Factors. This neural network adjustment improves modeling accuracy and reduces excessive model conservatism, particularly in situations involving relatively nearby aquatic receptors and larger source dimensions. Additional details of the neural network adjustment are provided in the Technical Manual.

2.10.3 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.

Example with Fast Deep Groundwater
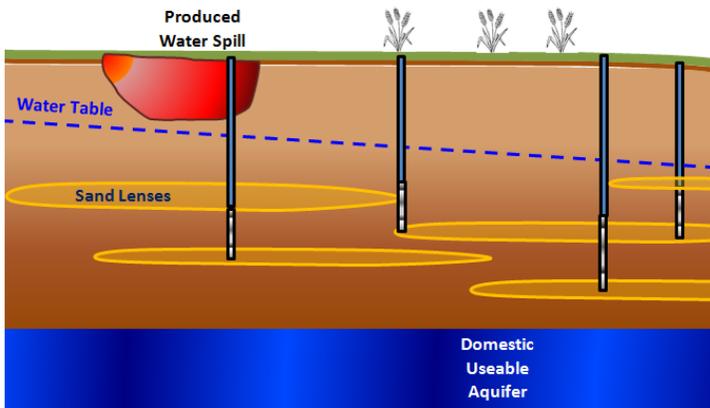
Example with Fast Deep Groundwater
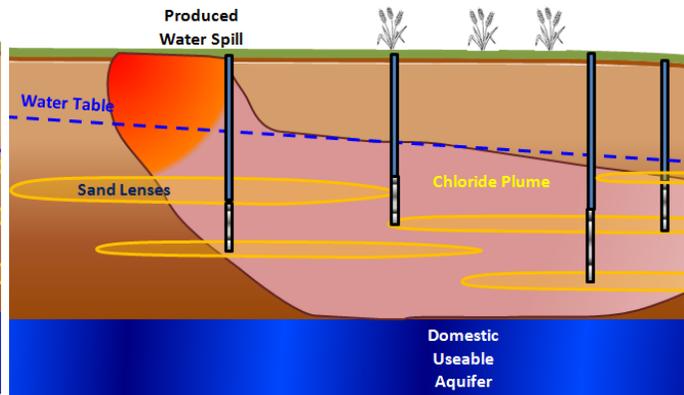
Example with Slow Deep Groundwater
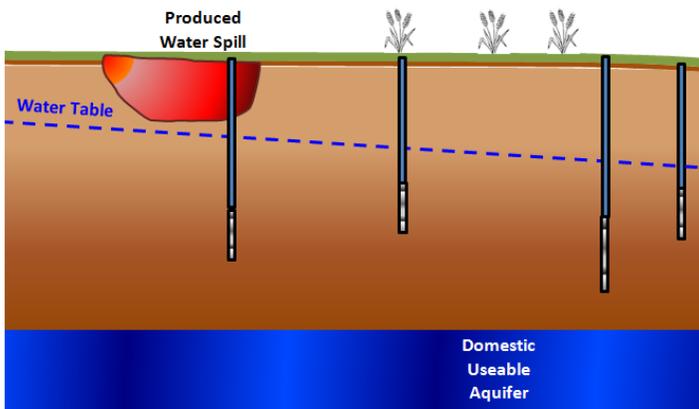
Example with Slow Deep Groundwater
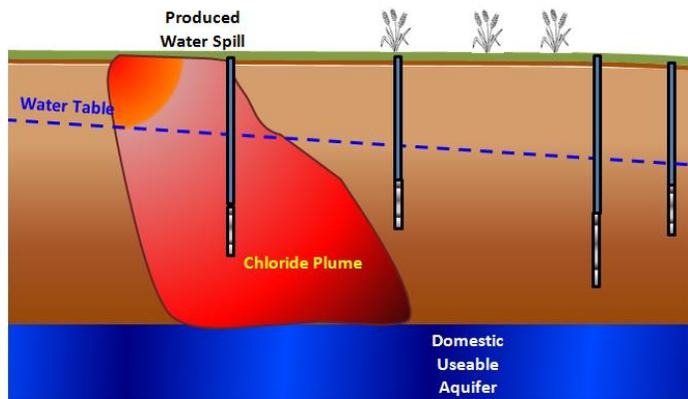
- The SST considers diffusion and dispersion in three dimensions (capped in the Z-direction) as a chloride plume leaches downward towards a DUA; and,
- 3DADE is used to simulate the reduction in peak breakthrough concentrations at a potential DUA depth caused by lateral groundwater flow and plume spreading 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,
- Increase in effective source length at surface of DUA due to lateral spreading in deep groundwater;

2.10.4 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 to the DUA is used to define the buffer thickness for this pathway. Situations where background-related TDS concentrations exceed 4,000 mg/L in a DUA indicate that this particular DUA interval may be excluded, but a deeper DUA cannot be ruled out. 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 AEP (2019a) 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.

2.10.4.1 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 AEP (2019a) 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 monitoring well data is collected to characterize a potential DUA, both arithmetic and geometric mean hydraulic conductivity values are calculated. The arithmetic mean hydraulic conductivity value is used to screen whether the unit should be assessed as a DUA in the SST. If the arithmetic mean is greater than or equal to 10^{-6} m/s, the unit is considered a DUA, otherwise it is not. 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.

2.10.4.2 Depth of DUA and Vertical Transport Buffer Calculation

As chloride leaches 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 between the maximum impact depth (5 m based on 100 mg/kg chloride) and the top of 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.
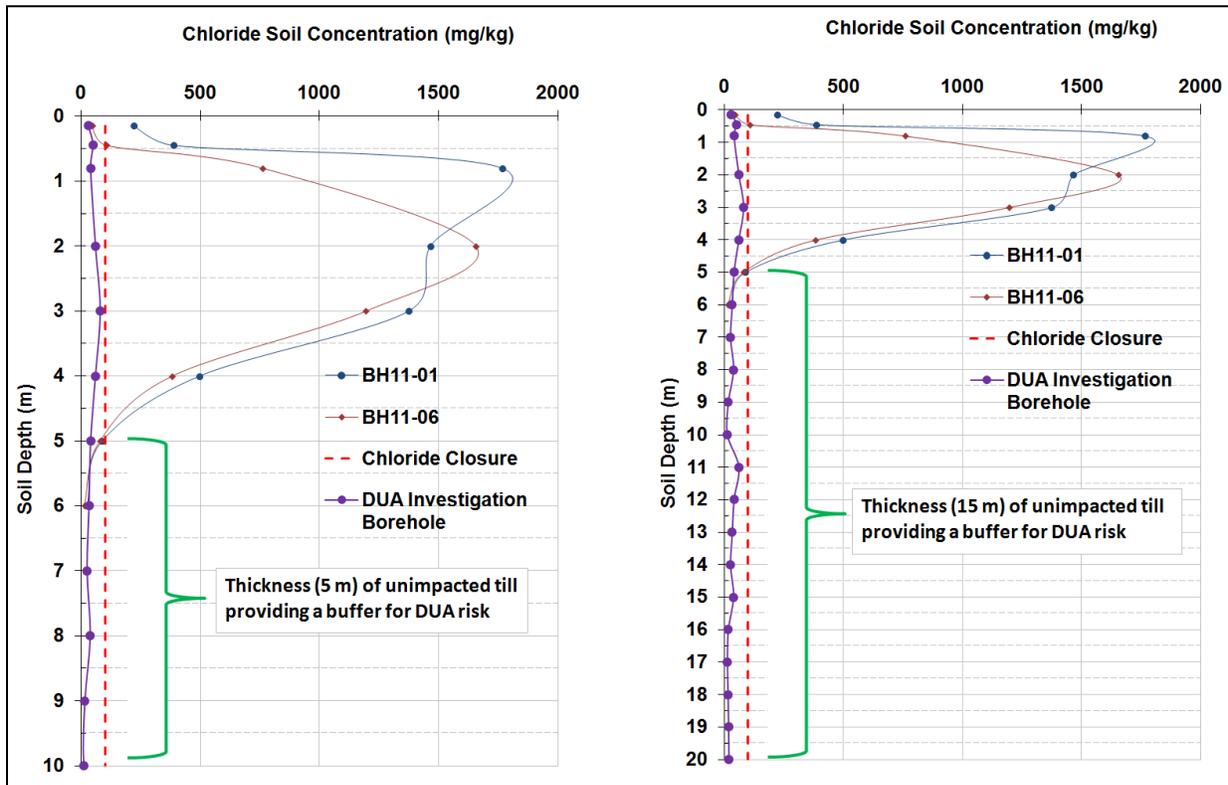
2.10.4.3 DUA Chemistry Buffer Based on Background Chloride Concentrations

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 must not lead to an exceedance of the 250 mg/L AEP (2019a) 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:

$$DUA_{Cl\,BUF} = DWQG_{Cl\,DUA} - BWC_{Cl\,DUA}$$

Where,

$DUA_{Cl\,BUF}$	=	Chemistry Buffer (mg/L) for chloride in the DUA – used to calculate a SRG for chloride protective of the DUA pathway
$DWQG_{Cl\,DUA}$	=	Drinking Water Quality Guideline for chloride in a DUA (250 mg/L; AEP 2019a)
$BWC_{Cl\,DUA}$	=	Background Water Concentration for chloride in a DUA (30 mg/L default, or determined from site-specific measurements)

Note that this DUA buffer calculation is provided as context to aid visualization of the conceptual model. Version 3.0 calculates the actual dilution of chloride within the DUA in a slightly different manner than previous versions. When the DUA buffer is large (approximately 220 mg/L or more), the calculation results are similar for Version 3.0 and previous versions. When the DUA buffer is smaller (less than approximately 220 mg/L), the dilution calculation performed by Version 3.0 (Summer's mixing model) is more accurate and less conservative than in previous versions. More detail on the Summer's mixing model is provided in the next section.

Note, if the background chloride concentration measured in the DUA is within 10% of the 250 mg/L guideline (*i.e.* >225 mg/L), or is greater than the guideline, the user must default to a Tier 2C approach since a minimal residual buffer is present.

Classification: Public

2.10.4.4 DUA Dilution Factor and Mixing Model

Dilution of chloride-laden porewater as it leaches into DUA from overlying till is calculated using the US EPA Summers mixing model (US EPA 1996). In cases where the background chloride concentration in the DUA is known to be (or assumed to be) relatively low (*i.e.*, near the default of 30 mg/L, or a DUA buffer or 220 mg/L or more), the dilution is similar to what would be calculated by the 'Dilution Factor' equation from AEP (2019a):

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

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.

In cases where the background chloride concentration in the DUA is higher than the default (and thus has a lower DUA buffer), the dilution calculation performed by the SST Version 3.0 produces more accurate values than the above equation which assumes negligible background DUA chloride concentrations. The dilution calculations within Version 3.0 utilizes the US EPA 'Summers mixing model' approach, whereby the mass fluxes of both chloride and groundwater are mixed between the DUA and leachate to estimate the final DUA concentration as shown below:

$$C_{DUA\_Final} = \frac{Q_L \times C_L + Q_A \times C_{DUA\_init}}{Q_L + Q_A}$$

Where,

C_{DUA_Final}	= Tier 1 Water Quality Guideline for human drinking water in DUA (mg/L)
C_L	= leachate chloride concentration (mg/L) from vertical transport modeling
C_{DUA_init}	= initial chloride concentration in DUA (mg/L)
Q_L	= vertical flux of leachate into the DUA (determined by drainage rate)
Q_A	= lateral flux of groundwater into DUA (determined by DUA properties)

Note that the above formula relates specifically to a single impact subarea, with a similar but more complex implementation of this formula used for multiple subareas as shown below. Additional details are provided in the Technical Manual.

Area 1

Source length, X1 (m)

Area 2

Source length, X2 (m)

Infiltration rate flux, I (m/yr)
C_{L1}

Infiltration rate flux, I (m/yr)
C_{L2}

$$C_{DUA\_Final} = \frac{(Q_{L1} \times C_{L1}) + (Q_{L2} \times C_{L2}) + (Q_A \times C_{DUA\_init})}{Q_{L1} + Q_{L2} + Q_A}$$

Mixing thickness (2 m)

DUA flux, V (m/yr)
$C_{DUA\_init} \neq 0$ (mg/L)

DUA output from Area 1
= DUA input to Area 2

Flux out (m/yr) = $X_1*I + X_2*I + V*Z$

Expanded Stepwise Summer's Mixing Model
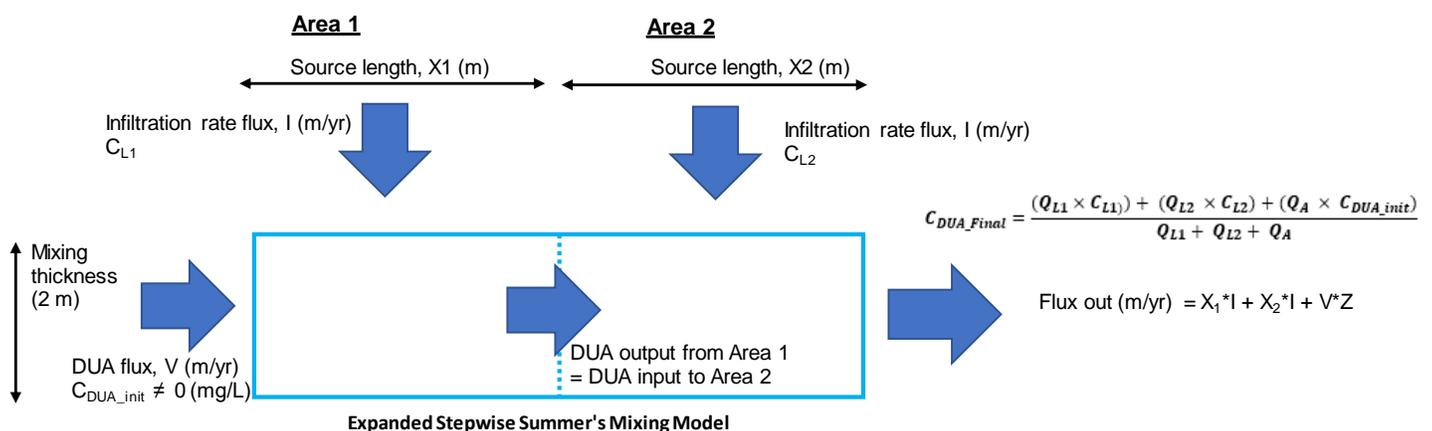
2.11 Dugouts

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 are assumed to be used for livestock watering and plant irrigation purposes. This is in alignment with AEP (2019a) 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 to 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 (i.e, non-Agricultural land) that are situated immediately adjacent of Agricultural land, the attenuation over the lateral transport to the agricultural property boundary is considered in a manner identical to the approach for aquatic life. A graphical example is provided below. The risk of sodium lateral transport to a potential future dugout on adjacent land is considered minimal, and protected sufficiently by the subsoil chloride guideline for this pathway.
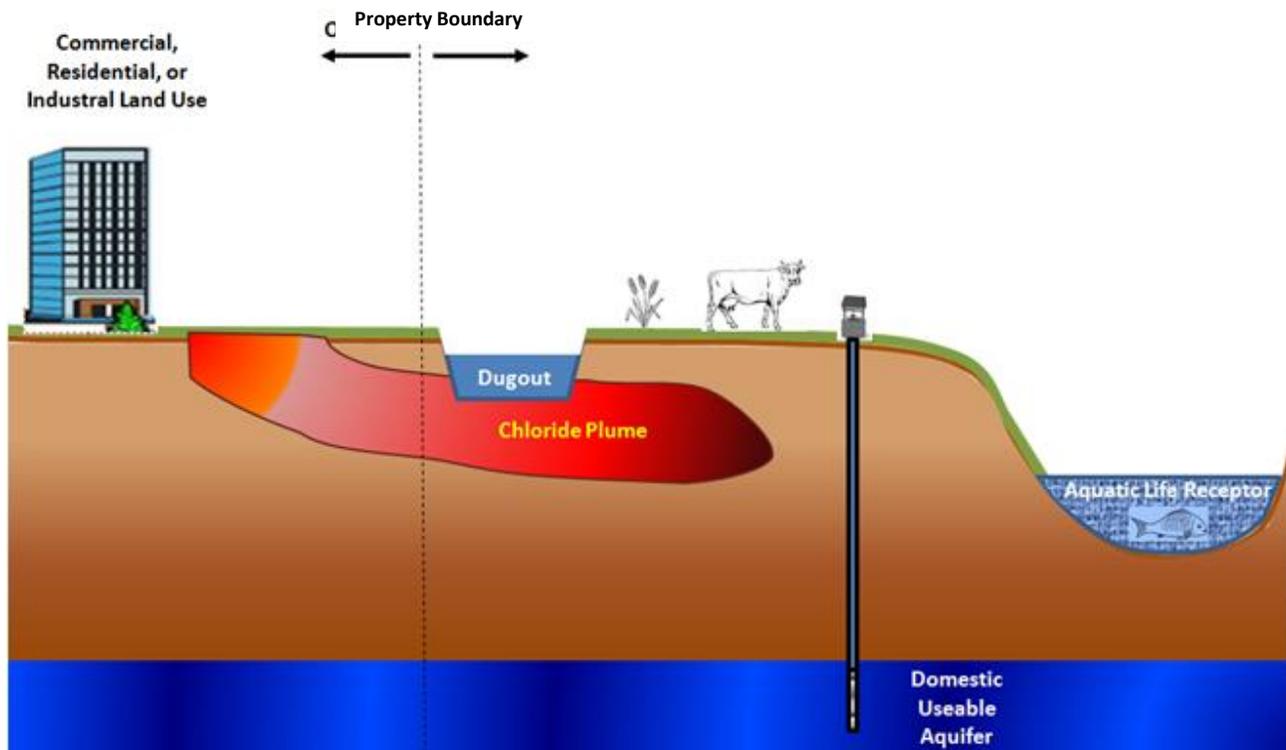
This pathway also applies to Natural lands adjacent to Agricultural lands

⚠️ ***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***

2.11.1 Dugout Pathways Elimination

A maximum dugout depth is assumed to be approximately 6 m (21 feet) based on dugout construction protocols described in Alberta Agriculture and Forestry (2015). Situations where the seasonal average groundwater table is greater than 6 m results in elimination of the dugout pathway for both livestock watering and irrigation water since interactions between potentially impacted groundwater and the dugout are considered negligible. There are also upper bound salinity (TDS) limits that result

in pathway elimination, when background groundwater TDS is sufficiently elevated that water collected in a dugout (taking into account mixing with surface runoff) would be a poor resource for livestock watering (>3,000 mg/L) or irrigation (>1,280 mg/L).

2.11.2 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. As in previous versions of the SST, coarse-grained soils with faster groundwater velocity generally result in higher groundwater loading to the dugout (a lower adjustment factor), than fine-grained soils with slower groundwater velocity (a higher adjustment factor).

The following variables were used to estimate adjustment factors for the dilution of groundwater discharging into a dugout due to mixing with runoff and precipitation. The adjustment factors were used to determine guidelines for 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 shallow hydraulic conductivity for groundwater discharge into the dugout; and,
6. Groundwater inflows (hydraulic gradient) and groundwater level 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 Alberta Agriculture (2015) document "Quality Farm Dugouts"; and,
- Dugout evaporation methodology from ESRD (2013) document "Evaporation and Evapotranspiration in Alberta".

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. The Case 3 scenario is assumed in the SST whereby water level in the dugout is assumed to be in equilibrium with groundwater level.

Fixed adjustment factors of 3-fold for coarse soils and 10-fold for fine soils used in previous versions of the SST are no longer used in Version 3.0. Instead, a more refined algorithm is used in Version 3.0 based on more detailed use of parameters such as climate, groundwater depth, and shallow groundwater velocity (via shallow conductivity and gradient). Assumptions about dugout construction practice from Alberta Agriculture (2015) are also included as described below.

Alberta Agriculture provides guidance on recommended and not-recommended dugout types, all of which have been observed in Alberta. Collecting groundwater within a dugout is not recommended, but will not be preventable in many areas and therefore the adjustment factor in the SST assumes some mixing of surface runoff with groundwater in dugout water.

Figure 2-2 Dugout Types
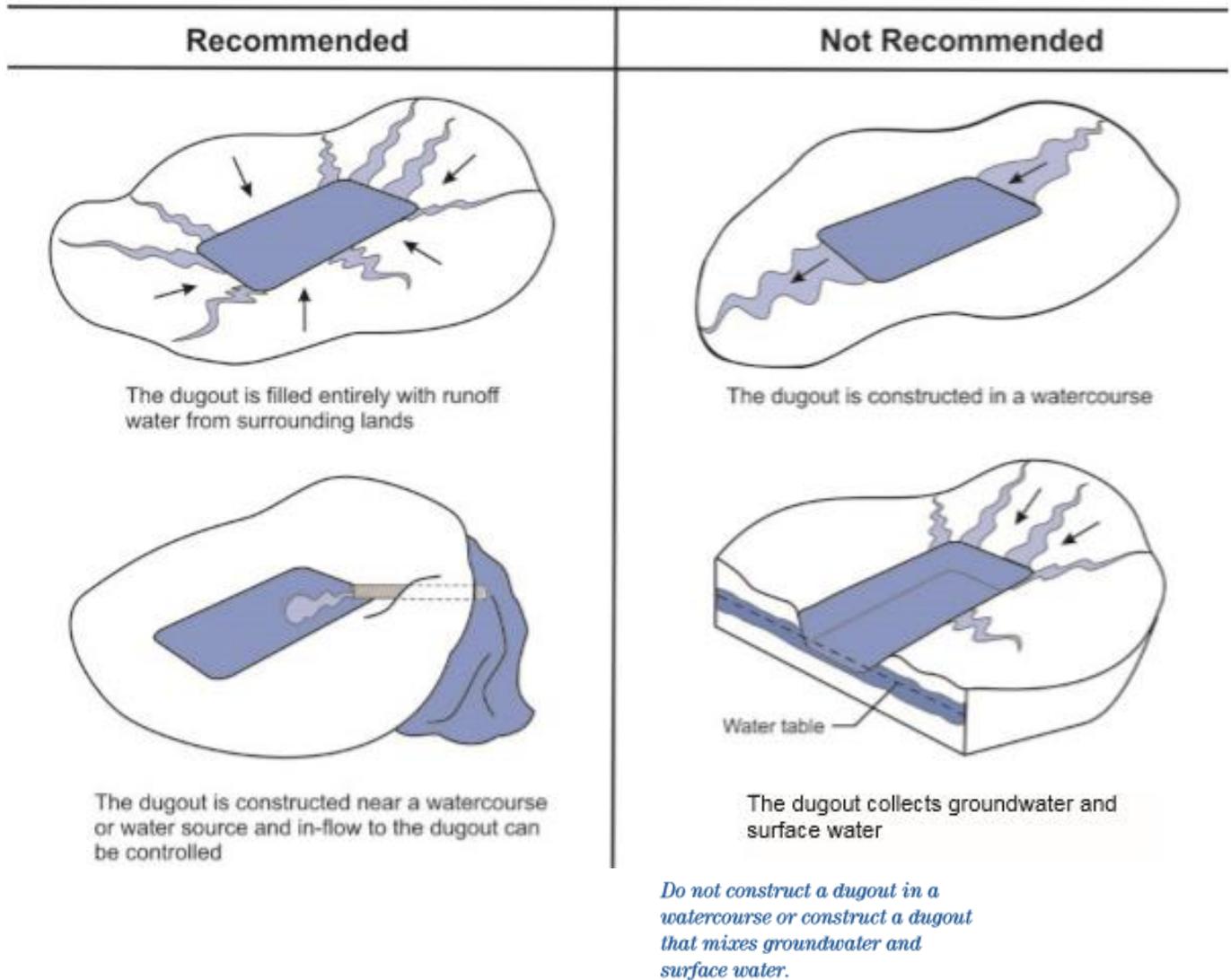
Source: Alberta Agriculture and Forestry, 2015

Dugout mixing (adjustment) calculations are based in-part on typical dugout construction design and aspect ratios. Slopes of 1.5:1 are used for both end slopes and side slopes as assumed in the dugout sizing worksheet from Alberta Agriculture (2015), along with a total depth of 21 feet (approximately 6 m). Assumed dugout production rates and dimensions are also based on sizing protocols from Alberta Agriculture 2015, with an assumed annual water production of 0.27 million imperial gallons (approximately 1,250 m^3). From these sizing protocols, this corresponds to a dugout surface width of approximately 25 m, and surface length of approximately 44-52 m as a function of climate. Due to evaporation effects, drier climates such as 'Evaporation Zone 4' (as per Alberta Agriculture 2015) generally require larger dugout dimensions than wetter climates such as "Evaporation Zone 1". These mapped evaporation zones from Alberta Agriculture (2015) are combined with more detailed evaporation data from ESRD (2013) for internal dugout sizing calculations performed by the SST as part of the adjustment factor calculations.

These dugout construction factors and other soil, groundwater, and evaporation parameters described above are used in the adjustment factor algorithm for the dugout pathways. The figure below shows a high-level schematic of some of the factors considered in the dugout adjustment factor calculation, including length, width, and depth of the dugout along with side and end sloping. Total water inflow into the dugout is assumed to be from a combination of surface runoff and groundwater inflow, with the groundwater inflow a function of the saturated thickness (a function of water table depth) and shallow groundwater velocity. Water losses include both evaporation and water withdrawal for agricultural use (livestock watering or irrigation). Further details of the adjustment factor algorithm are provided in the Technical Manual.
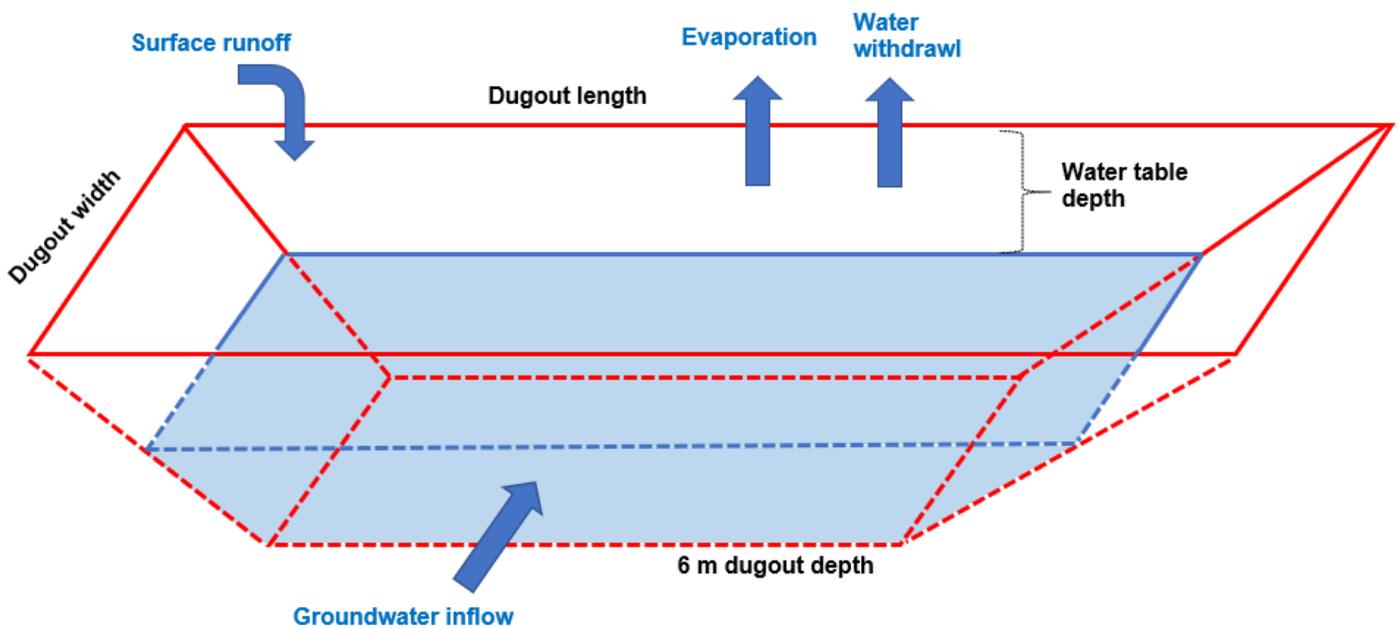
2.11.3 Livestock Water Buffer and Guideline Calculation

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 exceedance of AEP (2019a) Tier 1 guidelines for TDS when future chloride related impacts are added to background groundwater TDS values. Since this subsoil chloride guideline calculation process for livestock water also includes an allowance for the TDS contribution from balancing cations (such as sodium), a subsoil sodium guideline is not specifically required for this pathway.

The Tier 1 livestock watering guideline of 3,000 mg/L is used in the livestock buffer calculation and subsequent subsoil chloride guideline calculations. 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. At higher concentrations, there is an elevated probability for the occurrence of potentially serious and more deleterious adverse effects, and groundwater is considered potentially unsuitable for livestock watering purposes. The algorithms used to calculate the TDS buffer and corresponding subsoil chloride guideline for livestock watering are shown below.

For background TDS and buffer and calculations, the background TDS in shallow groundwater is first reduced (diluted) by the appropriate adjustment factor to account for the mixing between groundwater (with both background and impact-related TDS) and surface runoff (with negligible TDS). If the estimated background TDS in dugout water is greater than 3,000 mg/L, the pathway is excluded due to the high naturally-occurring salinity causing the water to be unsuitable for livestock watering. If not excluded, this background dugout water TDS concentration is then compared to the Tier 1 livestock watering guideline of 3,000 mg/L, with the difference between the two concentrations representing the 'livestock watering buffer', or the amount of additional impact-related TDS in the dugout water which can be tolerated before exceeding this guideline. If the diluted background TDS in dugout water is approaching (within 20%) of this 3,000 mg/L threshold, an allowable incremental increase of 20% in the dugout TDS is used as an alternative to the minimal buffer that would be otherwise calculated. Using various soil to pore-water conversions and mixing calculations, this livestock watering buffer is then used by the SST to back-calculate a subsoil chloride guideline which will not cause an exceedance of this buffer in the dugout water. The calculation method in Version 3.0 represents a form of 'mixing model' which calculates reductions in chloride concentrations as groundwater mixes with runoff/precipitation into the dugout. The algorithm is based on the Summers mixing model (US EPA 1996).

$$C_{GW\_Final} = \frac{Q_L \times C_L + Q_A \times C_{A\_init}}{Q_L + Q_A}$$

Rearranging and solving for C_{A_init},

$$C_{A\_init} = \frac{C_{GW\_Final} \times (Q_L + Q_A) - Q_L \times C_L}{Q_A}$$

Where,

C_{GW_Final}	= Tier 1 Water Quality Guideline for irrigation or livestock watering (mg/L)
C_L	= runoff/precipitation chloride concentration (mg/L) – assumed to be 1 mg/L
C_{A_init}	= allowable contribution to TDS from groundwater without exceeding Tier 1 water quality guideline (mg/L)
Q_L	= flux of precipitation/runoff water into the dugout that mixes with groundwater
Q_A	= flux of groundwater into the dugout

2.11.4 Irrigation Water Buffer and Guideline Calculations

Unlike livestock water, irrigation water has distinct Tier 1 guidelines for both chloride (related to EC and TDS) and SAR. Thus, distinct irrigation water guidelines may be calculated for chloride (related to EC/TDS) and sodium (related to SAR). Aspects of these guidelines are described below.

Irrigation water chloride guideline

Irrigation water SRGs for chloride are calculated for the protection of irrigation water via a dugout scenario by determining the future contribution of groundwater chloride concentration towards the dugout water chloride concentration. The SRGs are based on preventing an exceedance of a chloride irrigation guideline of 355 mg/L. This guideline is adopted as protective of Alberta crops from the range of chloride concentrations provided in the Environmental Quality Guidelines for Alberta Surface Waters (GoA, 2018) and represents an EC contribution of approximately 1 dS/m.

Like livestock watering, this irrigation water pathway is first evaluated for whether it is excluded based on levels of background salinity. Tier 1 guidelines are available for irrigation water EC, where EC in water can be converted to TDS based on the following equation:

$$\textbf{TDS (mg/L) = 640 X EC (dS/m)}$$

Source: Tanji, 1990

Irrigation water within a dugout 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 (>1,280 mg/L) is considered un-useable, and the pathway is eliminated if caused by background salinity. Note that these concentrations are based on the diluted concentrations directly within the dugout water, and thus the groundwater background TDS levels are adjusted (diluted) due to the mixing between groundwater and surface water entering the dugout before comparing to this threshold of 1,280 mg/L TDS (approximately 2 dS/m) for exclusion.

When the estimated TDS in the dugout water is greater than 1,280 mg/L due to naturally background salinity, the irrigation pathway is eliminated and no further guideline calculations are required. When background TDS in dugout water is less than 1,280 mg/L, the 'mixing model' described in the livestock water section is used to calculate a subsoil chloride guideline which will not cause an exceedance of the chloride threshold in the dugout water.

Irrigation water sodium guideline

Irrigation water SRGs for sodium are calculated for the protection of irrigation water via a dugout scenario by determining the future contribution of impact-related sodium (and other background cation concentrations) towards the dugout water SAR concentration. Alberta irrigation water quality guidelines for SAR are shown in the table below, with SAR and EC both considered simultaneously due to the protective effects of EC from the potential adverse effects of elevated SAR on soil structure. SAR values of 5 or less are considered 'Safe' for soil structure regardless of EC levels, whereas SAR values between 5 and 10 are likely safe provided EC values are at least 1 dS/m. SAR values greater than 10 are considered hazardous regardless of EC levels, and EC levels greater than 2 dS/m are also considered hazardous (unusable) as discussed in the irrigation water chloride section. These irrigation water guidelines thus provide a range of SAR/EC combinations for use in deriving subsoil sodium guidelines to protect irrigation water.

Alberta irrigation water quality guidelines for SAR and EC

SAR	EC (dS/m)	Irrigation suitability
≤ 5	≤ 1.0	Safe
> 5 to < 10	> 1.0 to < 2.0	Possibly Safe
≥ 10	≥ 2.0	Hazardous

Source: GoA, 2018 and AAFRD, 2002.

In addition to the EC/SAR interactions described above, soil texture (particularly clay content) also plays a role in acceptable SAR levels for irrigation water. In particular, fine/heavy-textured soils with clay content greater than approximately 35-40% are considered more sensitive to elevated SAR in irrigation water, and have a recommended SAR irrigation guideline of 5 irrespective of EC levels (Steppuhn and Curtin, 1993). Consequently, a SAR irrigation water guideline of 5 is applied if either root-zone or backfill clay content is in the 'high' range (>36%), whereas a SAR guideline between 5-10 described above is

applied when EC is between 1 and 2 dS/m and the maximum of root-zone or backfill clay is in the "low" (<18%) or "medium" (18-36%) categories.

Assuming the irrigation pathway is not excluded by high background shallow groundwater salinity causing mixed dugout water to have SAR >10 or EC >2 dS/m (equivalent to approximately >1,280 mg/L TDS), the calculation of a subsoil sodium guideline to protect irrigation water from excessive SAR levels is based on a similar 'mixing model' as used for subsoil chloride. Here, the background cation concentrations in shallow groundwater (either from direct background groundwater measurements or estimated from background subsoil data) are mixed with surface runoff to determine the background dugout water cation concentrations. For the purposes of these dugout water SAR calculations, the surface runoff is assumed to contain small concentrations of calcium and magnesium which are relatively negligible for TDS/EC calculations (which are based on total salt concentrations) but non-negligible when used in SAR calculations (which are based on ratios of cation concentrations). These calcium plus magnesium concentrations in surface runoff are assumed to total approximately 2.5 meq/L based on typical river water concentrations shown in AENV (2001). Based on these estimated dugout water concentrations from mixing background groundwater with surface water, the SST can then calculate the amount of additional impact-related sodium in subsoil which will not result in an exceedance of the SAR/EC guideline combinations for dugout irrigation water from the above table. This calculated subsoil sodium concentration is the subsoil sodium guideline to protect the irrigation water pathway.

2.12 <u>SubAreas and Source Dimensions</u>

Since chloride or SAR/sodium impacts frequently vary in magnitude or depth across an impacted site, grouping these impacts into subareas with common traits allows a more refined SST analysis and can frequently result in reduced remediation volumes. For example, a large site with widespread but low-intensity shallow chloride impacts plus a small central area with deeper and more concentrated chloride impacts should be divided into SubAreas (at least two) in order to best describe the details of the Site and avoid generation of excessively conservative guidelines.

Regardless of whether a site is divided into one or more than one SubArea, defining the source dimensions of these SubAreas is an important input parameter for the SST. One or more SubAreas may be used to represent a single contaminated zone, and each SubArea requires a 'Source Dimension' entered for it. SubAreas are flexible as to their shape, and may be defined (drawn on site figures) by the user to be square, round, or any other irregular shape (including nested shapes) that encompass the relevant impact area. Regardless of how SubAreas are defined by the user, SubAreas are treated internally by the SST as square representations with the same spatial area (footprint). The source dimension (in meters) of the SubArea is calculated by the user as the square root of the spatial footprint represented by the SubArea. Thus, if a user-defined SubArea covers 2500 m^2, it will be internally represented by a 50x50 m square regardless of its user-defined shape and the source dimension will be entered as 50 m. A user-defined rounded (circular) SubArea with a 50 m diameter will have an area of 1963 m^2, and will be represented internally as a square SubArea with the same area (source dimension entered as 44.3 m from taking the square root). Though rounded / irregular shaped SubAreas are most common and generally most efficient for users to define in practice, they are internally represented as square-shaped SubAreas for modeling purposes within the SST. This source dimension parameter for each SubArea is used for both the FAL and DUA chloride guideline calculations, and influences the interactions between SubAreas and cumulative loading onto these two receptors. Since the FAL and DUA pathways are not relevant for SAR/sodium, these source dimension inputs are not required for SAR/sodium guidelines.

In addition to these area-based source-dimensions required for each SubArea, SST Version 3.0 also requires an additional input parameter describing the 'Source Length for Entire Site'. This parameter is a linear measurement (not area-based), and represents the longest length across the source zone (delimited by 100 mg Cl/kg) in any direction (irrespective of any groundwater flow directions). This 'Source Length for Entire Site' parameter is used only for chloride dilution calculations for the DUA pathway (similar to DF3 calculations as per Tier 1 protocols), and does not influence any other pathways or guidelines.

As previously discussed in Section 1.4.2, maximum values for SubArea source dimensions and the source length for the entire site are summarized below. Sites with impacts larger than these thresholds must be considered on a Tier 2C basis.

Source dimension: - maximum of 100 m (representing 100 m x 100 m = 10,000 m^2) per SubArea
               - maximum of 40,000 m^2 (representing 200 x 200 m) for all SubAreas combined

Source Length for Entire Site: - maximum of 300 m

The examples below illustrate these concepts of determining 'Source Dimension' and 'Length for Entire Site' for some typical irregular-shaped SubAreas. In each case the user-defined SubAreas are shown as the solid blue outlines, and the equivalent square areas used internally by the SST are shown as dashed black squares. In each case the SubArea 'Source Dimensions' are shown in black text (corresponding with the dashed squares) and the "Source Length for Entire Site" shown in red text (corresponding with the red arrows). Other dimensions or parameters relevant to calculating these two input parameters are shown in blue text.

The first example shows a single irregular-shaped user-defined SubArea which encompasses all chloride concentrations above 100 mg/kg on a site. It is oblong in shape and was measured via graphical program to have a surface area of approximately 4,000 m^2. Based on this, a SubArea source dimension of 63 m was calculated for entry into the tool from the square-root of 4,000 m^2. The source length for the entire site was measured as 102 m by measuring the longest distance across the impacted area. In general, oblong impact areas will have a greater difference between the calculated source dimension (in this case 63 m) and measured source length for the entire site (in this case 102 m). The source length for the entire site will be larger than the calculated source dimension in all cases, with the difference being minimized for a circular area. For example, a circular area with a 50 m diameter (source length for entire site) will have a source dimension of 44.3 m from taking the square root of the 1963 m^2 area as previously discussed.

Area 1
4000 m²
=63 x 63 m
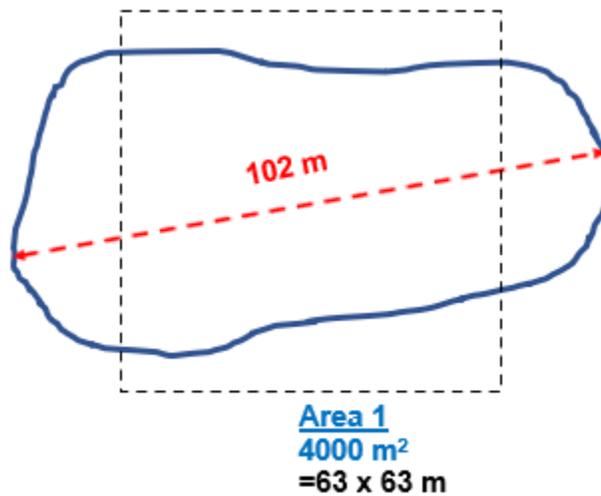
The second example below shows the same overall footprint (4,000 m^2) but divided into two irregular SubAreas. Area 1 has a measured area of 2400 m^2 (49 m source dimension via square root), and Area 2 has a measured area of 1600 m^2 (40 m source dimension via square root). The source length for the entire site remains the previous example at 102 m. Note that when entering these source dimensions for Area 1 and Area 2 into the SST, the tool will display at the bottom of the source dimension column the combined source dimension of all SubAreas combined. In this case the tool would display 63.3 m (consistent with the previous example), calculated as the square root of (49x49 m + 40x40 m). The tool then ensures that the user-entered 'Source Length for Entire Site' is not less than this combined area-based source dimension.

Area 1   **Area 2**
2400 m²   **1600 m²**
=49 x 49 m   **=40 x 40 m**
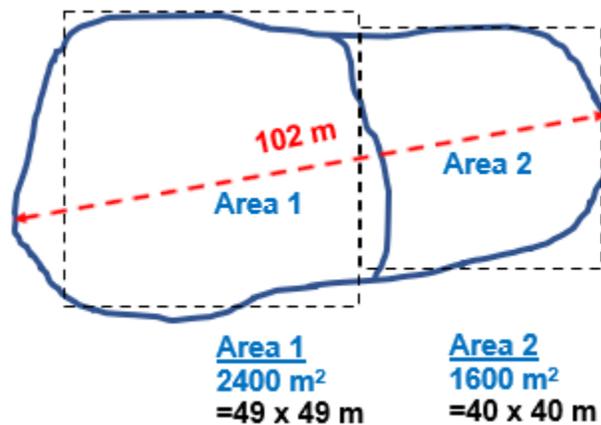
The third example below shows the common situation of nested SubAreas, and is frequently encountered where there is a smaller highly-impacted area surrounded by a less-impacted fringe area or groundwater plume. For defining source dimensions in such cases, subtracting the smaller inner area from the combined area is generally required to avoid double-counting areas. Alternatively, a variety of graphical software programs can be used to directly measure the area of irregular shapes without requiring this subtraction. For this example, the same overall 4000 m^2 impact area from the previous examples is divided into Area 1 (measured to be 784 m^2) and Area 2 (3216 m^2, either from graphical measurement or subtraction). Entering these source dimensions (28 m and 57 m respectively, via square-root) into the tool results in the same approximate 63 m combined source dimension being displayed (representing the entire 4000 m^2 area). These equivalent square areas of 28x28 m and 57x57 m which are internally used by the tool for modelling purposes are overlaid on the figure below as dashed black boxes. Note that the 57x57 m box represents the net Area 2 area (after removing Area 1), and the two boxes are thus added internally for modeling purposes. As in the previous examples, the source length for the entire site remains at 102 m. Other more complex scenarios with more SubAreas and/or other irregular shapes can be handled essentially in the same manner.

Area 1
784 m²
=28 x 28 m

Area 2
4000 m² - 784 m²
=3216 m²
=57 x 57 m
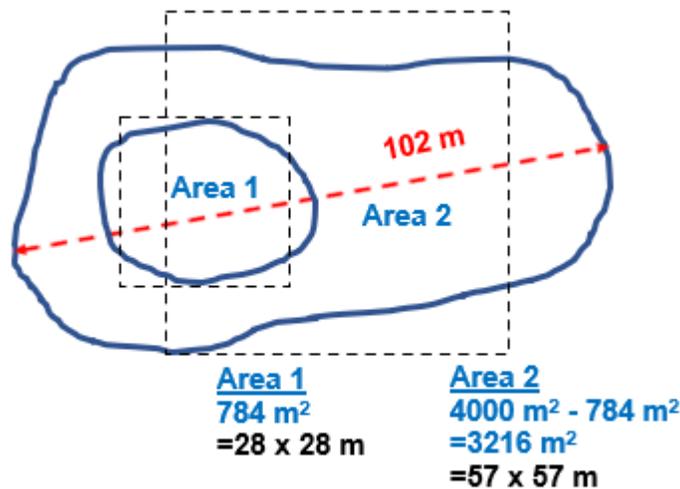
These three examples above all illustrate the most important and common scenario whereby the user defines irregular-shaped SubAreas based on the actual observed distribution of chloride impacts. In rarer cases the user may also choose to define square-shaped (or circular) SubAreas, but this would typically be limited to an interim approach where data is limited, an initial screening is desired, or site risks are clearly related to other pathways (such as the root-zone or dugout pathways) where source dimension aspects are less important. Defining SubArea shapes with straight lines and sharp corners (such as a square) requires measuring total source length for the entire site across the diagonal between these corners (longest length), and is rarely a realistic representation of impact distribution on a site (generally over-conservative). Some examples later in this manual assume square SubAreas for simplicity and illustration purposes, but in practice these would typically be replaced with more customized irregular shapes instead.

Note: Squares or other shapes with straight lines and sharp corners are generally not the most appropriate shapes for users to define for SubAreas.

Area 1
2500 m²
=50 x 50 m
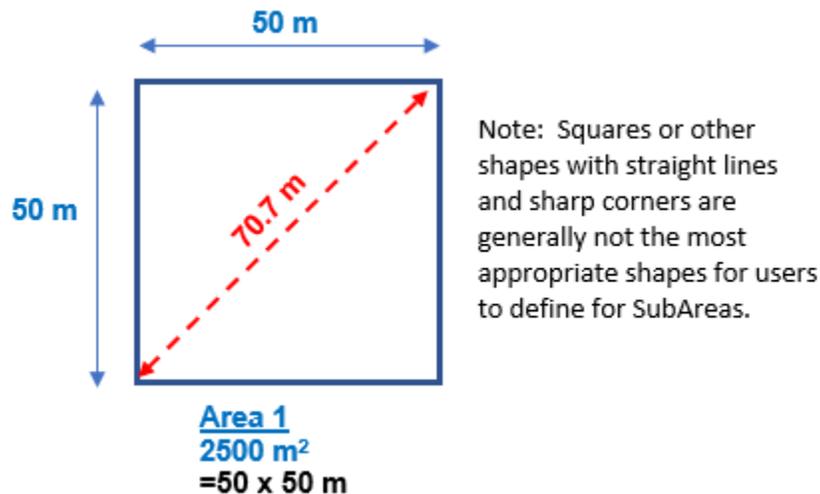
2.13 SubAreas Options

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 Pathways with One or More SubAreas
2. FAL and DUA Pathways with One SubArea
3. FAL and DUA Pathways with More than One SubArea 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 or Buffer Allocation Factors (BAF's) which are described more in option 3.

Note that while the examples which follow are based on generating subsoil chloride guidelines for different SubAreas, SubAreas can also be used for generating subsoil SAR/sodium guidelines using similar considerations. In particular, the first option (root zone and dugout pathways with one or more SubAreas) is of particular relevance to subsoil sodium guidelines since (like chloride) these pathways are not dependent on source dimensions for subsoil sodium. This is also the case for the soil structure pathway for SAR, which is evaluated independently of source dimensions.

2.13.1 Root Zone and Dugout Pathways with One or More SubAreas

Tier 2A and Tier 2B SRGs can be calculated for root zone and dugout (irrigation and livestock watering) pathways using SubAreas, with these SRG's independent of source dimensions. 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 shallow, the scenario can be run as a single SubArea. For sites with more complicated distributions of salinity impacts and multiple root zone scenarios (*i.e.*, unimpacted, impacted, excavate and backfill), dividing the source area into more than one SubArea can provide more refined SRGs for the root zone and dugout pathways. The development of SubAreas for these pathways is most commonly implemented in situations involving:

- 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.*;

SubAreas may also be useful on Sites with the following traits, although a separate run will be needed for each SubArea because the SST Version 3.0 does not allow these parameters to be varied between SubAreas within a single run:

- 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, at a site with highly variable background root zone EC, the mean and 95th percentile EC may stretch across three Tier 1 salinity categories (*e.g.*, mean EC of 2.8 dS/m = Good, 95th %ile EC of 6.9 = Poor; neither statistical parameter is within the Fair category). One option available for this situation, if supported by the spatial distribution of EC data, 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 5 m whereas the other half has a water table of 7 m (potentially due to topography differences). The dugout irrigation water and livestock watering guidelines would be applicable for the half of the site with a water table shallower than 6 m, but would be excluded for the other half.

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 that are separated from each other (*e.g.*, wellhead on one side of the site, flare pit on the other side), and different excavation depths can be developed for the distinct sources.

The process of developing SubAreas involves grouping borehole data from areas of similar 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 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 chloride SRG is greater than 1,200 mg/kg, then no excavation would be required for SubArea 2. The only area to be excavated would be the root zone for SubArea 1. Comparison against dugout, FAL, and DUA SRGs would also be required to determine the final assessment of SubAreas requiring excavation.

Classification: Public
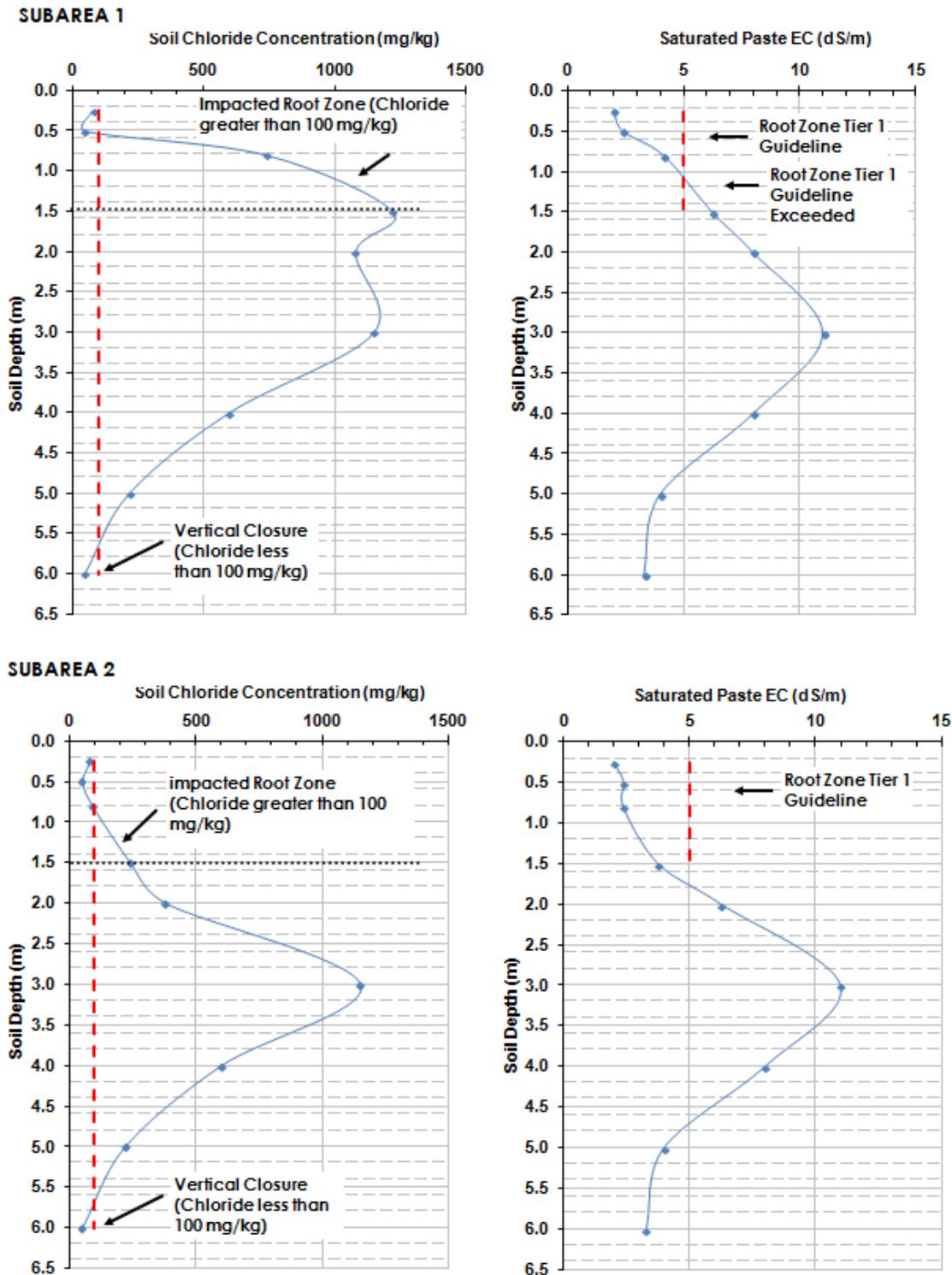
2.13.2 FAL and DUA Pathways with One SubArea

While source dimension is a required input for each SubArea in all SST chloride assessments, that parameter only influences the FAL and DUA pathways (and the dugout pathways when on non-agricultural land in close proximity to agricultural land). If there is solely one SubArea defined for a Site, then only one source dimension is required as input (plus the source length for the entire site). Though the SST has standard square source dimensions (areas) of 15 x 15 m, 25 x 25 m, 35 x 35 m, 50 x 50 m, 75 x 75 m, and 100 x 100 m for internal modeling purposes, Version 3.0 uses algorithms to interpolate guidelines for SubArea source dimensions that fall between two of these values. In contrast, previous versions of the SST conservatively rounded up to the next highest standard source dimension when a value between these standard dimensions was entered. If only one SubArea is defined for a chloride assessment, then the Buffer Allocation Factors for both the FAL and DUA pathways must be 1.0 each, thus representing a simplified case compared to the next section with multiple SubAreas.

The source dimension 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. A greater source dimension is associated with less attenuation of the peak concentration prior to reaching the receptor, and hence lower SRGs. In the example below, the site has an irregular-shaped impact area of approximately 7,225 m^2 bounded by lateral chloride concentrations of less than 100 mg/kg. This is equivalent to a source dimension of 85 x 85 m (determined by the square root of this area), shown as the dashed orange square on this figure for visualization purposes only. While previous versions of the SST would run this scenario as a 100 x 100 m source dimension for aspects of the FAL and DUA pathways, the smoothing/interpolation algorithms in Version 3.0 would treat the scenario as 85 x 85 m (as entered, without rounding up). This results in more refined guidelines in Version 3.0, and less need to optimize SubArea dimensions to match these standard sizes. The source length for the entire site is measured as 108 m across the longest length in this example, and influences guideline calculations for the DUA pathway.
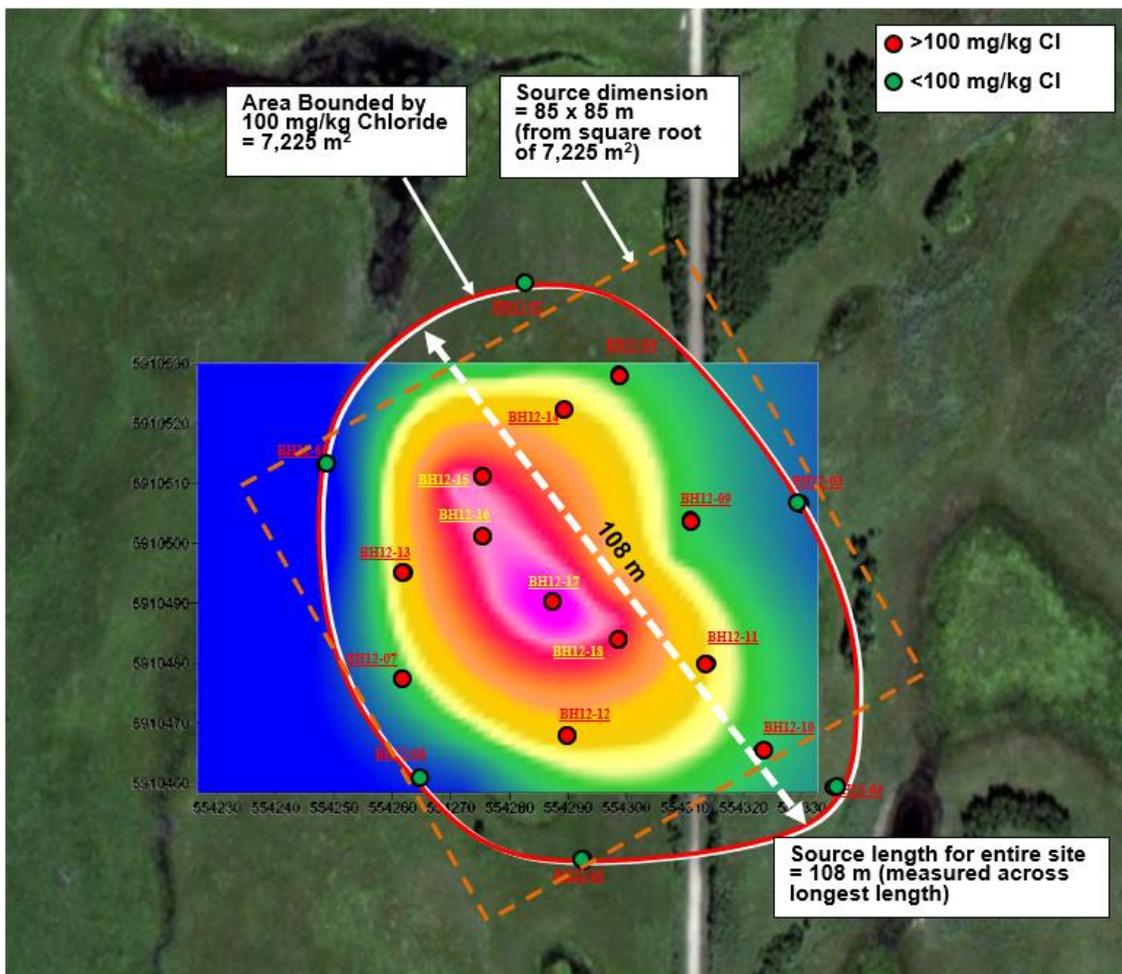
Borehole data is required for confirmation of concentrations in different areas of a salinity impact as well as for lateral closure (defined by chloride of $\leq$ 100 mg/kg). The first step in determining source area is to identify the area bounded by 100 mg/kg chloride. In the example above, the following boreholes had chloride concentrations < 100 mg/kg at all depth intervals (*e.g.*, from surface to 6 m): BH12-01 to BH12-06. These boreholes with <100 mg/kg are shown with green dots, and boreholes with >100 mg/kg shown as red dots. The area bounded by 100 mg/kg is highlighted with a blue/white line. Various software programs (Adobe Reader, Adobe Acrobat, Surfer, *etc.*) are available, or more conventional methods may be used, to calculate the area bounded by this line. In the example above, it represents an area of approximately 85 x 85 m, or an 85 m source dimension.

If the source dimension required for defining the lateral extent of impacts is greater than allowed for a single SubArea (*i.e.*, > 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 35 m). Multiple SubAreas allow for a more precise description of contaminant distribution and allow for more options in designing a cost-effective remediation program. This is because distinct SRGs are calculated for each SubArea using Buffer Allocation Factors as described in the next section.

Multiple impact areas can also be run as separate SubAreas in the SST. Under Tier 2A, calculations of SRGs will assume that salt loading at a receptor is cumulative from all SubAreas. Under a Tier 2B scenario with sufficient groundwater information, calculations of SRGs will still consider the potential for cumulative salt loading at a receptor, but will also accommodate instances where different impact areas do not combine because of groundwater flow direction. This is discussed further in the following section.

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

Under Tier 2A and 2B levels of chloride 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 for the FAL and DUA pathways, and represent the relative chloride loading assigned to each SubArea for each of these two pathways. 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. Multiple SubAreas should be considered in situations involving:

- SubArea shapes that are highly oblong and do not match well with the default SST square source dimensions (e.g., a 75 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 200 m, however, the resulting SRGs for the DUA and FAL pathways may potentially become very low and constrained for large source dimensions (depending on other Site conditions).

Example 1

A site has a 25 x 25 m flare pit impact and a 10 x 10 m wellhead impact, and chloride impacts from both source areas could combine to impact DUA or FAL receptors (such as if one area is downgradient of flow from the second area under Tier 2B, or there is unknown groundwater flow direction under Tier 2A). In these cases, the potential exists for a cumulative 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 to allow the application of BAFs in

assessing cumulative risk. 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 exceedances be anticipated, option 2 can be selected, SubAreas developed, and BAFs iteratively 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

Situations are also common 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. On the left the impacts are represented as a standard 50 x 50 m square-shaped impact dimension given that the impact length was determined to be 50 m. However, if the source width is less than 50 m, the 50 x 50 m square 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.
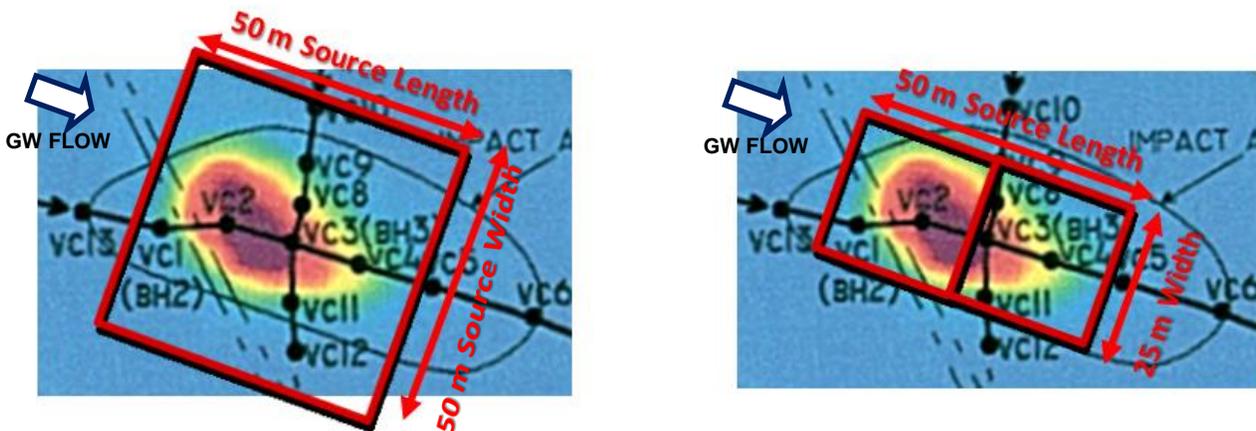
Example 3

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 semi-nested 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.

BAF's are allocated to each SubArea (the total must not exceed 100%), 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

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BAF can be applied to this area when calculating risk to the DUA and FAL receptors producing less constrained SRGs, which may lead to no excavation being required 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 exceedance of AEP (2019a) Tier 1 guidelines at receptor locations. More detailed guidance on how to develop SubAreas is discussed later in this User Manual.
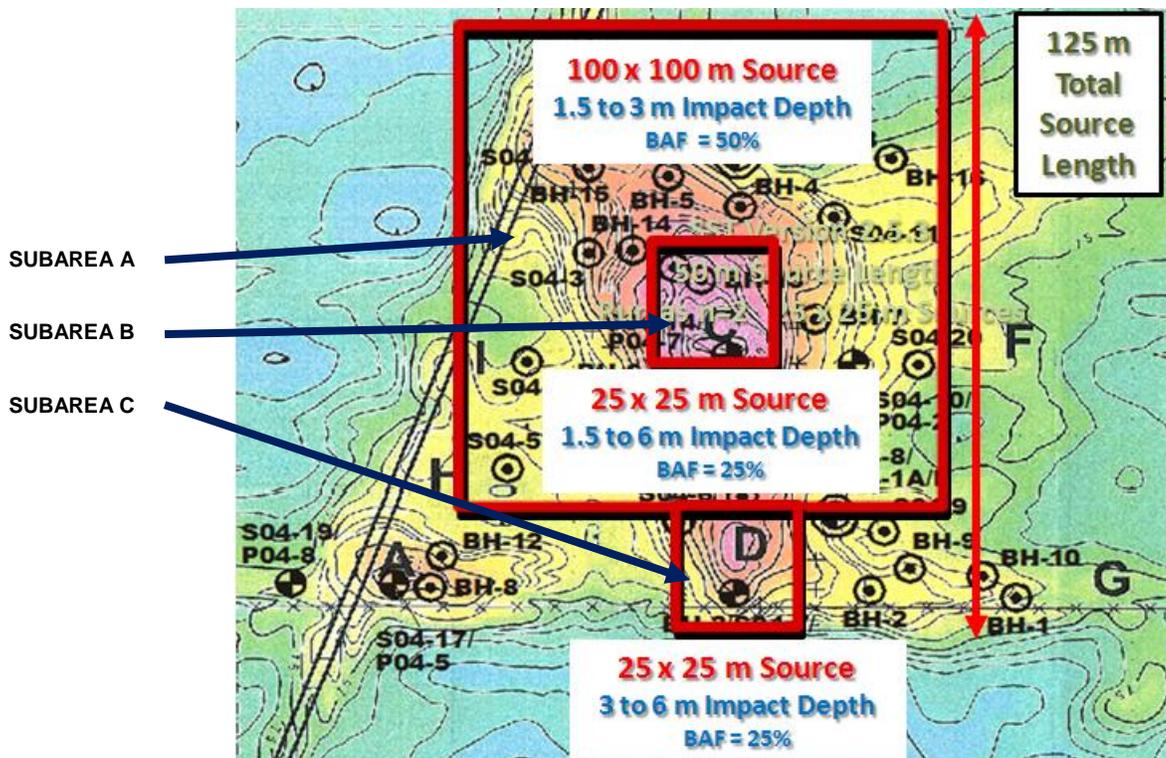
2.13.4 Impact Areas that are Cumulative for Risk and Guideline Calculations

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 are considered to have the potential for cumulative risk. A 60° arc (30° 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 <u>not 'touching'</u> (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° 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;
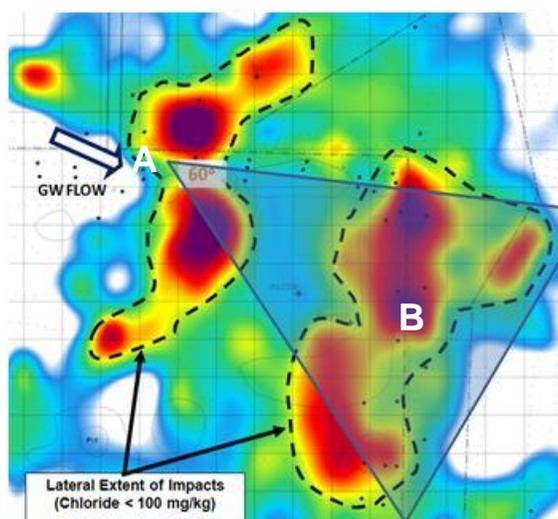
Case 2: SubAreas (A&B) situated in parallel (laterally adjacent) and separated by soils with < 100 mg/kg chloride (*i.e.*, not 'touching') - where a 60° arc at the centre of the most upgradient SubArea does not overlap with an adjacent SubArea – risks are non-cumulative. The SubAreas should be run as two independent scenarios. Each run could assign a single SubArea with a BAF factor of 1 or 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.*)
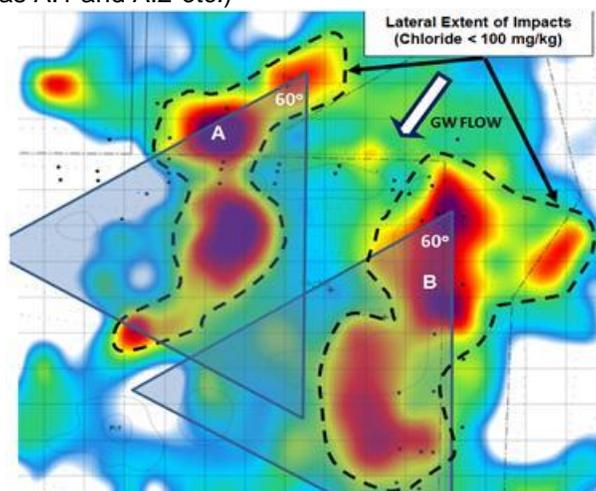
Case 3: SubAreas situated in parallel (laterally adjacent) but are not separated by soils with < 100 mg/kg chloride (*i.e.*, touching) – risks are cumulative, and separate SubAreas with source dimensions and BAF factors must be assigned, or the entire impact area considered as one SubArea with a single source dimension BAF factor of 1.
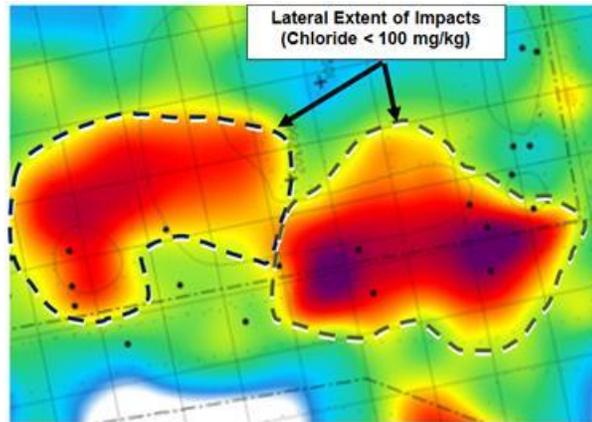
2.14 **SubArea Guideline Calculation Example**

This section provides an example of a typical subsoil chloride guideline calculation process involving SubAreas. In some cases it can be beneficial to first evaluate/optimize SRGs for the root zone and dugout receptors since the corresponding guidelines are generally based on vertical salt transport and are not dependent on source area or the interactions from neighboring SubAreas. The dugout pathway for adjacent agricultural land is an exception, where lateral transport and thus source dimensions are relevant in a manner similar to FAL. SRGs can subsequently be optimized for the FAL and DUA pathways (which are influenced by source dimensions and BAF's) and where the guideline calculations by the SST involve an analysis of cumulative risk from adjacent SubAreas.

Depth profiles for an example site that was divided into four SubAreas (1A, 1B, 2, and 3) are shown below, along with a site figure showing the SubArea layout which in this case is a typical nested SubArea configuration.

Vertical Chloride Profiles Broken down by SubArea
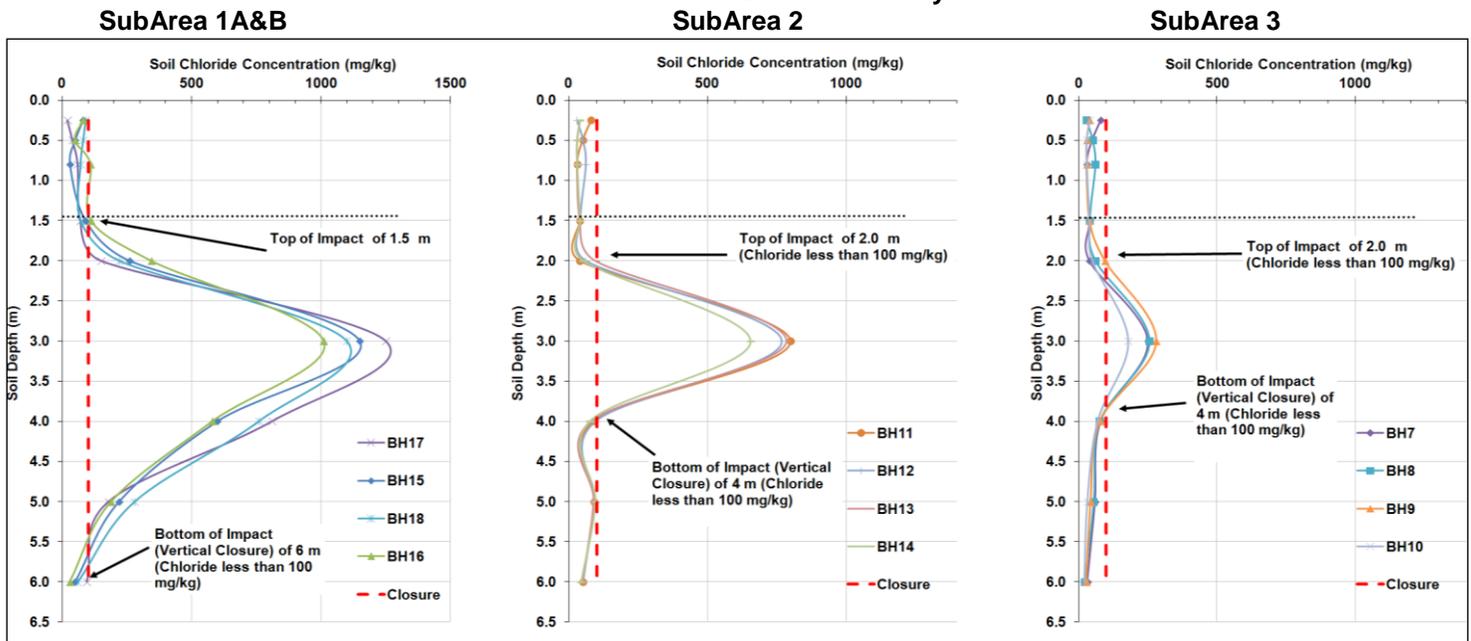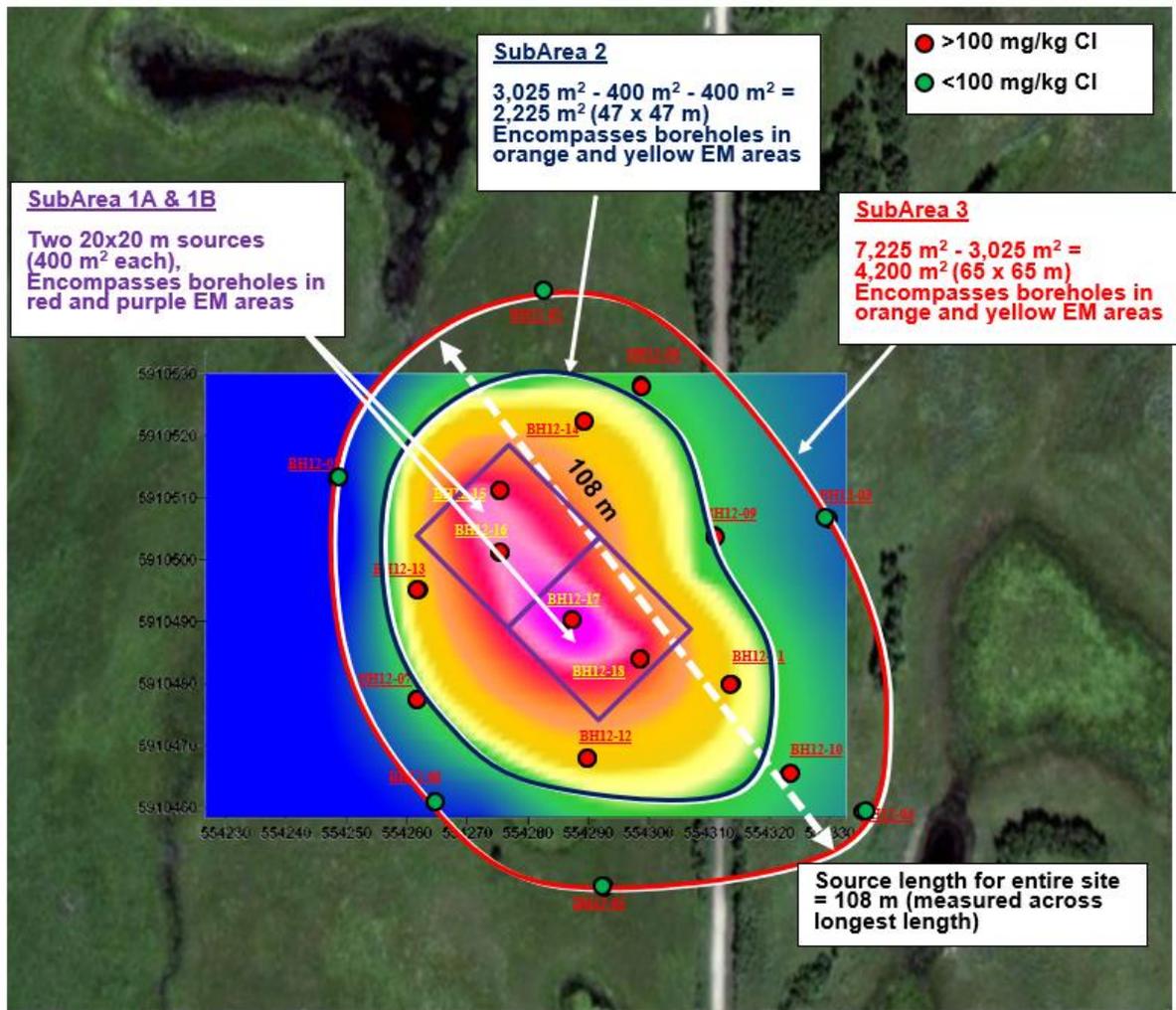
Typical source dimension calculations for nested SubAreas are shown in the table below. For cases like this with nested SubAreas, source dimensions can be adjusted for larger SubAreas that overlap smaller SubAreas to avoid double counting mass. Each of SubAreas 1A and 1B are shown as 20 x 20 m square areas (for 400 m² each). For SubArea 2, the unadjusted source area is 3,025 m². The area representing the encompassed SubAreas 1A&B (400 m² + 400 m²) can be subtracted from this area, resulting in an adjusted source dimension for SubArea 2 of 47 x 47 m (from the square root of 2,225 m²). The value of 47 m is entered into the SST for source dimension for SubArea 2. A similar calculation is completed for SubArea 3 (unadjusted 7,225 m²) where the unadjusted area from SubArea 2 (3,025 m²) is subtracted resulting in an adjusted SubArea 3 source dimension of 65 x 65 m (from the square root of 4,200 m²). The source dimension of 65 m is entered into the SST for SubArea 3. Note that the source dimension calculations above are all area-based calculations, and are entered into the "Source dimension" column in the SubArea information table for chloride.

In addition to the above area-based source dimension calculations for each SubArea, the 'Source Length for Entire Site' must also be measured as previously discussed. This is measured as the longest linear distance across the total impacted source area regardless of groundwater flow direction, and is shown as 108 m in the figure above.

Note that although this example uses square SubAreas for simplicity of the area calculations, the same techniques are also used for irregular or rounded SubAreas. In those cases, the source dimensions for each SubArea are calculated based on their individual area (source dimension of each SubArea calculated as the square root of its area), while incorporating appropriate adjustments if needed for nested SubAreas to avoid double-counting areas. The 'Source Length for Entire Site' is then measured as the longest total distance across the impacted source area in any direction.

Example Source Dimension Calculations for Nested SubAreas

Area	Source dimension calculations	Source dimension entered into SST (m)
SubArea 1A	20 x 20 m (400 m^2)	20
SubArea 2B	20 x 20 m (400 m^2)	20
SubArea 2	3,025 m^2 – 400 m^2 – 400 m^2 = 2,225 m^2 (47 x 47 m)	47
SubArea 3	7,225 m^2 – 3,025 m^2 = 4,200 m^2 (65 x 65 m)	65

*Source Length for Entire Site = 108 m
(longest measured distance)

In this example, these source dimensions and other input parameters such as top and bottom of impact and BAF's for the aquatic life and DUA pathways are entered as shown in the table below (other input parameters for soil and groundwater also entered but not shown here). In this case, an initial selection of BAF's was made for each SubArea in order to obtain initial guidelines, and to use as a basis for further optimization if needed. In this case, the majority of BAF was initially allocated to SubAreas 1A and 1B due to their higher chloride concentrations, with BAF's from all SubAreas totaling 1.0 (as always) for each of those two pathways. Based on these input parameters and initial BAF allocations, calculated subsoil chloride guidelines are also shown in the table and discussed below.

SubArea	Inputs				Guidelines (mg/kg)				
	Top of Impact (m)	Bottom of Impact (m)	FAL BAF	DUA BAF	Root-Zone	Irrigation	Livestock	FAL	DUA
Area 1A	1.5	6	0.35	0.29	1600	NA	6000	3500	920
Area 1B	1.5	6	0.35	0.29	1600	NA	6000	3500	920
Area 2	2	4	0.17	0.29	2900	NA	6900	1000	900
Area 3	2	4	0.13	0.13	2900	NA	6900	380	300
		Sum	1.00	1.00					

SubAreas 1A and 1B result in no numerical guideline (pathway excluded) for the irrigation water pathway as the diluted background TDS in dugout water was determined to be > 1,280 mg/L by the SST. For SubAreas 1A and 1B, the livestock water pathway SRG is 6,000 mg/kg and the root zone SRG is 1,600 mg/kg. For SubAreas 2 and 3, the irrigation water pathway is also excluded, the livestock pathway SRG is 6,900 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 previously shown. Note that these dugout and root-zone guidelines are independent of source dimension and BAF's, and thus SubArea 2 and 3 have the same dugout and root-zone guidelines despite having different source dimensions and BAF's.

SRGs for the DUA and FAL pathways have more complex SubArea interactions and are influenced by source dimensions and BAF's. The SST calculates SRGs for these two pathways such that the modeled future concentrations in the DUA and at the FAL receptor do not result in an exceedance 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. In this example, SubAreas 1A and 1B have FAL and DUA guidelines of 3500 and 920 mg/kg respectively. Area 2 has FAL and DUA guidelines of 1000 and 900 mg/kg, and Area 3 has FAL and DUA guidelines of 380 and 300 mg/kg.

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 are below the FAL SRG but exceed the DUA SRG from approximately 2.5 – 4 m, indicating remediation may be required in these areas in order to achieve closure.

Before concluding excavation is required, however, it is advisable to first determine whether further optimization of BAF's could result in a reduction in exceedances, or result in exceedances in a more desirable SubArea in terms of excavation logistics (proximity to pipelines, etc). In this case, increasing DUA BAF in SubAreas 1A and 1B can marginally increase the DUA guidelines in those areas, but at the expense of creating DUA exceedances in the other areas. It was thus concluded

that the DUA BAF's as shown can already be considered to be reasonably optimized, and remediation scenarios for SubArea 1A and 1B can then be evaluated.

In this example, an excavation depth of 3 m (incorporated via an updated top of impact within an 'excavate and backfill' scenario) resulted in a DUA SRG of 1,300 mg/kg for SubAreas 1A and 1B. Comparing this 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 AEP (2019a) Tier 1 SRGs.

Vertical Chloride Profiles by SubArea with DUA and FAL Subsoil SRGs
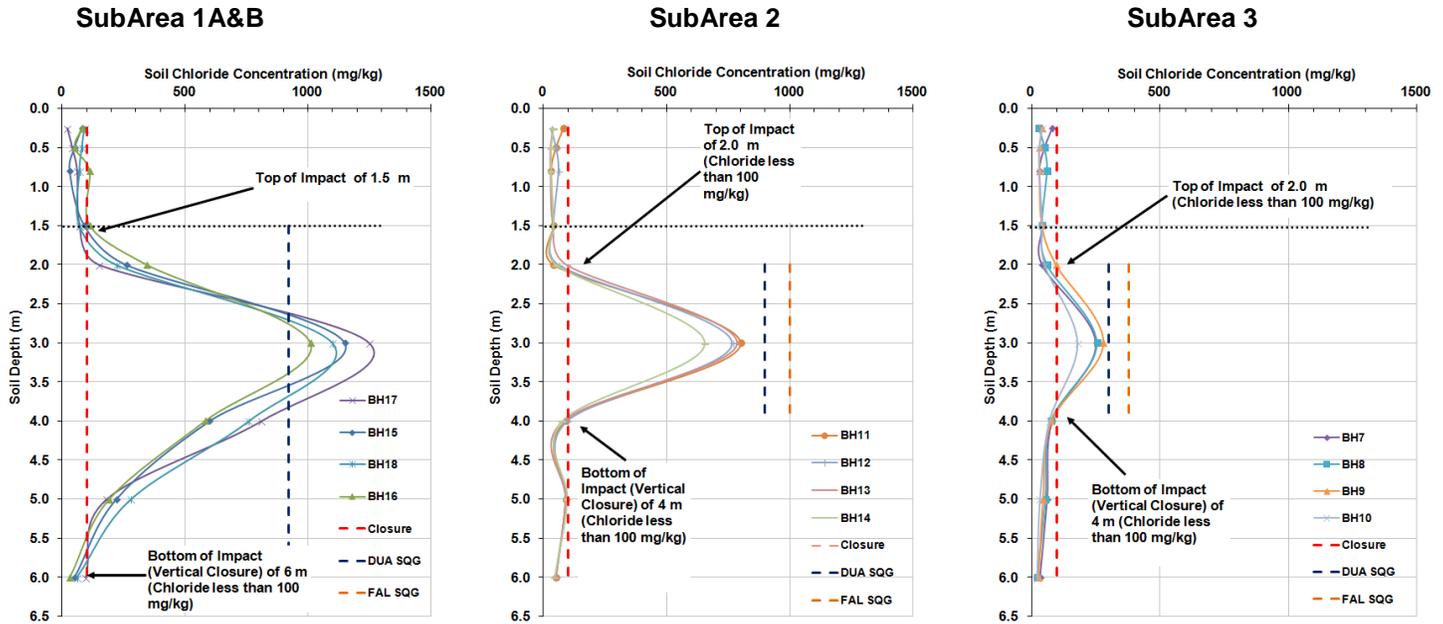
In this example, the consequence of not dividing the site into SubAreas would have been the development of SRGs under a single scenario characterized by the maximum lateral impact dimension (85 x 85 m) and the maximum vertical impact dimension (1.5 to 6.0 m). This would overestimate the mass of chloride 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.

In general, each SubArea would preferentially 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.

As previously discussed, guidelines for certain scenarios for a particular pathway may exceed Management Limits for chloride (10,000 mg/kg for fine soil and 7,000 mg/kg for coarse soil). Closure via the SST cannot be obtained if chloride concentrations exceed Management Limits. Risk management/exposure control can be conducted when Management limits are exceeded, or potentially re-evaluation on a Tier 2C basis.

2.15 Constraining Soil Guidelines and Groundwater Guidelines

Regardless of whether one or more SubAreas are defined for a site, each SubArea will have one soil chloride guideline (the lowest one) which becomes the constraining soil remediation guideline (SRG) for that SubArea. This constraining SRG represents the maximum allowable soil chloride concentration (mg/kg) in that SubArea which would not result in any predicted current-day or future exceedances of any relevant receptors. This automatically includes any potential interactions or cumulative loading with other SubAreas, if present. This minimum (constraining) soil guideline for each SubArea is displayed by the SST in red text under the soil chloride guidelines for the five potential chloride pathways. It is the maximum concentration of chloride allowed within the impacted volume of that SubArea as defined by its lateral source dimensions and top and bottom of impacts.

A similar procedure is used for the constraining guideline for subsoil sodium, though since there are at most two relevant pathways for subsoil sodium (upward migration to the root-zone, and irrigation water), the constraining subsoil sodium guideline is displayed as the minimum of these two pathways. The soil structure pathway for SAR is always displayed separately when performing a SAR / sodium assessment, with more details for that pathway provided in Section 2.20.

When performing a Tier 2B chloride assessment, a groundwater chloride guideline is typically generated for each SubArea on the basis of the constraining soil guideline for that SubArea. This equivalent groundwater guideline for each SubArea is analogous to the constraining soil guideline, and represents the maximum groundwater concentration that would be allowable in that SubArea assuming a monitoring well was screened within the impacted area and depth interval. This guideline is provided largely for additional context, and is generated regardless of whether any monitoring wells are actually present in that SubArea or not. There is no requirement to specifically install wells for comparison to these groundwater guidelines, as meeting the relevant soil chloride guidelines is generally considered sufficient. In the rare case that soil data meets the soil remediation guidelines but a monitoring well exceeds the groundwater guideline within that SubArea, it may be an indication of either limited soil data in an area of potentially high impacts, or may indicate different soil bulk density / porosity conditions than what is assumed in the soil to pore water conversions which are used to generate the groundwater guidelines. Professional judgement is required in such cases to determine the likely cause of the groundwater guideline exceedance, and whether it is a trigger for additional evaluation of assessment or remediation plans.

As mentioned above, groundwater guidelines for each SubArea are calculated based on soil to pore water conversions using the default soil bulk density and porosity for the overall soil lithology defined for the site (fine or coarse). For example, for fine-grained soils with a default bulk density of 1.4 and porosity of 0.47, a soil chloride guideline of (for example) 1,000 mg/kg would correspond to a groundwater guideline of approximately 3,000 mg/L. In comparison, for a coarse soil with a bulk density of 1.7 and porosity of 0.36, a soil guideline of 1,000 mg/kg would correspond to a groundwater guideline of approximately 4,700 mg/L. Note that these calculations assume that at least some of the impacted thickness for that SubArea is below the water table (saturated), and not entirely in the vadose zone above the water table.

The figure below shows an example of constraining soil remediation guidelines and corresponding groundwater guidelines for a hypothetical fine-grained site with three SubAreas, a 4 m water table, and impacts as deep as 9 m in the deepest area. The grey shaded areas indicate chloride impacts spanning from 1.5-9 m in Area 1, from 2-8 m in Area 2, and 2-4 m in Area 3. Example constraining chloride SRG's are shown for each area, including 1,000 mg/kg in Area 1, 1,400 mg/kg in Area 2, and 2,000 mg/kg in Area 3. Groundwater guidelines of approximately 3,000 mg/L and 4,200 mg/L would be displayed for Areas 1 and 2 respectively since at least some of the initial impacts are below the water table. For Area 3, a numerical groundwater guideline would not be calculated, and would instead display as "NA-vadose" in the SST since all initial impacts are above the water table in that SubArea.

These groundwater guidelines also play a strong role in the sentinel well options described in the next section.
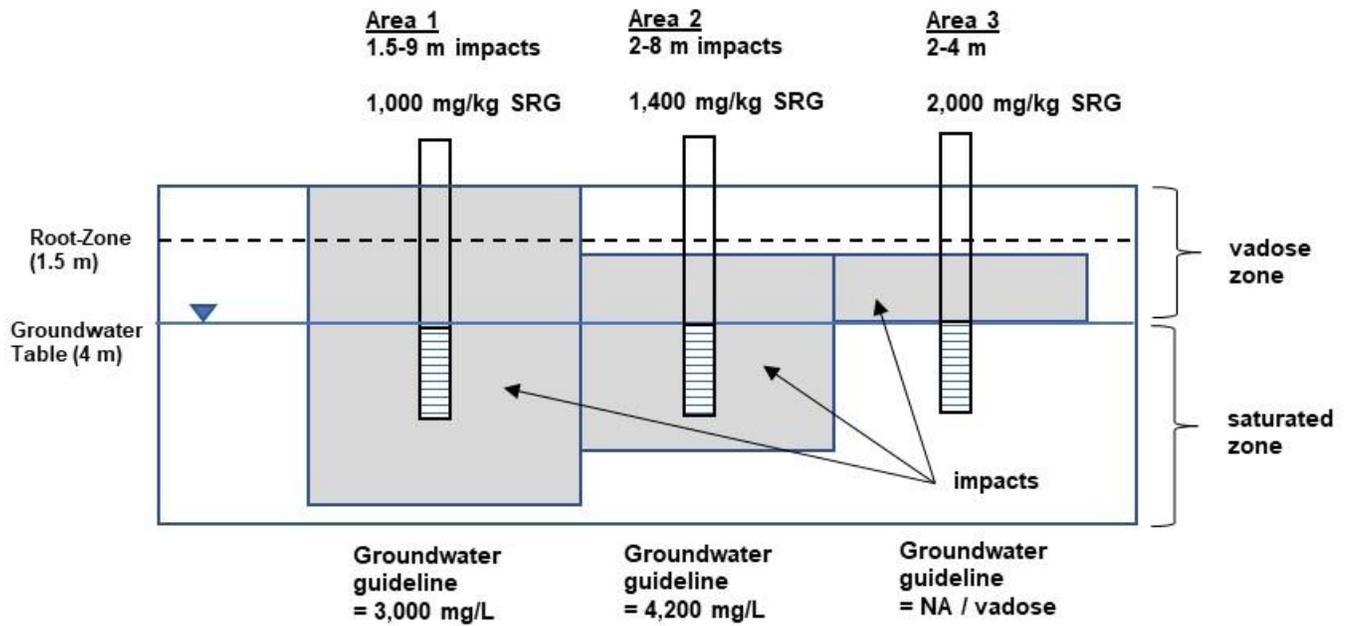
2.16 Sentinel Wells

An additional tool added to Version 3.0 for the management of FAL risk (and potentially dugout risk on adjacent agricultural land) is the 'sentinel well' option. If the FAL sentinel well option is selected in a Tier 2B chloride assessment, the user is prompted to enter the lateral distance to a hypothetical sentinel well installed in shallow groundwater between the site and the nearest FAL receptor. A figure showing this scenario is shown below, with this sentinel well distance measured from the edge of the SubArea nearest the FAL receptor, and can range in value from 0 m (directly at the edge of the impacts) to the same distance as the FAL receptor.

Classification: Public
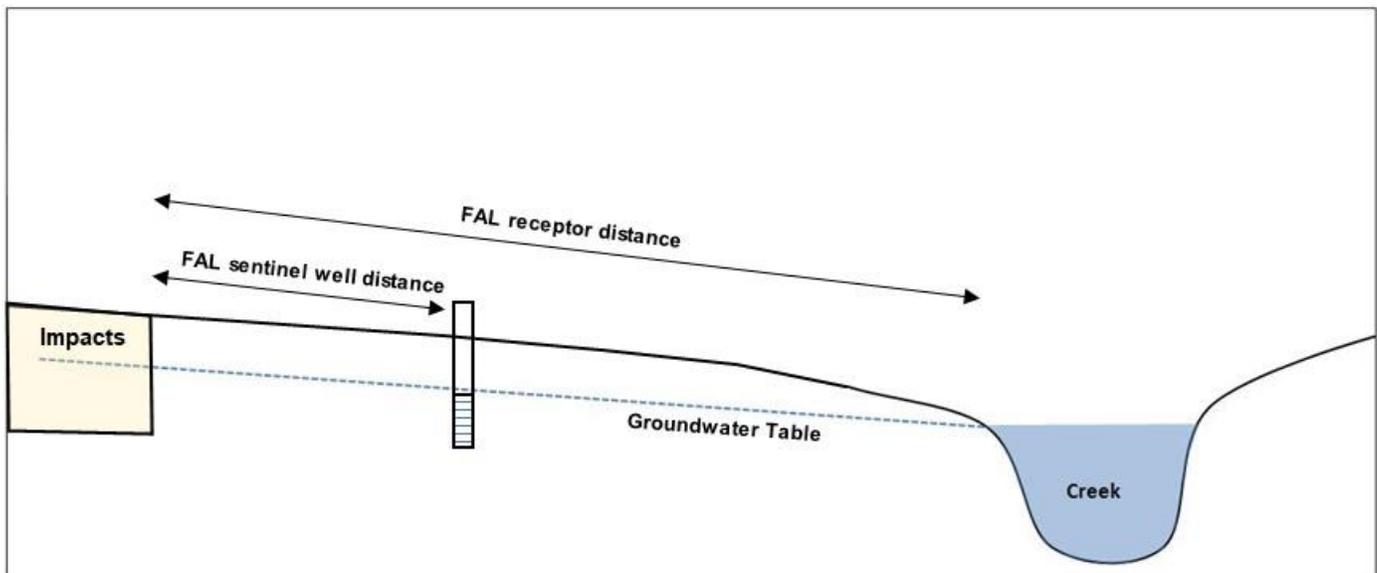
If this option is used, as a supplement to the subsoil chloride guidelines generated within the impact area for the FAL pathway, the SST also then calculates the upper range of concentrations that this sentinel well should not exceed in the future based on the lateral transport modelling performed by the tool. This can help ensure that observed concentrations remain consistent with modelled assumptions in the SST, and can provide a potential trigger for additional assessment or remedial activity if appropriate. Since there is no specific requirement to monitor groundwater concentrations after remediating a site to guidelines generated by the SST, this option is primarily of value for risk management or monitoring activities when immediately obtaining full site closure is not possible or practical. For example, if a site is under risk management, a sentinel well may be used to monitor whether the program is achieving adequate protection of off-site receptors. This sentinel option may also be useful in providing some additional monitoring / risk management targets within a Tier 2C assessment.

A typical example of sentinel well concentrations as a function of sentinel well distance is shown in the graph below. This scenario is for a typical fine-grained site with a single SubArea and an FAL receptor distance of 500 m. When the FAL sentinel well distance is set to 500 m (equivalent to the FAL receptor distance), the maximum allowable sentinel well concentration is 120 mg/L (consistent with the Tier 1 aquatic life guideline). At distances approaching 0 m (i.e, directly adjacent to the edge of the impacts), the maximum allowable sentinel well concentration is approximately 6,700 mg/L. This is comparable to the 6,900 mg/L source area groundwater guideline generated by the SST for the FAL pathway, derived from a 2,300 mg/kg soil guideline for the FAL pathway. A similar pattern is observed when multiple SubAreas are present, with the maximum sentinel well concentration near the edge of the impacts calculated as an area-weighted average of the corresponding source area FAL groundwater guidelines for each SubArea.
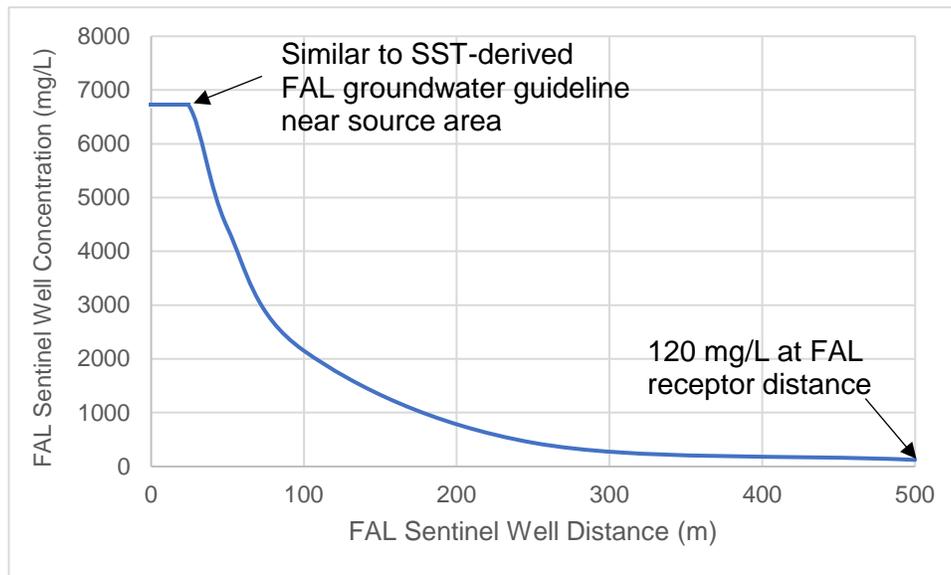
A similar sentinel well option is also provided for adjacent agricultural land, whereby the user may specify a separate sentinel well location between the site (if on non-agricultural land) and nearby adjacent agricultural land (If relevant). This adjacent agricultural land sentinel well functions in a similar manner as the FAL sentinel well, but provides optional risk management / monitoring information relevant to the dugout pathways on adjacent agricultural land (the SST assumes a future dugout could be installed at the agricultural land use boundary). This adjacent agricultural land sentinel well incorporates lateral transport modeling and SubArea interactions in a manner similar to the FAL pathway, with FAL BAFs used to apportion cumulative dugout loading from the various SubAreas.

2.17 <u>SAR Effects on Soil Structure</u>

Guidelines for subsoil SAR are generated within the SAR/sodium module of the SST, and are based on the estimation of potential risk to soil structure. This pathway does not involve interactions between adjacent SubAreas, and is thus independent of source dimensions and BAF's. Like the sodium guidelines, there is also no groundwater guideline associated with the SAR soil structure pathway.

A key potential effect of elevated SAR in soils is the dispersion and swelling of clay particles resulting in the loss of water infiltration capacity or saturated hydraulic conductivity (K_{sat}). These effects on soil structure are related to the exchange of sodium for calcium or magnesium on the soil cation exchange complex, and are highly influenced by soil texture and clay content. An important observation from literature is that these potentially negative SAR effects on soil structure are also strongly influenced by EC, with higher EC values providing protective effects from SAR-induced hydraulic conductivity losses.

Soil structure stability is more sensitive to the negative effects of elevated SAR near the soil surface because of shear from rain-drops or tillage. Since these factors make the root-zone the most sensitive interval for potential SAR effects, root-zone SAR values must be remediated to Tier 1 SAR guidelines. However, in subsoil below 1.5 m, where soil is generally free of disturbance, the potential risk of SAR-induced soil structure instability is reduced compared to the root-zone, and substantially higher subsoil SAR values are generally tolerable. Some of the factors influencing potential soil structure risks are discussed in this section, along with a high-level description of the conceptual model used by the SST for generating subsoil SAR guidelines. Additional details beyond the summary presented here are provided in the Technical Manual.

2.17.1 SAR/EC/K_{sat} Relationships From Literature

Though elevated SAR is known to have the potential to cause deleterious soil dispersion, it has also been known for more than 60 years that elevated electrolyte concentration (EC) can help protect from these SAR effects (Quirk, 1955). The concept of EC 'thresholds' for SAR effects was introduced in this Quirk 1955 paper, with additional data and refinements related to this concept generated by numerous other researchers in the subsequent decades (Quirk, 2001). For example, it was noted that this protective effect may diminish as salt (electrolytes) are leached from soils by low-EC rainwater (Minhas, 1986). This effect may be more immediately relevant to root-zone soils than subsoils due to the closer proximity of root-zone soils to the source of low-EC rainwater. Regardless, the study of EC/SAR relationships and how they affect K_{sat} has been a common theme for SAR research over many decades.

Useful research was performed by Curtin, Steppuhn, and Selles examining SAR/EC/K_{sat} relationships through the Agriculture and Agri-Food Canada research branch in Swift Current, Saskatchewan (Curtin et al 1994a, 1994b, 1994c, 1995a, 1995b). The focus of this research was primarily topsoil, with losses in hydraulic conductivity in topsoil due to SAR potentially further exacerbated in the field by shearing due to tillage and low EC raindrops. This research also has relevance to subsoil, though these exacerbating factors such as tillage and shear by raindrops would not be present in subsoil. This research was also targeted toward the development of irrigation thresholds (such as in Steppuhn and Curtin, 1993), and thus included the evaluation of scenarios with very low EC values which are generally less relevant to in-situ subsoil conditions.

These experiments were generally performed by measuring saturated hydraulic conductivity (K_{sat}) from soil cores with varying electrolyte solutions, and measuring how hydraulic conductivity values are reduced from baseline as protective EC levels are lowered while SAR values remain constant. Results were found to be highly dependent on soil texture and clay content, with the figure below showing an example of EC/SAR interactions for a loam / clay loam soil with 28% clay (Curtin, 1994c). At the highest SAR value of 40, K_{sat} was reduced by more than 10-fold below the baseline as EC was reduced from 80 dS/m to approximately 1 dS/m. Lesser effects were seen at lower SAR values, with a significant portion of the effects occurring at solution EC below 1 dS/m. As noted previously, this range of EC below 1 dS/m has primary relevance for topsoil and irrigation, and has lesser relevance for subsoils where background salinity is often above these levels.

SAR/EC Effects from Literature on Clay Loam Soil (28% clay)
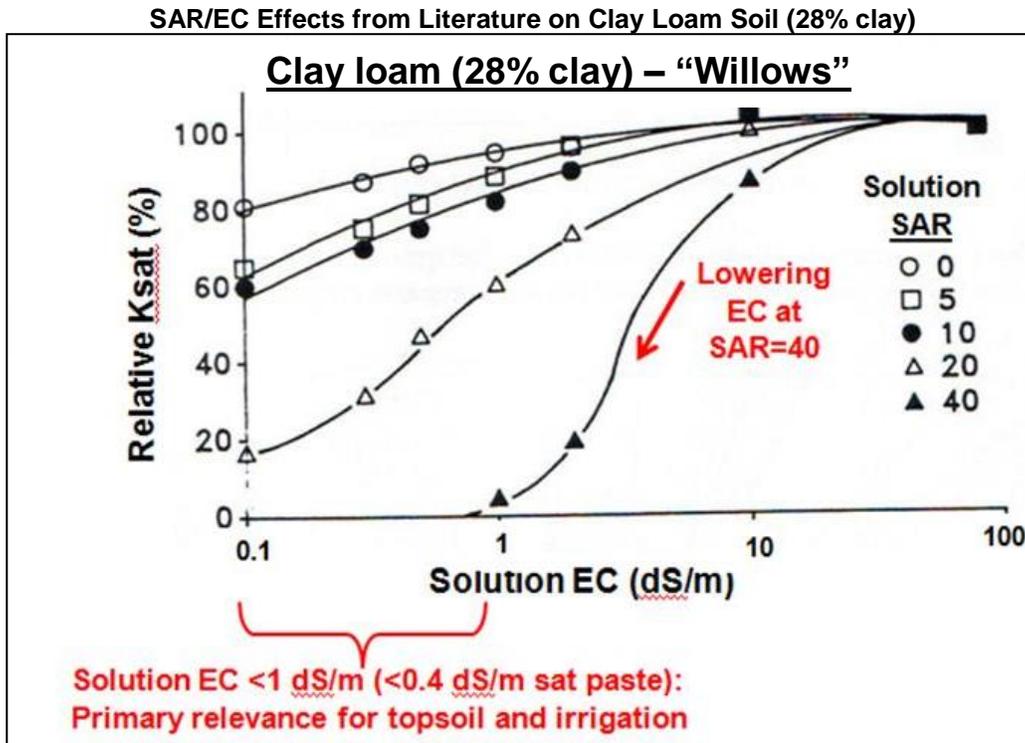
Adapted from Curtin et al, 1994c

The behaviour of soil with a higher clay content (54% clay) is shown in the figure below (adapted from Curtin, 1994c). A steeper reduction in hydraulic conductivity as EC decreases is noted compared to the previous figure, suggesting that soils with higher clay content may be more sensitive to SAR-induced K_{sat} losses.

SAR/EC Effects from Literature on Clay Soil (54% clay)
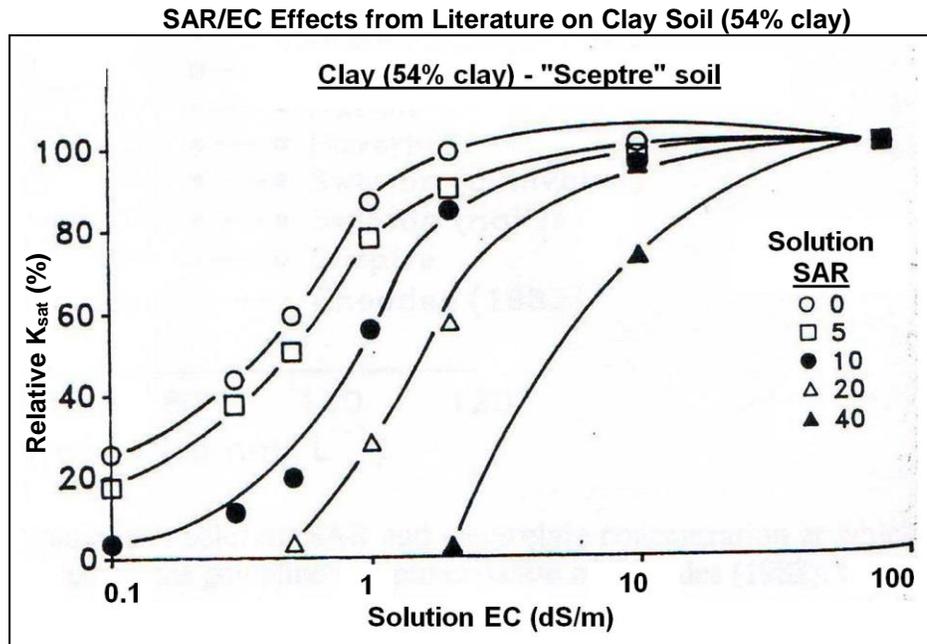
Adapted from Curtin et al, 1994c

In contrast, the behavior of a sandy loam soil with lower clay content (13% clay, "Hatton" soil) is shown in the figure below (also adapted from Curtin, 1994c). This coarse soil generally exhibited less response to SAR than the soils with higher clay content examined above. For example, a solution SAR of 40 resulted in less than a 2-fold K_{sat} reduction for solution EC above 1 dS/m. Other soils with intermediate textures (such as loams) investigated in Curtin 1994c tended to have responses intermediate between they clayey and sandy soils shown here.

SAR/EC Effects from Literature on Sandy Loam Soil (13% clay)
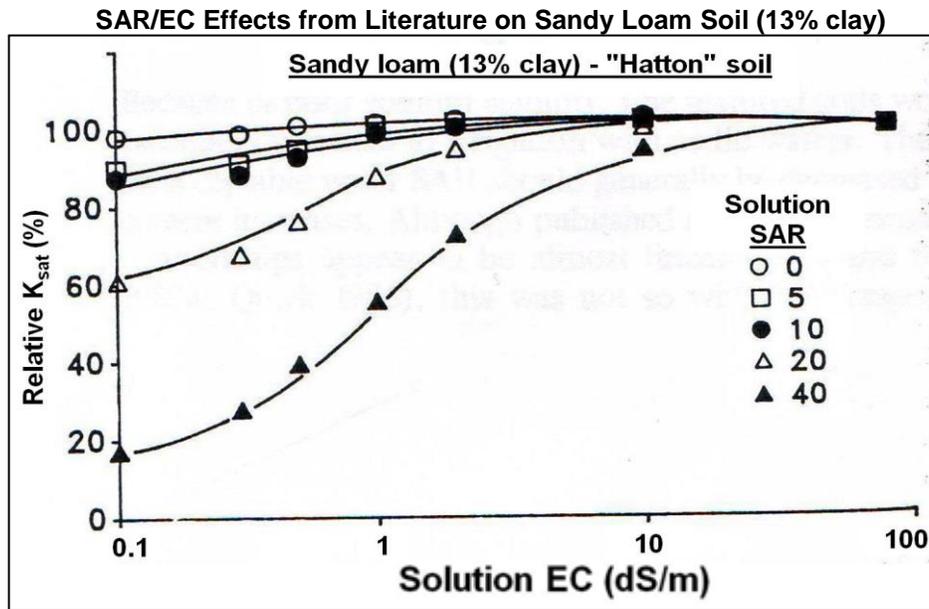
Adapted from Curtin et al, 1994c

2.17.2 K$_{sat}$ Thresholds

Data from leaching studies such as those described above can be rearranged to examine the EC/SAR combinations that result in a particular loss of K_{sat}. Much of this research has been performed to evaluate irrigation water quality, where a threshold has often been defined as a 25% K_{sat} reduction as evaluated by these repacked leaching column experiments. It is important to note that this 25% threshold does not necessarily imply that a 25% reduction in hydraulic conductivity in itself will cause significant degradation of root-zone (surface) soils. This threshold is intended to represent the onset of potential soil instability due to SAR effects, which could lead to poor infiltration in surface soils due to the development of soil structure problems such as surface crusting or hardpan. Exacerbating factors present in surface soils include wet/dry cycles, dilution by low-EC snowmelt or rainwater, impact and shearing by rain droplets, or shearing by tillage.

The figure below shows typical threshold curves for various soils demonstrating the range of SAR and EC values for which a 25% reduction in hydraulic conductivity would be predicted (Curtin et al, 1994c). For Willows soil (clay loam with 28% clay), a solution SAR of 40 thus requires a solution EC of approximately 7 dS/m (70 mmol cations/L) to remain stable according to this defined 25% threshold.

SAR and EC Threshold Curves for 25% Hydraulic Conductivity Reduction

Notes: -Adapted from Curtin at al, 1994c
  -EC and SAR shown on a solution basis
  -electrolyte concentrations initially reported in meq/L have been converted to EC (dS/m) using a 10:1 ratio

For deeper subsoils below the root-zone, very little has been written in literature regarding suitable SAR thresholds. Compared to root-zone soils, subsoils are not exposed to the exacerbating factors of raindrop impact, direct dilution by low-EC rainwater or snowmelt, or shearing by tillage. Consequently, a threshold which allows a higher hydraulic conductivity reduction is appropriate for subsoils.

Context for determining potentially significant K_{sat} reductions may be obtained by evaluating natural variability in hydraulic conductivity due to factors other than SAR. For example, it is not uncommon to observe saturated hydraulic conductivity (K_{sat}) results from soil cores varying by one to two orders of magnitude within the same site despite having low SAR and similar lithology from location to location. This natural variability of up to 1 to 2 orders of magnitude has been observed between samples within a 3 m depth interval within the same borehole, and did not exhibit any apparent deleterious effects on water transport.

This large natural range in subsoil K_{sat} often observed within individual boreholes with consistent lithology suggests that other factors such fractures, micro-channels, and/or compaction/bulk density effects can play a substantial role in influencing K_{sat} in the absence of SAR effects. Thus, the influence of SAR on K_{sat} should be considered one factor of many in overall water transport. For this reason, plus the reduced sensitivity to SAR effects of subsoils compared to surface soils, preliminary K_{sat} thresholds in the order-of-magnitude range (approximately 10-fold) appear reasonable in the context of natural variability. While the SST V3.0 uses K_{sat} thresholds developed from modelling of water movement under a range of soil and climate conditions (see Section 2.17.5), a 10-fold reduction in Ksat provides a useful departure point for evaluating the interaction of EC, SAR, and soil texture, as discussed in the following sections.

2.17.3 Alberta leaching column experiments

To supplement the literature results from the previous section, a comprehensive set of leaching column experiments were also performed over several years on Alberta soils from dozens of sites across the province. These Alberta experiments were generally performed with undisturbed soil cores from a variety of lithologies and depths, with a selection of results described below. Further examples and details are provided in Equilibrium 2012a and the Technical Manual.

Example #1: SAR=40 in sandy clay loam: relatively sensitive response

This experiment shows an example of SAR=40 in a sandy clay loam soil. As EC is reduced from 80 to 1 dS/m at a fixed SAR of 40, the initial baseline K_{sat} of approximately 2.0×10^{-9} m/s was maintained while EC dropped from 80 to 17 dS/m with a minor reduction in K_{sat} observed as EC was further reduced to 10 dS/m. K_{sat} loss was approximately 10-fold at EC=5 dS/m, with further reductions observed as EC decreased to 2 and 1 dS/m. These effects resulted in hydraulic conductivity losses of approximately 20-fold from baseline, resulting in a final K_{sat} of less than 1.0×10^{-10} m/s. For context, the final leaching solution of EC=1, SAR=40 represents a very low calcium plus magnesium concentration of approximately 0.12 meq/L which appears unlikely to occur in practical subsoil conditions below the root-zone.
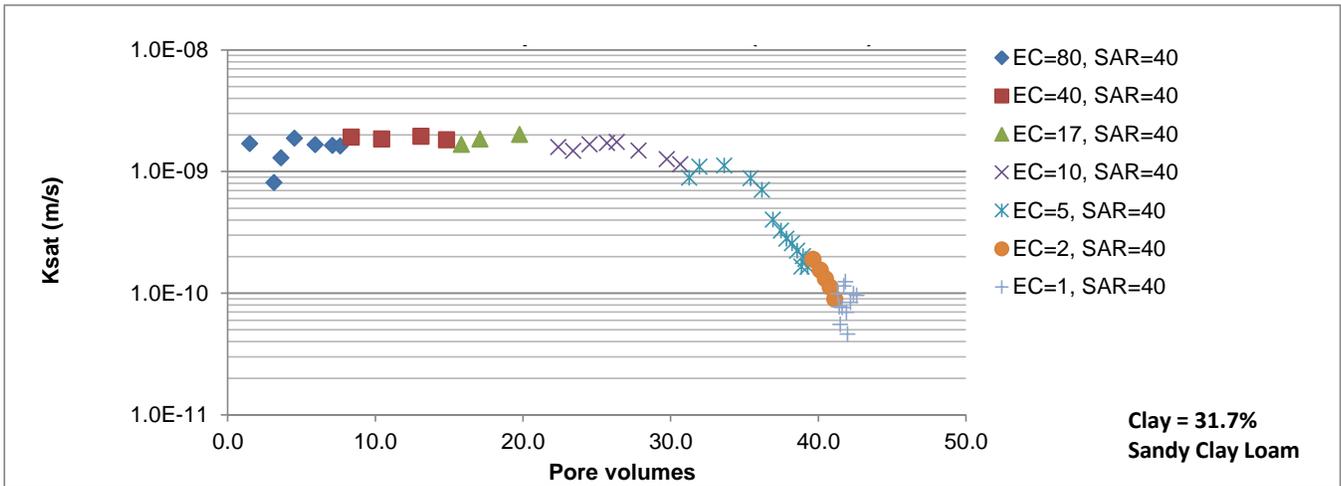
Example #2: SAR=69 in low-conductivity clay loam: negligible response

This example at higher SAR (69) was performed on a low-conductivity clay loam soil with initial hydraulic conductivity of approximately 2×10^{-10} m/s. No changes in K_{sat} were observed as SAR was increased from 1 to 69 while maintaining EC=2 dS/m. This and other similar experiments indicate that there appear to be practical lower limits on K_{sat} values below which SAR effects are unlikely to reduce K_{sat} further.
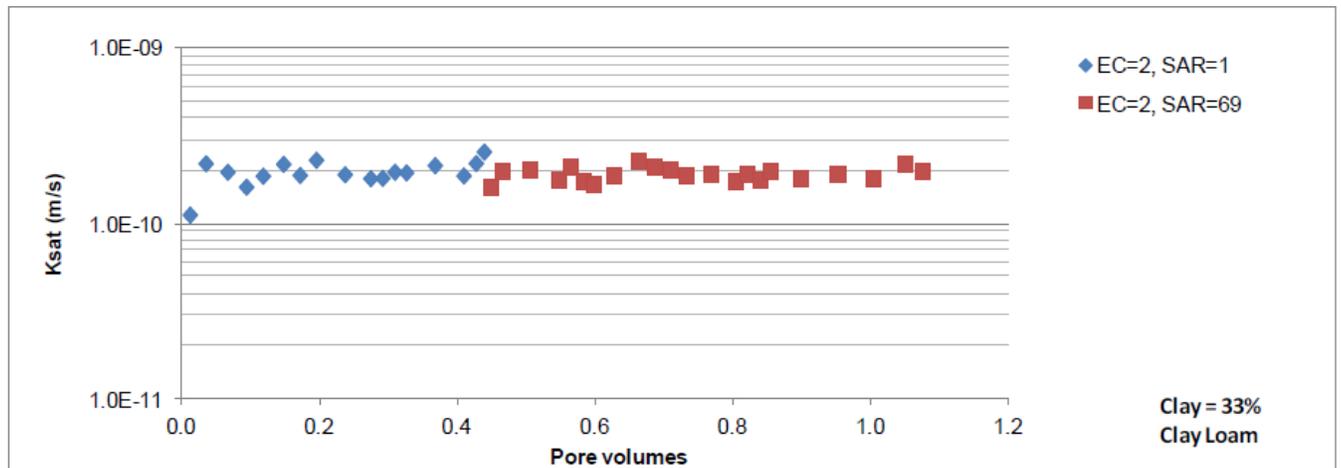
Example #3: SAR=40 in loam/sandy loam: negligible response

This experiment shows an example of a SAR=40 experiment for a fairly coarse loam / sandy loam soil with 14.9% clay. The first leaching solution of EC=80, SAR=40 resulted in a starting K_{sat} of approximately 2.0×10^{-8} m/s which increased somewhat with continued leaching with EC=10, SAR=80 (potentially due to factors such as physical redistribution or reorientation of soil particles during leaching). No reductions in K_{sat} were then observed as EC was reduced from 10 to 1 dS/m with SAR fixed at 40. A final treatment with SAR of 100 also did not result in any K_{sat} reductions. Thus, other than experimental variability, negligible effects were observed on K_{sat} over the wide range of SAR/EC values tested for this coarse soil.
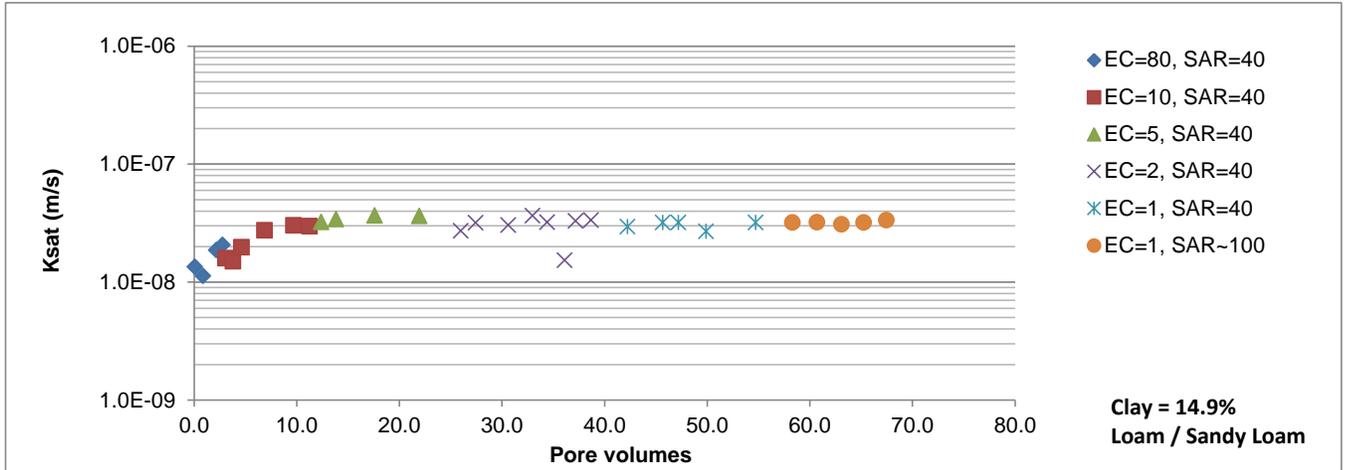
Example #4: SAR=69 in sandy loam: sensitive response

This example shows a coarse sandy loam soil with 13% clay treated with a SAR=69 series. After an initial baseline near 1×10^{-6} m/s, an approximate 10-fold K_{sat} reduction was observed as EC was reduced to 9 and 5 dS/m. A substantial additional reduction (more than two additional orders of magnitude) was then observed as EC was reduced to 2 dS/m. This soil is more sensitive than the previous sandy loam, indicating that there are a range of potential responses for soils of a similar texture. It is also notable that the final EC=2, SAR=69 solution implies a very low calcium plus magnesium concentration of approximately 0.17 meq/L which appears unlikely to occur in practical subsoil conditions, particularly given that this soil is from an area generally high in background salinity and sodicity.

Classification: Public
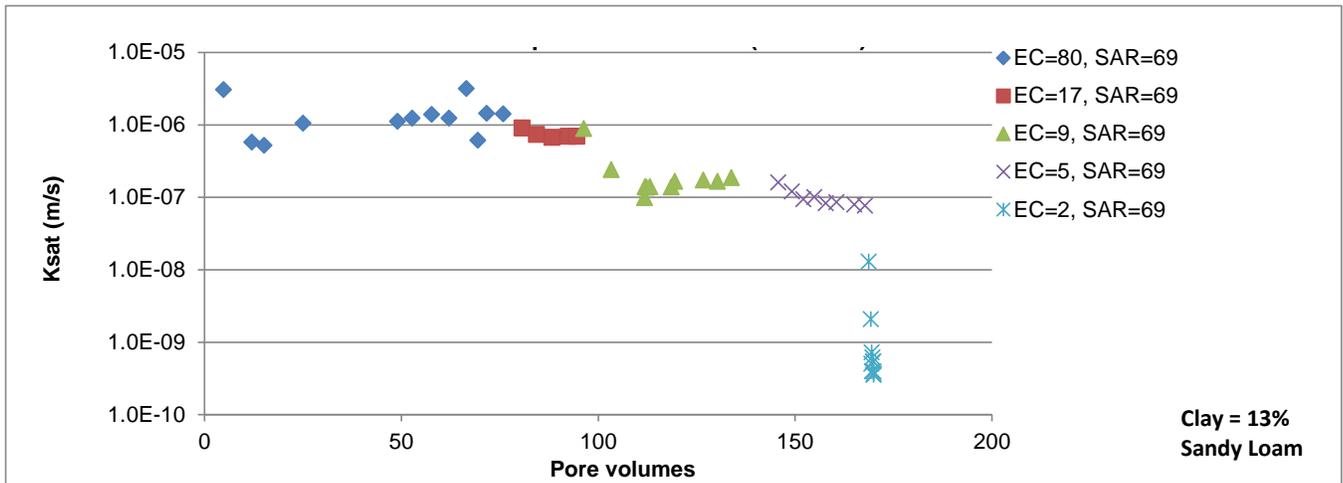
2.17.4 Combining Literature and Alberta Results for Ksat Thresholds

The combination of results from the Alberta and literature leaching column experiments can then be used as a basis for deriving suitable K_{sat} thresholds for deriving subsoil SAR guidelines for protecting soil structure. The two figures below show the combination of literature and Alberta results for soils with >18% clay ("Medium" or "High" subsoil clay content as entered into the SST) and <18% clay ("Low" subsoil clay content as entered into the SST). These thresholds capture 90% of the variability in the literature and Alberta data (further details in the Technical Manual), and thus represent a reasonable yet conservative estimate of typical Alberta soil behavior. While substantial similarities are present between the two sets of curves, the soils with low clay content still show a response to SAR but somewhat less than for the medium or high-clay soils.
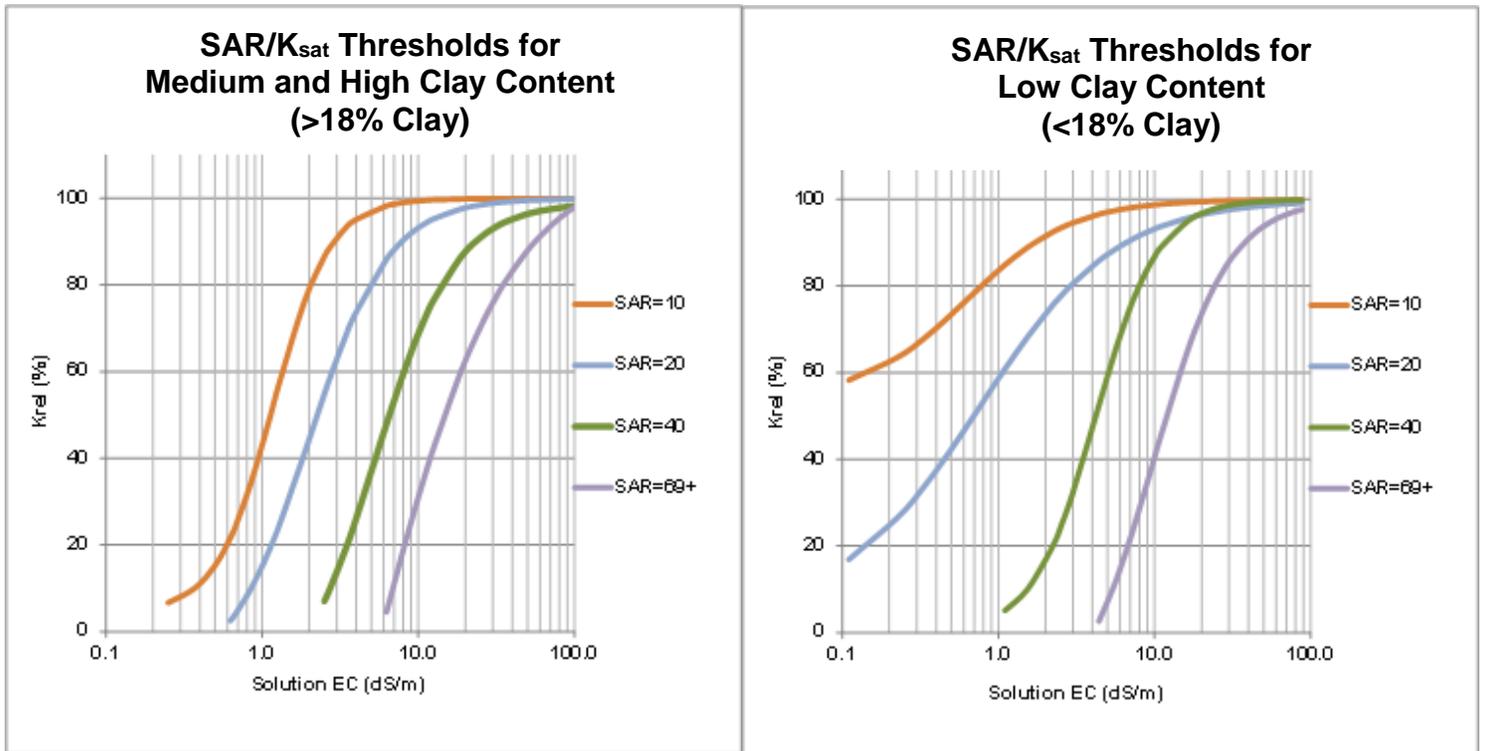
2.17.5 Water Table Modeling

One aspect of developing subsoil SAR guidelines involves combining the results from EC/SAR/hydraulic conductivity experiments (Alberta soil cores and from literature) with water table modeling used to evaluate the potential for adverse effects on moisture transport due to SAR. As mentioned previously, the primary potential adverse effect of SAR in subsoil is creating a shallower and/or perched water table through reduction in moisture transport through soil. If this creates a water-logged root-zone, adverse effects on plant growth may be possible.

The figure below shows a conceptual model for the effects of SAR on water table which could include factors such as magnitude of K_{sat} reduction, infiltration rate, impact size, impact depth, original water table depth, soil texture, and other factors. For example, deeper and smaller impacts likely have less effect on water table whereas shallower and larger impacts may be more likely to have significant effects. These effects may be modelled on either a 1-dimensional (vertical) or 3-dimensional basis for comparison, with the 1-dimensional scenarios less complex due to the absence of lateral transport and assumed infinite lateral source dimensions.
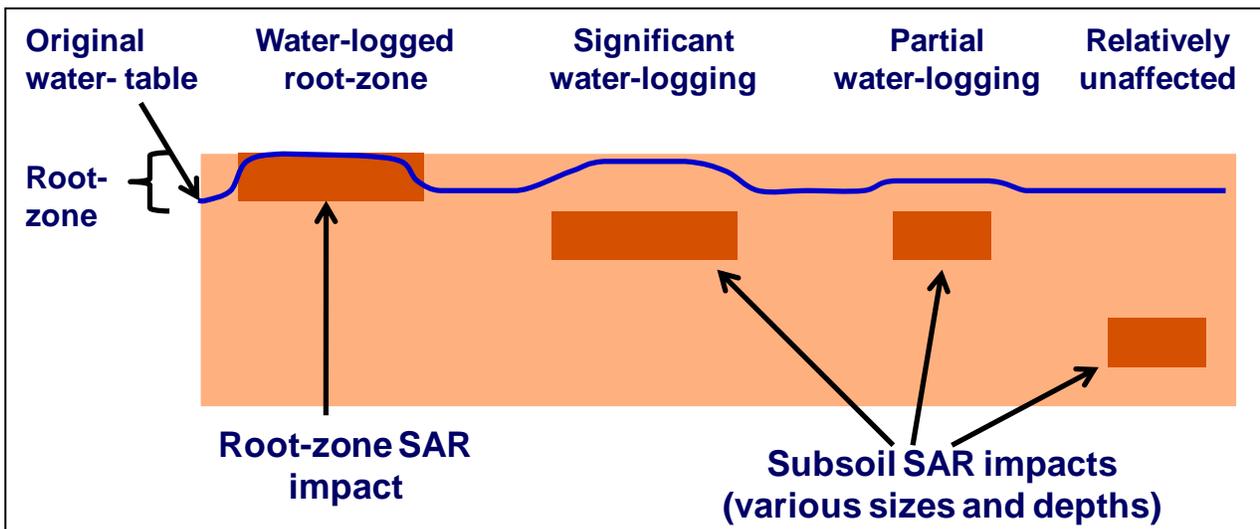
A reasonably detailed and realistic way to examine the interaction between these parameters is through three-dimensional transport modeling using a program such as Modflow™. Such a model allows selecting numerous transport and lithology parameters to create a baseline scenario followed by altering various parameters to evaluate their effects.

For context, a generic baseline model was created consisting of a 3 m water table, 30 mm/year infiltration rate, 1×10^{-8} m/s vertical hydraulic conductivity, and a 1×10^{-7} m/s horizontal hydraulic conductivity. The baseline scenario has essentially vertical water flow with a flat water table and no lateral flow. This model is not intended to represent any specific site, but rather to show general trends and patterns applicable to a wide range of sites.

Starting from this baseline scenario, a first model scenario ("Scenario #1") was created to evaluate the potential effects of a 10-fold (1-order-of-magnitude) K_{sat} reduction in a 40 m wide, 1 m thick impact located at from 7 to 8 m deep. The figure below shows the results of this model scenario graphically, showing a slight disturbance in water flow in the vicinity of the SAR impact as water moves through the impact at a somewhat slower rate and also flows around the edges laterally. The water table is observed to become somewhat shallower above the impact, but the maximum change in water table depth is less than 0.5 m and does not extend into the assumed 1.5 m root-zone which typically contains the majority of root-mass. This scenario is not considered to represent an adverse effect, especially in the context of seasonal water-table fluctuations which can span 1 m or more in many situations.

Conceptual Model Scenario #1: 10-fold K_{sat} Reduction at 8 m Depth
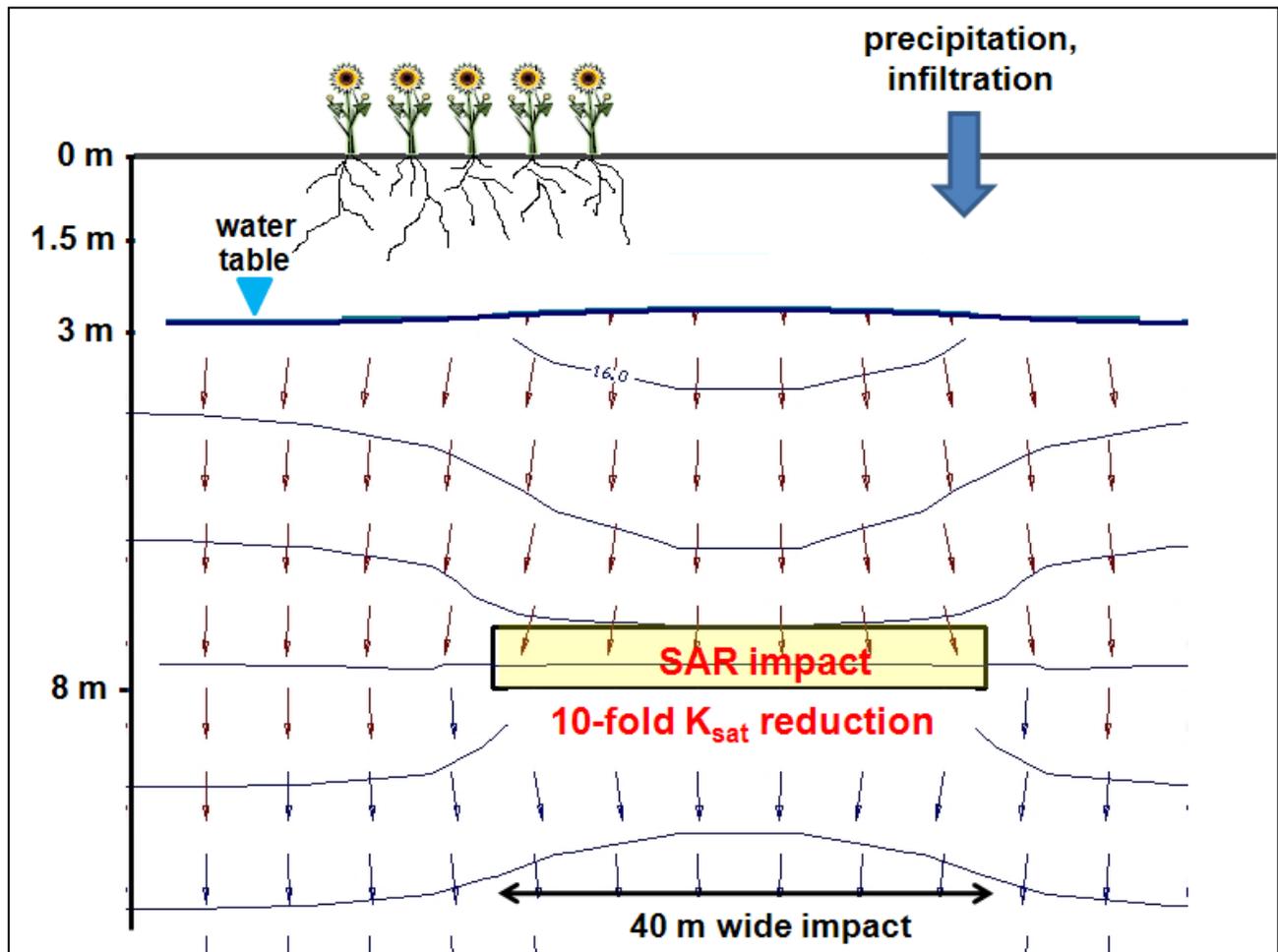
Model scenario #2 involved creating a thicker (5 m thick) SAR impact with the same 10-fold K_{sat} reduction but occurring over the 3 – 8 m depth interval (figure below). A more visible disturbance in water flow is observed in the vicinity of the SAR impact, with more water traveling around the impact due to the increased restriction to flow through the impact. The modeled water table became shallower by 1 – 1.5 m, approaching the root-zone located at 1.5 m. This scenario still does not represent an apparent adverse effect in terms of creating a water-logged root-zone, but is clearly nearer to such a threshold than scenario #1 was.

Conceptual Model Scenario #2: 10-fold K_{sat} Reduction at 3 m Depth

Classification: Public
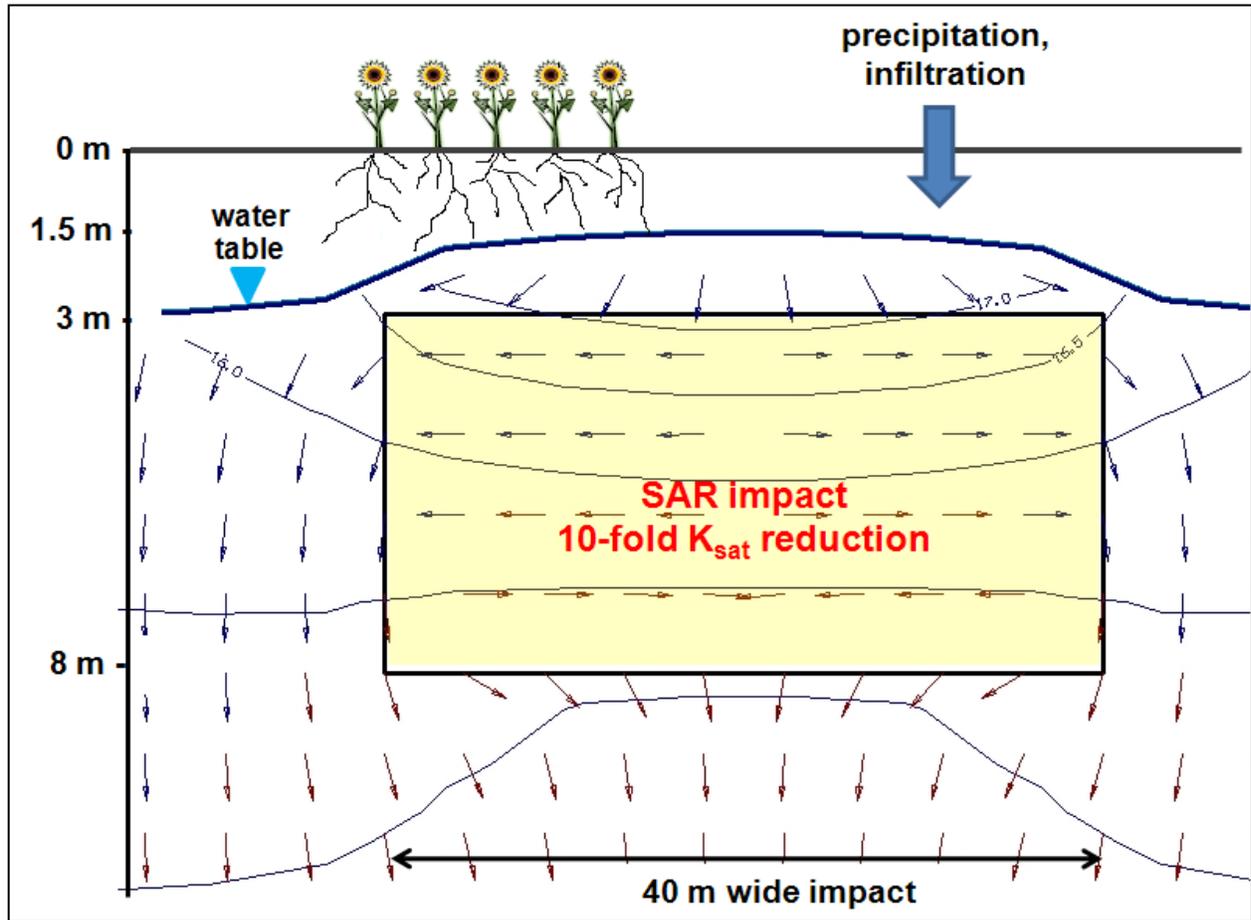
To examine a potentially severe SAR impact, scenario #3 simulated a 10,000-fold (4-order-of-magnitude) K_{sat} reduction over the 3 – 8 m depth interval. The figure below shows results from this scenario, showing a significant reduction in water table depth and water-logging of the root-zone. Compared to scenario #2, water was largely unable to penetrate through the thick SAR impact and thus required a complete reliance on lateral transport. While this lateral transport was able to minimize effects on water table near the edge of the 40 m wide impact, the effects were more significant toward the center of the impact. This provides an initial indication of the influence of impact size on potential water table effects, and can only be studied in the context of a 3-dimensional rather than 1-dimensional model.

Conceptual Model Scenario #3: 10,000-fold K_{sat} Reduction at 3 m Depth
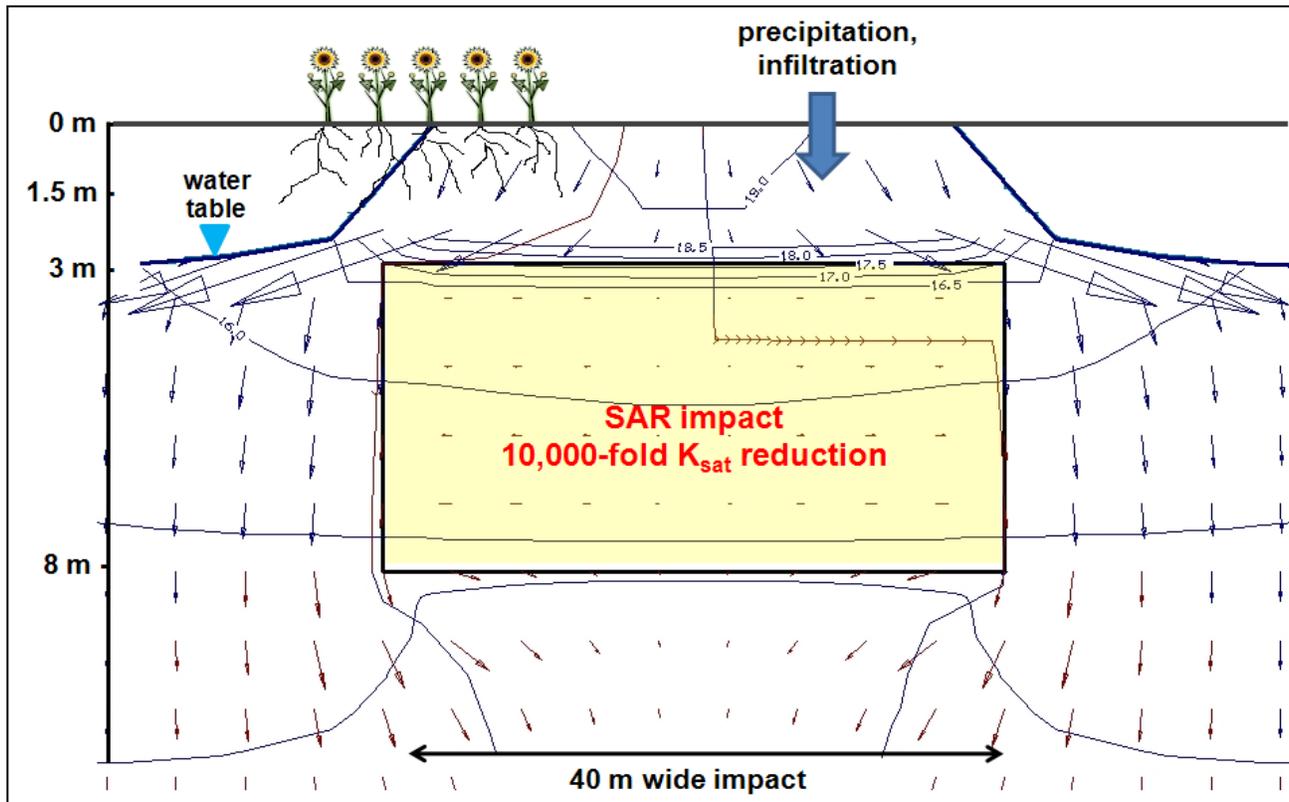
Based on many such model runs, subsoil K_{sat} reductions of 10- to 100-fold appear to be tolerated in many 3-dimensional model scenarios without causing significant water-logging of root-zone soils. This is especially true of deeper, smaller impacts or in cases with deeper water tables. Overall, when combined with more conservative 1-dimensional models (which essentially assume an infinitely wide SAR impact), it appears that subsoil K_{sat} reductions of approximately 10-fold in are unlikely to cause significant water-logging or water-table perching in the majority of scenarios. Thus, an approximate 10-fold K_{sat} reduction threshold is appropriate for evaluating SAR/EC combinations in the majority of scenarios, with somewhat higher K_{sat} reductions tolerated in some scenarios and somewhat lower K_{sat} reductions tolerated in other scenarios.

Within the SST, acceptable K_{sat} loss levels are selected based on a combination of factors such as soil texture, drainage rate, vertical gradient, and top of impacts. These acceptable levels can range from as low as a 4-fold K_{sat} loss (such as for shallow impacts in soils with high drainage rates) to as high a 25-fold K_{sat} loss (such as for deeper impacts in soils with lower drainage rates). Further details of the algorithm for selecting acceptable K_{sat} loss levels are shown in the Technical Manual.

2.17.6 Deriving Subsoil SAR Guidelines

After the SST selects the appropriate K_{sat} threshold based on parameters such as soil texture, drainage rate, and impact depth, a subsoil SAR guideline to protect soil structure can then be derived. This first involves performing various conversions between pore water and saturated paste concentrations, since results from all leaching column experiments are expressed on a pore water basis whereas soil analytical results from a site are expressed on a saturated paste basis. This conversion between pore water (soil solution) and saturated paste concentrations is a function of soil porosity, bulk density, and saturation percentage, and allows generation of an 'EC ratio' and 'SAR ratio' to convert between pore water and saturated paste concentrations for each parameter respectively. Due to the buffering effect of cation exchange reactions and the square-root in the SAR calculation, the change in SAR values between a pore water and saturated paste basis is less than the ratio for EC values. In other words, SAR values tend to stay more stable with changes in water content than EC values do. The SST calculates these ratios internally, which frequently range from approximately 2-3 for an EC ratio and 1.3-1.5 for a SAR ratio. Further details are provided in the Technical Manual.

The SAR guideline is a function of soil EC, because of the role EC plays in protecting soil structure from the effects of sodium. The figure below shows an example of subsoil SAR and EC data from a site plotted against an SST-derived soil threshold after conversion to a saturated paste basis. All subsoil site data lies on the right-hand side of this threshold, indicating that there is sufficient protective EC such that K_{sat} losses will not exceed the derived threshold (in this case, a 10-fold K_{sat} reduction threshold for a fine soil with >18% clay). This indicates current-day risk to soil structure is minimal in this case.
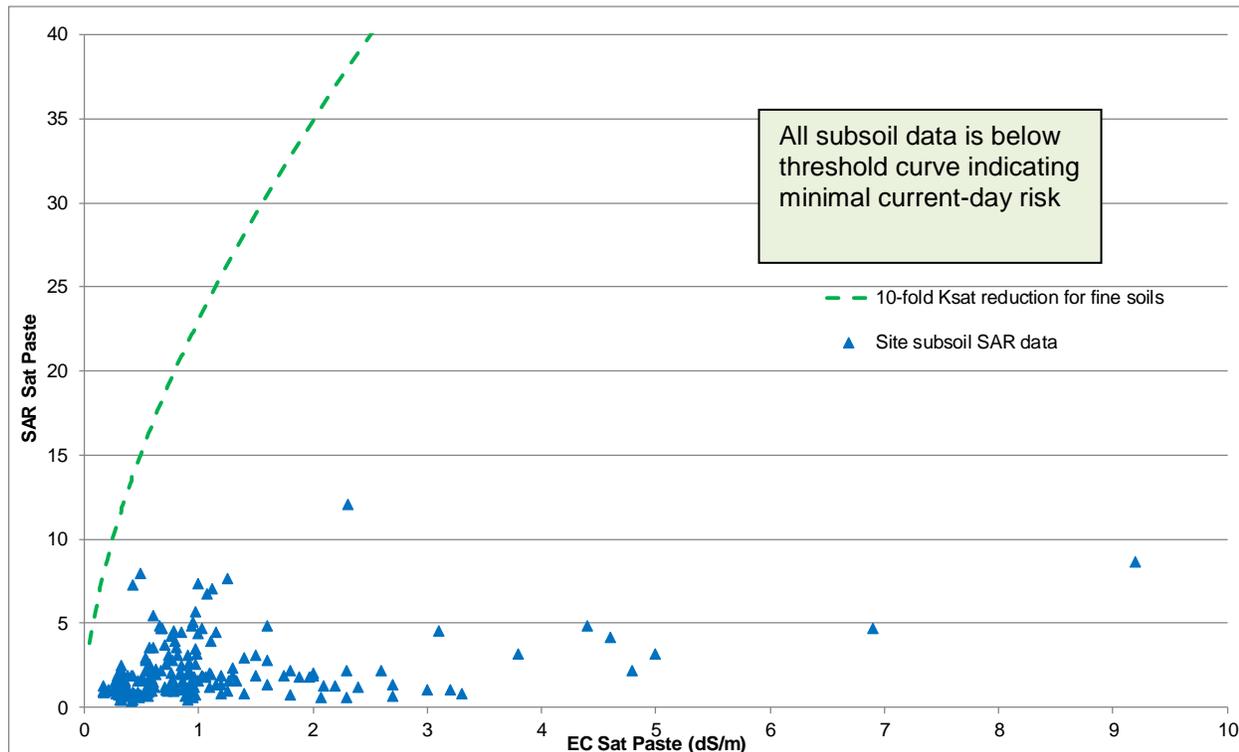
Over time it is possible that EC and SAR values may begin to revert back to levels observed at background locations (i.e. through the vertical and horizontal transport of ions away from the area). Due to the buffering effect of cation exchange reactions, EC is likely to revert to background conditions more rapidly than SAR in the future, and thus there may be potential for samples to potentially cross the K_{sat} threshold in the future. In the most conservative scenario, EC could potentially revert to background conditions while SAR remains elevated at current-day levels, which would be represented by samples moving directly to the left on these threshold curves.

To consider the possibility of future changes in the ratio of EC to SAR, an example of a background line (vertical dashed red arrow) is depicted on the figure below representing the average EC of background subsoil (0.6 dS/m) along with the 10-fold >18% clay threshold and site data previously shown. The background line helps to visualize a potential future scenario in which high SAR soils might revert back to EC values similar to ambient conditions while SAR remains at the original, elevated value. The intersection of this line with the 10-fold threshold curve indicates that SAR values less than approximately 17.5 would be unlikely to cause an unacceptable reduction to hydraulic conductivity based on background subsoil EC values of 0.6 dS/m. In this case, all samples at the Site are below this derived subsoil SAR guideline, thus indicating that both current day and future day subsoil SAR risk to soil structure is considered low and does not warrant additional remediation for this pathway.
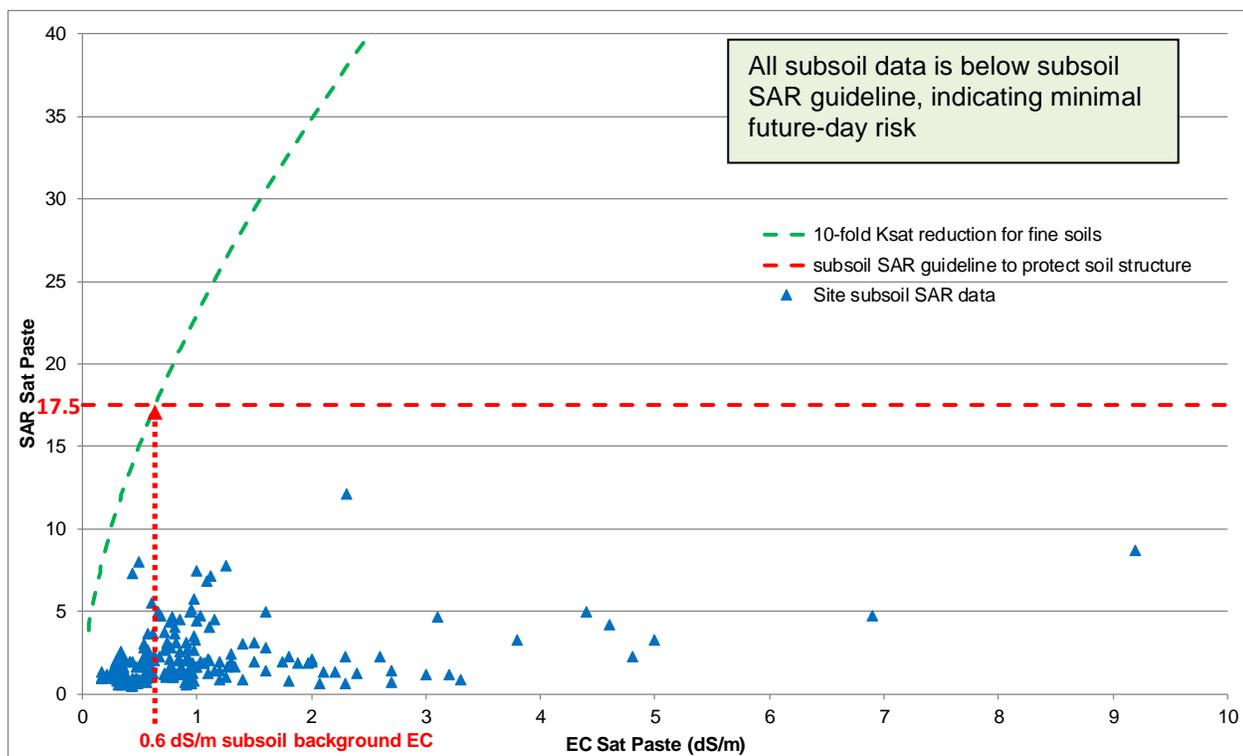
When the SST generates the subsoil SAR guideline in this manner, it also includes a check to ensure that the intersection of the SAR threshold curve and the background subsoil EC does not represent an unrealistic soil condition with calcium plus magnesium concentrations below practical minimum levels. This check ensures that overly conservative subsoil SAR guidelines are not generated under certain situations with very low background EC, and indicates that in such situations that both SAR values and EC values in the impact area will likely reduce over time rather than solely EC reducing. These lower limits on calcium plus magnesium concentrations are dependent on texture (clay content), with values of 0.7 meq/L used for soils with ≥18% clay and 0.2 meq/L used for soils with <18% clay. These values are conservatively based on an analysis of the lower 1st percentile of soil data from a large number of Alberta sites, with further details provided in the Technical Manual.

2.18 Example of SST Input Parameters Table

An example summary table of SST input parameters for a Tier 2A chloride assessment with four SubAreas is shown below. Similar tables along with appropriate additional supporting information should be provided in SST submissions to AER.

TABLE OF SST INPUT PARAMETERS FOR EXAMPLE SITE (CHLORIDE ASSESSMENT, TIER 2A)

SST Input Parameter	Value	Units	Notes
Tier of Guideline	2A	- -	No monitoring wells present
Land Use	Agricultural	- -	See Report Figure x.
Subregion and Climate Moisture Index Category	Central Parkland, Slightly Dry	- -	Based on site legal land location
Overall Soil Lithology	fine	- -	Based on laboratory sieve data, borehole logs, and saturation percentage data from unimpacted boreholes
Measured vertical gradient	N/A	m/m	Not applicable – Tier 2A
Hydraulic conductivity relevant to drainage	N/A	m/s	Not applicable – Tier 2A
Nearby Dugout used as a fish farm?	No	- -	See Report Section x.
Water Table Depth	2 to 4	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
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 Tier 1 EC Guideline (1.0 to 1.5 m)	10	dS/m	'Poor' soil quality category based on the 95th percentile, no outliers, doesn't span three categories
Lateral hydraulic gradient for Shallow Groundwater	0.028	m/m	Default for Tier 2A
Lateral hydraulic conductivity for Shallow Groundwater	1E-06	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
DUA depth or max. drill depth	18	m	Deepest drill depth and no DUA found – see Report Table x.
Source Dimensions	20 x 20	m	Area 1A – see Report Figure x

SST Input Parameter	Value	Units	Notes
	20 x 20	m	Area 1B
	47 x 47	m	Area 2 (unadjusted = 55 x 55 m, adjusted = 47 x 47 m)
	65 x 65	m	Area 3 (unadjusted = 85 x 85 m, adjusted = 65 x 65 m)
Source Length of Entire Site	108	m	Longest distance measured across entire impacted source area
Distance to surface waterbody that is an aquatic life receptor	502 500 490 480	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.
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
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

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

A similar summary table of SST input parameters for a Tier 2B SAR/sodium assessment with four SubAreas is shown below. Compared to the chloride assessment, some additional parameters have been added (such background subsoil salinity and clay content of various intervals), while other parameters are not needed (source lengths, BAF's, FAL distances). Similar tables along with appropriate additional supporting information should be provided in SST submissions to AER.

TABLE OF SST INPUT PARAMETERS FOR EXAMPLE SITE (SAR/SODIUM ASSESSMENT, TIER 2B)

SST Input Parameter	Value	Units	Notes
Tier of Guideline	2B	- -	Several monitoring wells present
Land Use	Agricultural	- -	See Report Figure x.
Subregion and Climate Moisture Index Category	Central Mixedwood, moist	- -	Based on site legal land location
Overall Soil Lithology	coarse	- -	Based on laboratory sieve data, borehole logs, and saturation percentage data from unimpacted boreholes
Measured vertical gradient	0.06 down	m/m	Average from one nested pair, two events
Hydraulic conductivity relevant to drainage	N/A	m/s	Not measured
Nearby Dugout used as a fish farm?	No	- -	See Report Section x.
Water Table Depth	4	m	Average shallow water table depth from monitoring wells – see Report Appendix x and Table x.
Background TDS in shallow groundwater	1,050	mg/L	Average of background wells installed in shallow groundwater – see Report Table x.
Average Root Zone background	38.5	%	Calculated, see Report Table x.

SST Input Parameter	Value	Units	Notes
saturation % (1.0 to 1.5 m)			
Average Root Zone background EC and SAR (1.0 to 1.5 m)	1.1 1.0	dS/m, SAR	Calculated, see Report Table x.
95th Percentile Root Zone background EC and SAR (1.0 to 1.5 m)	2.2 1.8	dS/m, SAR	Calculated, see Report Table x. Note: no outliers. See Table x for outlier analysis. **Label Depth Sat% EC (dS/m) SAR Chloride (mg/kg)** BH1 1.25 38 0.8 0.9 45.2 BH2 1.25 38.5 2.5 2.1 12.3 BH3 1.25 39 0.9 0.8 10.5 BH4 1.25 37 1.1 1.0 74.6 BH5 1.25 40 0.6 0.9 14.6 BH6 1.25 38.5 0.5 0.4 36.3
Root Zone Tier 1 EC and SAR Guideline (1.0 to 1.5 m)	3 dS/m, 4	dS/m, SAR	'Good' soil quality category based on the 95th percentile, no outliers, doesn't span three categories
Lateral hydraulic gradient for Shallow Groundwater	0.022	m/m	Measured gradient from shallow wells – see Report Table x.
Lateral hydraulic conductivity for Shallow Groundwater	2.1E-07	m/s	Arithmetic average from four wells – see Report Table x.
Lateral hydraulic gradient for Deep Groundwater	0.028	m/m	Default, not measured
Lateral hydraulic conductivity for Deep Groundwater	5E-08	m/s	Default for coarse soils, not measured
Background groundwater chloride at aquatic life receptor	30	mg/L	Default, not measured
Background chloride in the DUA	30	mg/L	Default, not measured
Lateral gradient for the DUA	0.028	m/m	Default, not measured
Lateral conductivity for the DUA	1E-06	m/s	Default, not measured
DUA depth or max. drill depth	12	m	Deepest drill depth and no DUA found – see Report Table x.
Root-zone clay	Low		<18% clay in root-zone, see Report Table x.
Background subsoil EC	1.0	dS/m	Average background from 1.5-6 m, see Report Table x.
Background subsoil SAR	0.9		Average background from 1.5-6 m, see Report Table x.
Background subsoil sat%	35	%	Average background from 1.5-6 m, see Report Table x.
Background subsoil clay	Low		<18% clay from 1.5-6 m, see Report Table x.
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 5 3 3	m	Area 1A – see Report Figure x and Table x Area 1B Area 2 Area 3
Type of Root Zone Analysis	Exc+backfill Exc+backfill Unimpacted Unimpacted	- -	Area 1A – see Report Figure x and Table x Area 1B Area 2 Area 3
Backfill properties (average EC, SAR, sat%, clay)	1.0, 1.0, 40, low	dS/m, SAR, %, clay	From backfill characterization – see Report Table x.

⚠️ ***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 as listed below. The majority of information is the same regardless of whether a subsoil chloride or subsoil SAR/sodium assessment is being performed, though some types of information may be required for one type of assessment but not the other (*e.g*, clay content data is required for a SAR assessment but not a chloride assessment). The following information is required on the 'Site Information' page regardless of whether a site is Tier 2A or Tier 2B:

1. Tier selection;
2. Land use;
3. Dugout as fish farm;
4. Subsoil lithology; and;
5. Natural Subregion.

Additional vertical flow information may also be entered on this page, though this is accessible only in Tier 2B assessments and is covered in more detail in Section 4.

In addition to the above, additional site and user information is also required to be entered on the initial 'Submitter Information' page when an assessment is finalized and submitted to AEP/AER. This information includes:
- User name and SST certificate number;
- Company name and information;
- Location LSD;
- Site Name;
- Nearest town or city (can also be used for scenario tracking instead).

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 for the development of SRGs. The land uses defined by AEP (2019a) are Agricultural, Natural Areas, Residential/Parkland, Commercial and Industrial. If an SST assessment is being conducted for non-agricultural land 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   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 in any direction from the site under Tier 2A, or 500 m downgradient of groundwater flow under Tier 2B) that 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.

Once the dugout fish farm checkbox has been checked, the distance to the dugout is entered into the SST instead of any longer distance to a relevant Freshwater Aquatic Life Receptor

Aquatic Life Receptor

Dugout

Distance to dugout is < 500 m, and closer than the nearest aquatic life receptor

Scale: 100 m
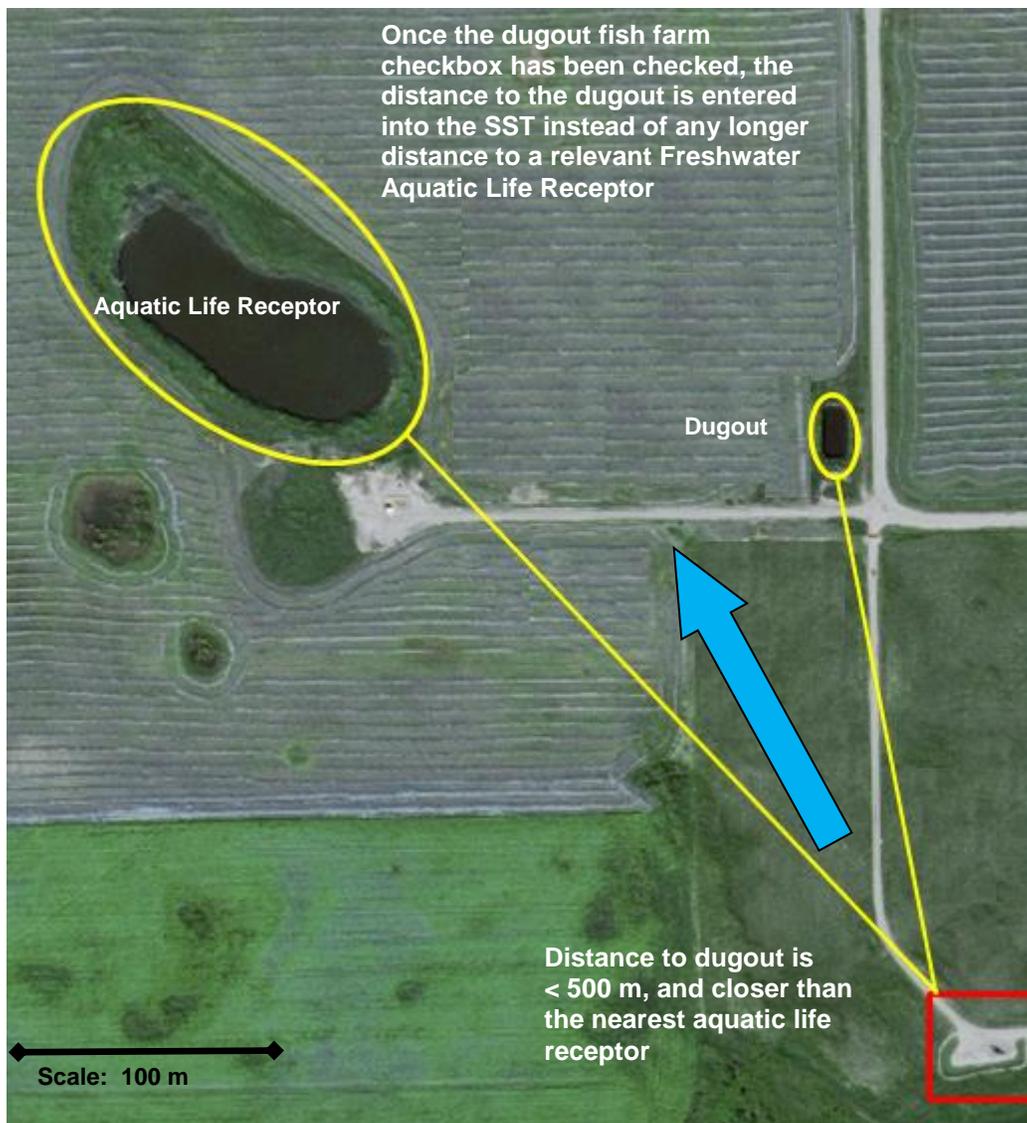
Blue Arrow – groundwater flow direction for a Tier 2B assessment

3.4 <u>Natural Subregion and Climate Moisture Index Category</u>

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 two 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.
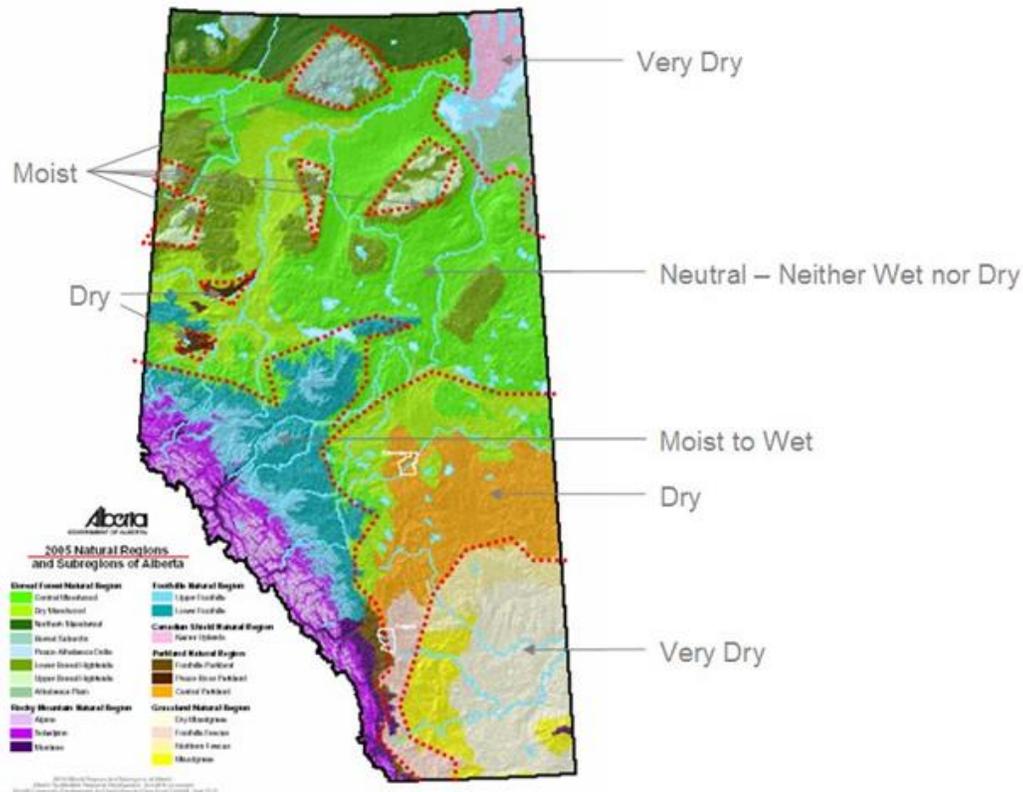
Vertical recharge/discharge rates, determined in part by the selected Subregion and associated CMI, can be further modified by the application of a site-specific vertical gradient and potentially hydraulic conductivity relevant to drainage. This vertical gradient information is calculated from seasonal average nested well elevation data and is applicable only under a Tier 2B approach.

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 practitioner's fine silty clay may be another practitioner's coarse sandy loam). Soil texture data via sieve are required for:

- boreholes located within the salt impacted area;
- 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,
- material intended to be used as backfill.

While sieve data may be sufficient for chloride assessments, additional hydrometer data may also provide additional insight into lithological transitions and transport potential, and thus may be optionally collected. Hydrometer is required along with sieve data for SAR/sodium assessments due to the importance of clay content in cation transport and exchange reactions.

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 (both root-zone and subsoil), 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 and in subsoil. For backfill material, a minimum of three textural analyses are required. The sieve data should be noted from laboratory results and soils classified into the following general categories for use within the SST:

1. Fine Soil (50% or less retained on 75 μm sieve)
   - generally includes heavy clay, clay, clay loam, silty clay, silty clay loam, silt, silt loam, most loams.
2. Coarse Soil (more than 50% retained on 75 μm sieve)
   - generally includes sandy soils with sand content >50% such as sand, loamy sand, sandy loam, and potentially sandy clay loam or sandy clay

Soil textural information can be recorded in tables or on borehole logs for site-specific SST guideline documents submitted to AEP/AER. 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 AEP/AER for assistance with determining appropriate salinity guidelines for muskeg/peat layers.

Hydrometer data and clay content

When a SAR/sodium assessment is performed, texture by hydrometer (particularly clay content) is required in addition to sieve data. Average clay content is required for the root-zone (<1.5 m), subsoil (1.5 m to approximately 6 m), and (if relevant) backfill. A minimum of three samples for each interval is required. Each interval is classified as to whether clay content is "low" (<18%), "medium" (18-36%), or "high" (>36%) for SAR/sodium guideline development based on the arithmetic average clay content for each interval.

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 correlated to 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:

Clay content	Sat %	Texture by sieve
• Low clay concentrations (*i.e.* <18% clay)	20% - 50%	(potentially coarse by sieve)
• Medium / high clay concentrations (*i.e.* ≥18% clay)	50% - 70%	(likely fine by sieve)
• Heavy clay (*i.e.* >60% clay)	70% - 120%	(very likely fine by sieve)
• Organic soils	90% - 130%	(very likely coarse by sieve)

Additional Alberta-specific analyses have been conducted under contract to the Petroleum Alliance of Canada (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 SST is able to model sites both with relatively consistent lithology (i.e., uniformly fine or coarse), and is also able to model more complex lithologies where a site is a mixture of fine and coarse lithologies. This is done through the use of three independent lithology selections, including overall lithology (governing vertical transport), shallow groundwater lithology (governing lateral transport to FAL receptors, into dugouts, and toward adjacent agricultural land), and deep groundwater lithology (governing lateral attenuation of impacts during vertical transport toward the DUA). Either fine or coarse must be selected for each of these lithologies regardless of whether a Tier 2A or Tier 2B assessment is performed. In the case of a Tier 2A assessment, default hydraulic parameters are assumed for each of these lithologies based on whether fine or coarse is selected. For a Tier 2B assessment, the user may additionally include site-specific measured values for hydraulic gradient and/or conductivity for any of these three lithologies (further details on measured groundwater parameters provided in Section 4). For each lithology category (overall, shallow, or deep), the arithmetic average % retained by sieve 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 for each category.

Lithology selection 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 coarse continuous layers of limited thickness may potentially be considered 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. The lithology selection for shallow groundwater allows the user to address this scenario and ensure that as a minimum, shallow 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. This is also relevant to the dugout pathway since shallow groundwater properties also strongly influence the mixing of groundwater into dugout waters.

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 must 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.

In general, 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 for overall soil lithology, shallow groundwater lithology, and deep groundwater lithology.

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

An overall lithology for vertical transport of 'fine' would be entered into the SST for this example. The impacts are located within fine soils, and the drainage rate is influenced by transport through fine surficial soils. Similarly, for the root zone pathway, impacts must be transported vertically within the fine till. 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 potentially 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, the primary saturated lithology through which impacts may transport into the dugout is coarse, and thus a shallow groundwater lithology of 'coarse' would be applicable. For the FAL receptor, a coarse texture would also be applicable for shallow groundwater due to the continuous saturated coarse interval which may connect the salinity impact with a FAL receptor. The shallow groundwater selection allows default coarse hydraulic parameters to be used for shallow groundwater (*i.e.*, hydraulic conductivity of 1x10^{-5} m/s and hydraulic gradient of 0.028) to ensure the derived SRGs are appropriate for sites where continuous coarse intervals in shallow groundwater are encountered in predominantly fine till.
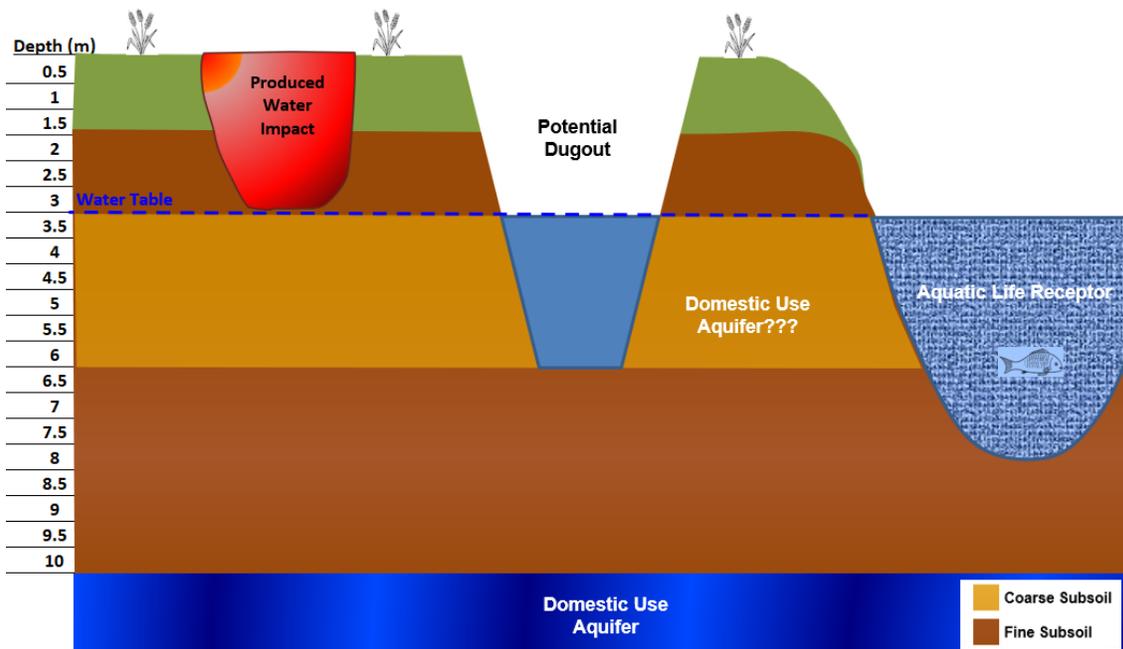
Tier 2B

For a Tier 2B assessment, a fine overall lithology would be selected as per Tier 2A. For shallow groundwater, a coarse lithology would be appropriate for the same reasons as Tier 2A, with the exception that monitoring wells could be screened within the coarse interval and site-specific values for the hydraulic gradient and conductivity of shallow groundwater could be determined. The hydraulic conductivity of wells within the coarse interval could also be measured to determine whether this unit is a DUA. Similarly, a pump test to determine groundwater yield 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, and coarse saturated subsoil from 3 to 6 m, if a site-specific vertical gradient is to be determined, it will generally be necessary for the installation of multiple wells nests. Such scenarios with variable lithology frequently require more than one set of nests, with ideally at least one set of nests to be installed within each distinct lithology. For example, nested well data from the underlying fine textured soil (from 6 to 10 m) would be relevant to deep groundwater, 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 Section 4.10.

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 overall soil lithology would be selected for vertical transport. 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. Fine soil lithology should also be selected for shallow groundwater (relevant to the FAL receptor and dugout pathways). 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 thus do not represent a DUA, and the DUA depth is thus set at the maximum depth of drilling (10 m).
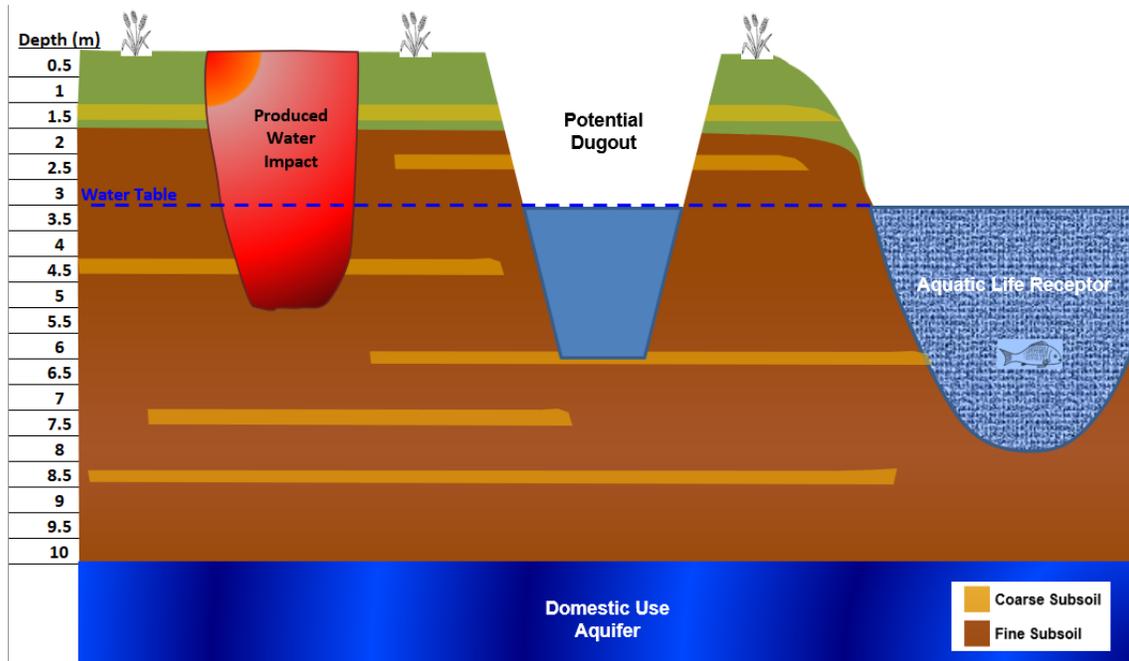
Tier 2B

Under Tier 2B, a fine overall lithology would similarly be selected. Shallow groundwater would also be considered fine, and shallow groundwater wells would be required with screen intervals installed near the water table surface if site-specific values were to be used for shallow groundwater. 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 nested 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 generally 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. Fine soils were then encountered to 10 m (maximum depth of drilling).
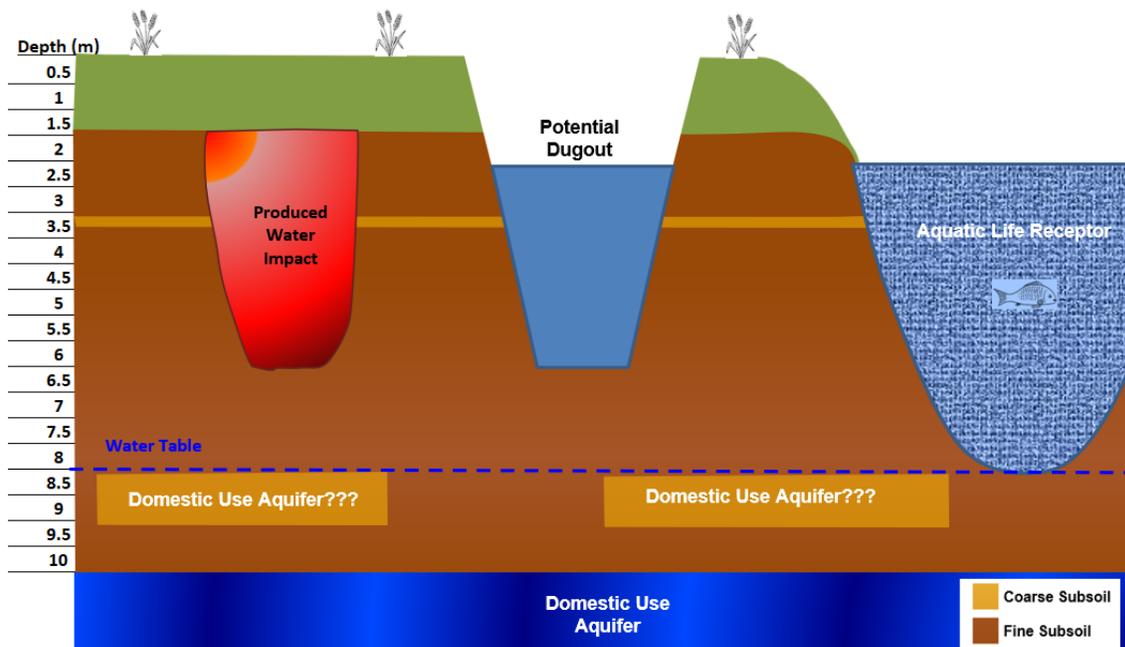
Tier 2A
Under Tier 2A, a fine overall lithology would be entered into the SST for vertical transport. The root zone scenario would be an Unimpacted Root Zone. The dugout pathway is eliminated as the water table is deeper than 6 m. The thin coarse continuous interval at 3.5 m is thinner than 0.5 m and as a result it is not considered a DUA. Furthermore, this interval is within the vadose zone and is unsaturated, therefore it will not control lateral transport to the dugout or aquatic life receptor. For the FAL receptor, coarse lithology would be selected for shallow groundwater since the lithology at the water table has relatively thick and not uncommon coarse intervals. For deep groundwater, 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 overall lithology would similarly be fine for vertical transport. The dugout pathway is eliminated based on water table depth. For the FAL receptor, a coarse lithology would be selected and monitoring wells screened across the shallow water table at 8 m could be used 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 1×10^{-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 (the maximum depth of drilling).
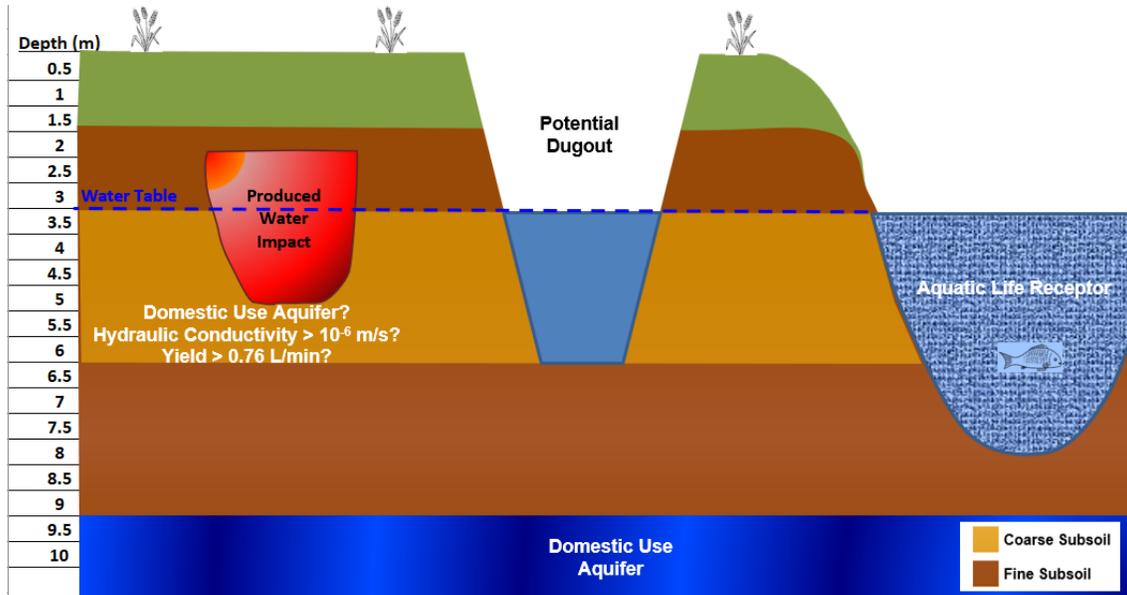
Tier 2A
Under Tier 2A, the DUA is assumed to be at 3 m, which is the top of a continuous coarse interval (>0.5 m thick) characterized by coarse sieve data. The site would be considered fine for overall lithology, and coarse for shallow groundwater. Fine soil lithology controls upward movement of chloride toward the root zone and downward movement of that portion of chloride that is above the water table. The impacts below the water table are primarily subject to lateral flow conditions, which are controlled by shallow groundwater lithology. However, 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 225 mg/L, it is possible to conduct a Tier 2B assessment and calculate appropriate SRGs (given uncertainties in the measurement and modeling, the SST cannot be used when DUA impacts are within 10% of the guideline). The site would be run as a fine texture for overall lithology (and coarse for shallow groundwater) 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 chloride drinking water objective of 250 mg/L. If monitoring well data for the DUA indicate that chloride concentrations exceed 225 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. Of these, the majority of groundwater data is most relevant to subsoil chloride assessments due to the importance of transport pathways such as the DUA and aquatic life. However, some groundwater data is also useful for subsoil SAR/sodium assessments, including water table depth, and shallow groundwater properties including hydraulic properties and TDS. The groundwater investigation requirements shown in this section 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 <u>Water Table Depth</u>

The depth of the water table is a parameter in the SST that influences essentially all pathways for chloride or SAR/sodium. SRG's for the root-zone pathway are influenced by water-table depth via the degree of unsaturation of the root-zone and subsoil and consequent influences on diffusion and transport. SRGs for the livestock and irrigation watering pathways are determined based on the predicted peak breakthrough concentrations occurring between the depth of the water table and a maximum depth of 6 m. The pathways can be eliminated if the water table is greater than 6 m. These dugout pathways are also strongly influenced by water table depth since it influences the estimated flux of groundwater into the dugout (deeper water table results in less groundwater flux into the dugout to mix with surface runoff) SRGs for the FAL pathway are dependent on the peak chloride breakthrough concentration occurring at the water table depth, as well as peak concentration attenuation during subsequent lateral transport through shallow groundwater 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 in deep groundwater 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, as in the majority of cases a shallower water table results in more predicted receptor risk and more restrictive guidelines. 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 shallower end of the range is conservatively used to calculate SRGs, with (for example) a 2 to 4 m water table depth range selected by the user treated as 2 m within the tool. If the user selects <2 m for water table depth, it is treated as 1.5 m (thus, directly below the base of the root-zone) in the tool. An example of borehole data from a single site 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 Entered Range

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, unless borehole evidence is provided to show that the depth of groundwater is below the maximum depth of drilling. In that case, a single well screened to the maximum depth of drilling is sufficient to confirm the borehole observations. 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). 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. A Tier 2C approach is required 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).

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 whether groundwater is excessively naturally saline for the use of dugout water for livestock or irrigation (potentially excluding the pathways under certain scenarios), and also influences mixing calculations and/or chemistry buffers for livestock or irrigation SRG's. It is assumed that the potential future dugout can be located anywhere on a site.

4.2.1   Tier 2A

Background soil concentrations of sulphate and bicarbonate are used to estimate a background groundwater TDS concentration in the absence of monitoring well data in Tier 2A scenarios. Carbonate data can also be included, although carbonate concentrations are typically non-detectable at typical site pH's. The estimated groundwater TDS concentrations are subsequently used in the SST during SRG calculations for the irrigation water and livestock watering pathways. At sites where it is estimated the water table will be shallower than 6 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 up to 2 m above the estimated water table (to a minimum of 1.0 m) and down as deep as 6 m can be 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 6 m can be used to estimate background groundwater TDS. If the water table is at 2 m, data from 1 m to 6 m can be used. Topsoil samples or data from the top 1 m of soil are generally 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 in the section below (the calculations are done internally in the SST).

The table below shows an example calculation from a fine-grained site with a 3 m water table and background boreholes generally drilled to 5 m. It shows the sulphate concentrations pre-averaged (outside the tool) for each borehole over the relevant 1 to 5 m depth interval, along with the estimated groundwater TDS calculated by the SST from entering the average sulphate concentration into the tool (see next section for details). The TDS that would have been calculated individually by the SST for each borehole is also shown for context.

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 Groundwater TDS (mg/L)
BH11-01	1.0	145	n.m.	n.m.	42	55	141.4	611
BH11-01	2.0	162	n.m.	n.m.	34	58		
BH11-01	3.0	133	n.m.	n.m.	38	54		
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	113.4	490
BH11-02	2.0	118	n.m.	n.m.	24	68		
BH11-02	3.0	101	n.m.	n.m.	37	52		
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	123.7	534
BH11-03[1]	2.0	133	n.m.	n.m.	38	57		
BH11-03[1]	3.0	111	n.m.	n.m.	22	53		
BH11-04	1.0	106	n.m.	n.m.	8	48	106.0	458
BH11-04	2.0	104	n.m.	n.m.	12	47		
BH11-04	3.0	103	n.m.	n.m.	14	49		
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**	**523**
SST Calculated:	- -	- -	- -	- -	- -	- -	- -	**523**

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.***

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, 2012b). 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 addressed later in the manual.

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

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

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

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

where,

$BGWC_{TDS}$	=	Estimated Background Groundwater Concentration (mg/L) for sulphate-derived 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 change in gypsum solubilisation is addressed
		fine soils 369
		coarse soils 233
ρ	=	Dry bulk density of soil – texture dependent (g/cm^3)
		fine soils 1.4
		coarse soils 1.7
θ_T	=	Porosity – total (assumes saturated soils, unitless)
		fine soils 0.47
		coarse soils 0.36
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 and calcium
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 (for example, a Ca:SO$_4$ ratio of 0.99 on a milliequivalent basis, which is a cation solution composed of 99% calcium), greater proportions of calcium in solution can cause the formation of gypsum (CaSO$_4$). This 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). In this case, 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.
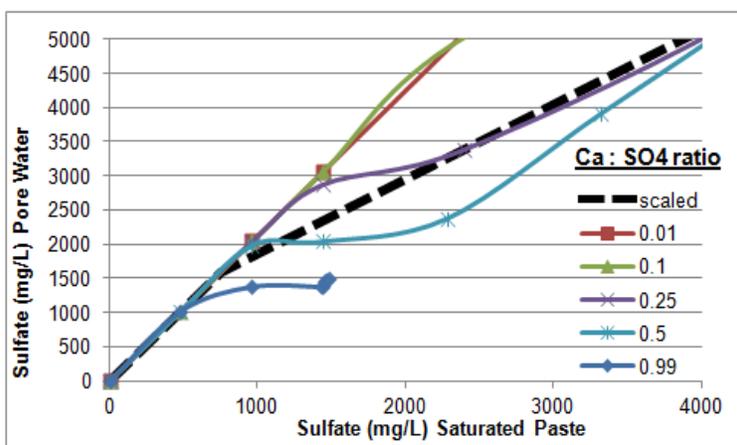
Equilibrium, 2012

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 used for determining the matching cation milliequivalent.

4.2.1.2 Laboratory Reporting of Sulphate

The SST requires the user to enter sulphate data in units of mg SO$_4$/kg soil. There are multiple expressions of sulphate data used by analytical laboratories in Alberta, and care is required to ensure the data entered into the SST is expressed in appropriate units. Some examples are provided below:

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

*The notations shown in black font above indicate the entire sulphate molecule (SO4) is reported, whereas the notations in **orange font** indicate solely the sulphur (S) portion is reported. Some notations (such as Sulphate (SO4-S)) may be ambiguous and could potentially represent different measures from different laboratories. **If a sulphate notation is uncertain, consult with the issuing laboratory for confirmation.***

With the exception of notations shown in orange font (and potentially the ambiguous case shown with an asterisk), the notations in black font above indicate the laboratory is reporting the full sulphate molecule (SO4) and accounting for the molecular weight of sulphur and four oxygen atoms. These values (in mg/kg) can be directly entered into the SST to

calculate background TDS. The notations shown in orange (such as **Sulphate-S** or **SO4-S** or **Sulphate as Sulphur)** indicate solely the sulphur (S) portion is being reported and an adjustment is required. If the starting data being used is on a milliequivalent basis, the cases become equivalent and the following adjustment does not need to be made, although the data must be converted to mg/kg. But if reported in units of mg/L saturated paste or mg/kg soil, the **Sulphate-S** or **SO4-S** or **Sulphate as Sulphur** concentrations (or any other sulphur-based reporting) need to be multiplied by three (molecular weight of sulphate (96) divided by the molecular weight of sulphur (32), both having a 2- charge) prior to entering into the SST. The other ways of reporting sulphate (as SO4) do not require an adjustment.

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

Where,

SO$_4$	=	sulphate as sulphate (mg/L or mg/kg)
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

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 on a sulphur basis) so that the results are reported as mass of sulphate (hence terms such as Sulphur as Sulphate). 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 (<300 mg/L chloride for fine soils, or < 470 mg/L chloride for coarse soil, 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 6 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 300 mg/L (fine) or 470 mg/L (coarse) in groundwater are within the range that determines 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.

The adjusted TDS (adjusted to 30 mg/L chloride) 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.

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

Where,

BGWC$_{TDS\_ADJ}$	=	Adjusted to 30 mg/L 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

This equation simplifies to the following, assuming the cations are composed of 50% calcium and 50% sodium.

$$BGWC_{TDS\_ADJ} = BGWC_{TDS} - ([BGWC_{Cl} - 30] \times 1.61)$$

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) cannot be used directly because of the incorporation of a monitoring well with chloride concentrations above 30 mg/L. Using the formula above, this unadjusted TDS 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 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 from background and site-related impacts to aquatic life inhabiting the interface between surface water and groundwater (*i.e.*, sediment dwelling). 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 that case the allowable chloride contribution to the aquatic life pathway from the site under study 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 caused by 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 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. If this background chloride concentration is greater than 90% of the 120 mg/L Tier 1 aquatic life guideline (*i.e*, >108 mg/L) then a Tier 2C assessment must be performed.

4.4   DUA Depth

The depth to a DUA is used with the depth of chloride impacts to calculate 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 AEP 2019a/b 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 25 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 AEP (2019a).

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 AEP (2019a). 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
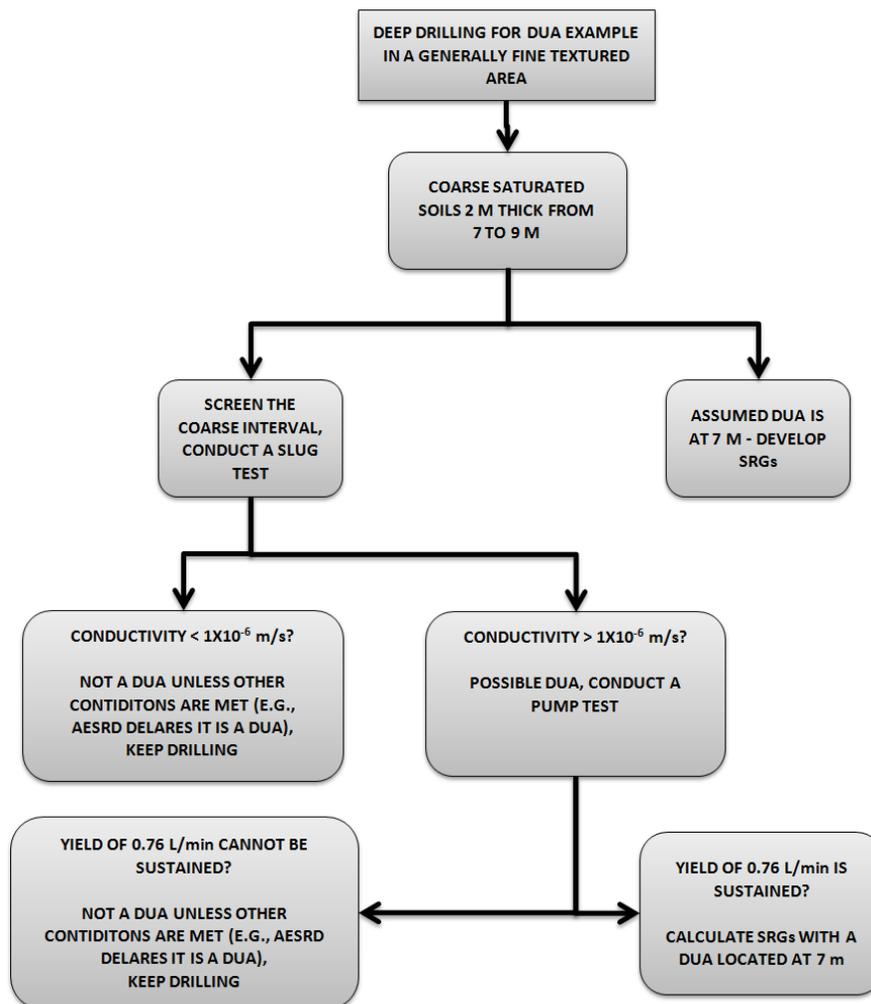
4.4.2 Regional Water Well Search

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 <u>Distance to Aquatic Life Receptor</u>

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 Alberta Wetland Classification System (ESRD, 2015). The "Classification Key to Wetland Classes and Forms" should be consulted (Page 11 of ESRD, 2015), and anything that is classified as terrestrial non-wetland (i.e. Classes 2a and 2b) is not considered an aquatic receptor in the SST. This includes terrestrial Class 2a "Upland" features (described as "No evidence of water tolerant vegetation, water altered soils or surface water"), and Class 2b "Ephemeral Water Bodies" (described as "Evidence of water altered soils may be found deeper than 30 cm below the ground surface or may not be present at all. Surface water is present in most years, but only for a brief period of days after snowmelt or a heavy rainfall. Although some water tolerant vegetation may be present, they are not dominant and are intermixed with a majority of upland species"). Class 2a "Aquatic" features are considered an aquatic receptor.

⚠️ ***Clear diagrams showing the site and all potential nearby surface water bodies must be reported. It should be noted that a Tier 2C analysis must be conducted if the distance to a FAL receptor in the SST is less than 25 m for total source dimensions less than or equal to 25 x 25 m (625 m^2), or less than 50 m for total source dimensions of greater than 25 x 25 m but less than or equal to 50 x 50 m (2500 m^2), or less than 100 m for total source dimensions greater than 50 x 50 m (2500 m^2). Situations where the chloride contamination is within the high water mark boundary of a SST FAL receptor require a Tier 2C assessment.***

Subsoil SST SRGs for the FAL receptor are dependent on the contribution of facility-related chloride impacts, added to a reasonable worst case estimate of a mean background chloride concentration, to the FAL chloride water quality guideline of 120 mg/L. The SST calculates the contribution of facility-related chloride 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. 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 exceedance 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 25 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.
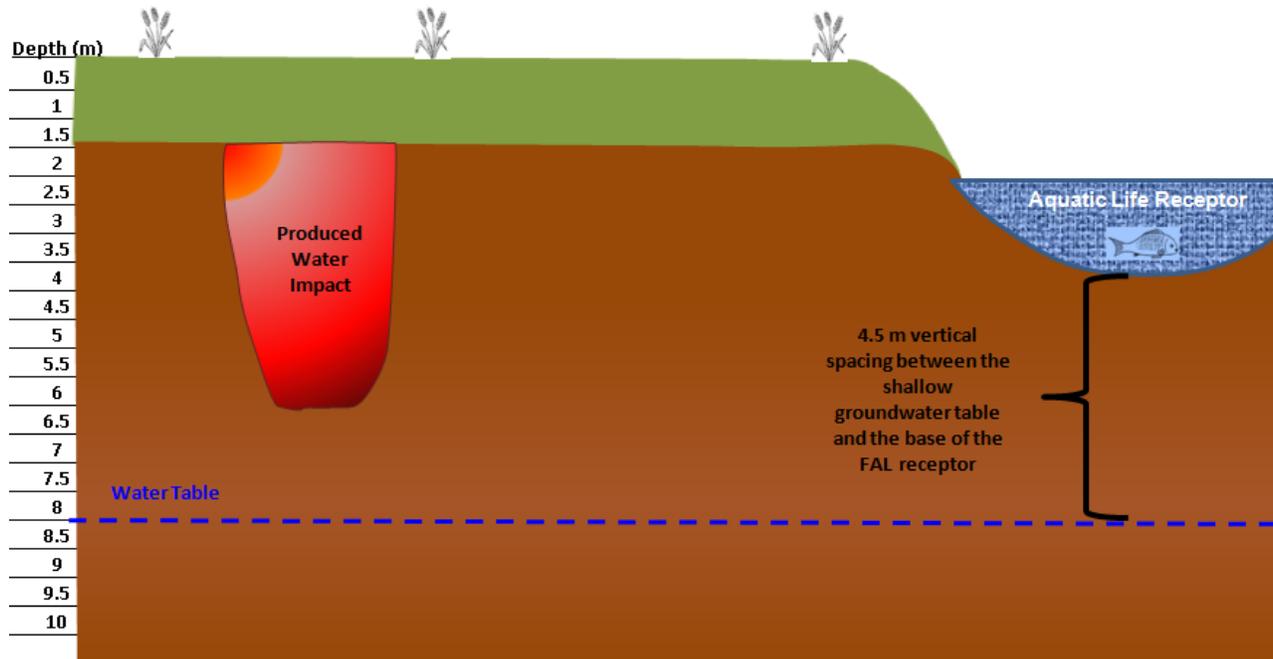
4.5.1 Tier 2A

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 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° arc (or 30° 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 exceedances of 120 mg/L at the groundwater/surface water interface in a FAL receptor.
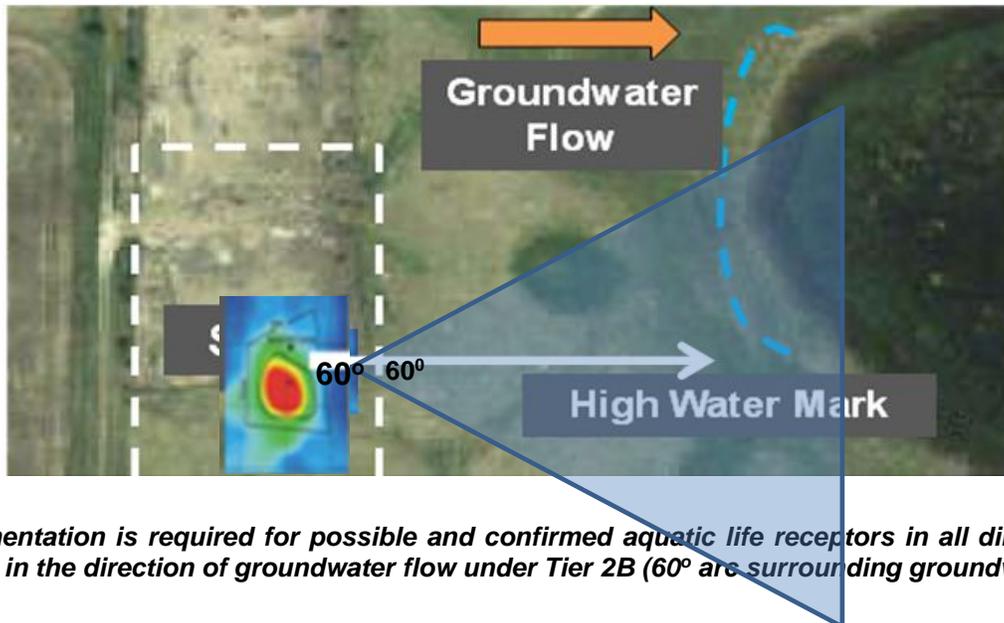
⚠️ *Proper documentation is required for possible and confirmed aquatic life receptors in all directions of the site under Tier 2A and in the direction of groundwater flow under Tier 2B (60° arc surrounding groundwater flow).*

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, or to adjacent agricultural land. It also represents the water bearing zone in contact with a hypothetical future dugout, and thus influences mixing and guideline calculations for the livestock and irrigation pathways.

4.6.1 Tier 2A

Shallow groundwater conductivity and gradient parameters cannot be changed for Tier 2A assessments. SST default parameters are consistent with the Tier 1 defaults, as follows:

Shallow Groundwater: Coarse Soil   Hydraulic gradient   0.028 m/m
                                                     Hydraulic conductivity 1×10^{-5} m/s

Shallow Groundwater: Fine Soil   Hydraulic gradient   0.028 m/m
                                                     Hydraulic conductivity 1×10^{-6} 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. It also determines the velocity and attenuation factor during flow to adjacent agricultural land (if relevant), and the rate of shallow groundwater entering a dugout and mixing with surface runoff. Significant differences in hydraulic conductivity and gradient measured within a site may a reason for separating the site into SubAreas. This may occur where distinct soil lithology exists and/or where multiple groundwater vectors are 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. The SubAreas established for this reason must be run separately and if the chloride plumes from the SubAreas are interacting, discussions with the regulator may be necessary to ensure the complexities introduced by distinct hydrogeological environments are being adequately evaluated.

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 25 m/yr. A Tier 2C assessment must be conducted if the shallow groundwater velocity exceeds 25 m/yr. It should be noted that a groundwater velocity of approximately 1.9 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.
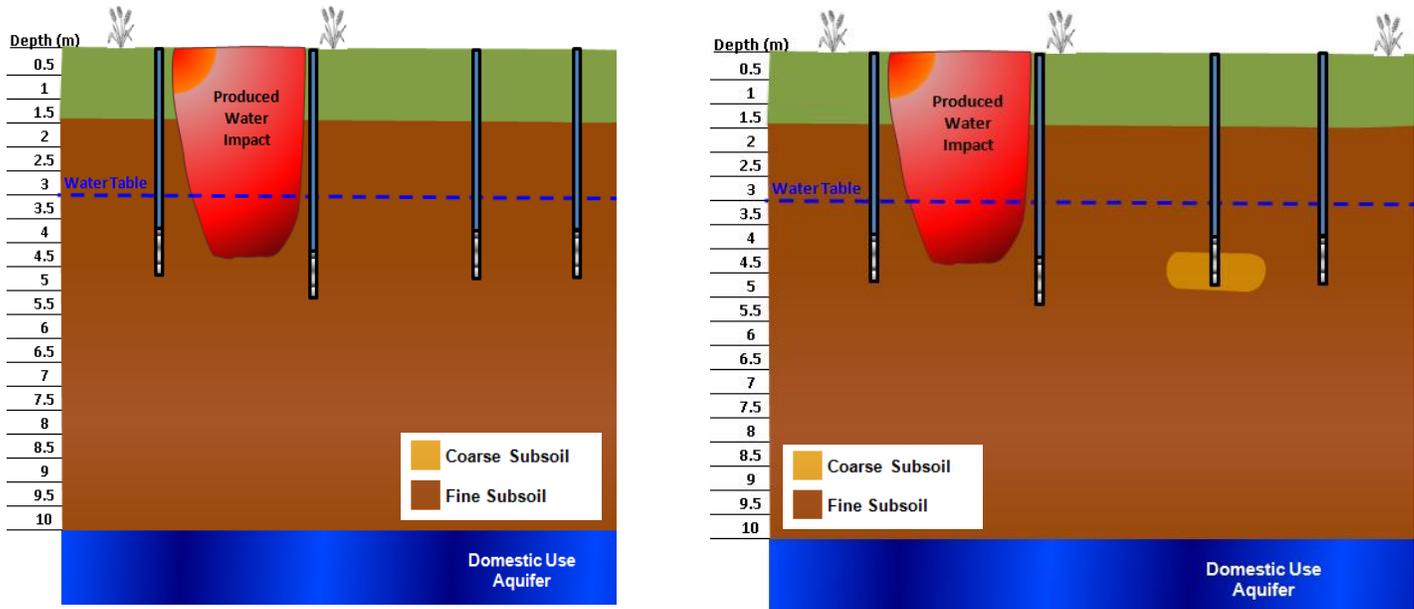
A seasonal average hydraulic gradient is calculated based on two monitoring events each from a distinct season (winter, spring, fall, summer). The events should avoid periods of snowmelt/spring runoff, which may reflect a short term change in the annual average gradient. Gradients from both seasons can 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.
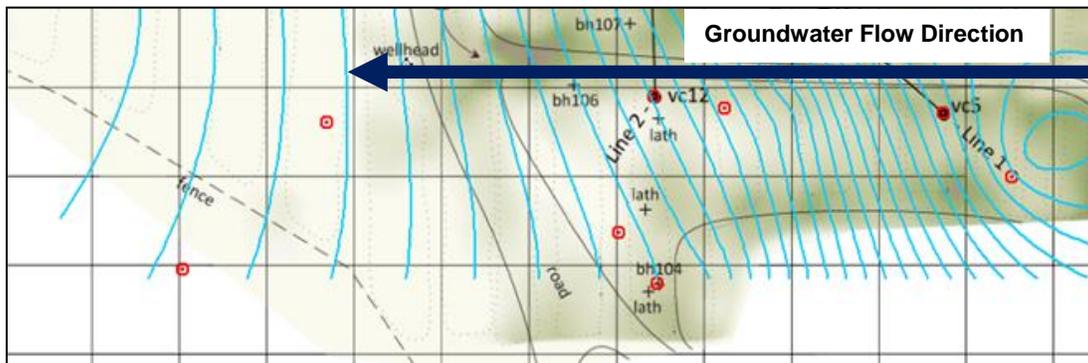
A US EPA online calculator is available that can be used to calculate lateral hydraulic gradients (US EPA, 2016a). However, in some circumstances it can produce potentially misleading gradients, particularly if there is poor well spacing or complex groundwater flow patterns. For example, three wells that are installed in a line with one well slightly laterally offset may lead to an inaccurate calculated gradient. Sites with complex flow in multiple directions may also give misleading results when expressed as a single average flow direction and gradient, such as inward or outward radial flow which may produce an average flow direction and gradient of near zero. To avoid such issues, as a replacement or supplement to such tools, a groundwater contour diagram should be developed to allow for a professional assessment of flow direction and gradient prior to entering 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, and do not affect drainage rates (these are determined separately by texture, climate, and potentially vertical gradient and hydraulic conductivity relevant to drainage). 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 deep 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. However, this is considered a Tier 2C approach because each SubArea must be run independently and interpretation of the results will require additional discussion with the regulator.

As with shallow groundwater, a minimum of two monitoring events is required for elevation 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. The arithmetic average hydraulic conductivity and lateral gradient for deep groundwater are automatically internally constrained to velocities less than 1 m/year, to avoid guideline calculation issues related to a reduced differential velocity between deep groundwater and the DUA. If the calculated deep groundwater velocity is greater than 1 m/year, the SST will conservatively use a deep groundwater velocity of 1 m/year for SRG calculations for the DUA.

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 statistical estimate of the hydraulic conductivity and hydraulic gradient of deep groundwater across a site. Note that this is a specific exception to the typical Tier 2 requirement of requiring 4 wells to use a statistical measurement rather than a conservative value. 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 25 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 does 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 for overall lithology (vertical transport and drainage rate are not directly influenced by deep groundwater parameters).
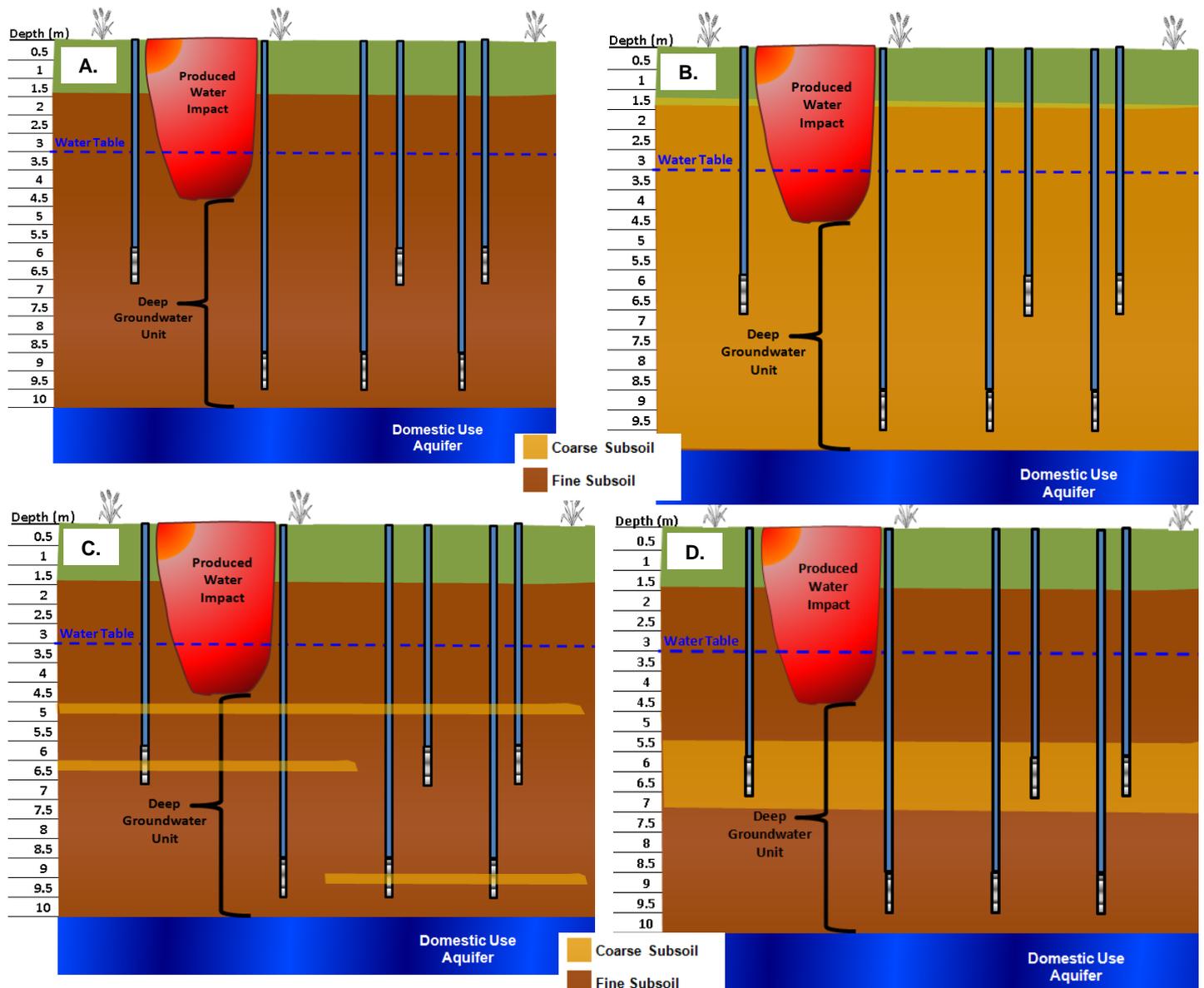
4.8   Hydraulic Conductivity and Gradient of the DUA

The hydraulic conductivity and gradient of the DUA is used primarily in calculating the value of the DF3 parameter (implemented in Version 3 using the Summer's Mixing Model), 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 as follows. Note that this assumes the DUA has not been specifically characterized, and is thus conservatively assumed to be a 'fine-grained' DUA with parameters consistent with Tier 1. These DUA assumptions cannot be changed under a Tier 2A scenario.

1. DUA hydraulic conductivity $1x10^{-6}$ 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 25 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 $1x10^{-6}$ 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. For situations where the arithmetic mean exceeds $1x10^{-6}$ m/s, the geometric mean is entered into the SST for the DUA hydraulic conductivity. 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 $1x10^{-6}$ 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 flux (Darcy velocity) of 0.88 m/year. If the DUA flux calculated by the SST is less than 0.88 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 225 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 <u>Vertical Hydraulic Gradient</u>

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 potentially complicated process, requiring professional judgement and 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, 2016b). An example input and output from the calculator is provided below, showing the 'concise' output display which uses the most relevant 'screen midpoint value' (0.017 downward [recharge] in this case).

Input Parameters	Surface Elevation	Depth to Well Screen	Screen Length	Depth to Water
Shallow Well	695.85	4.2	3.3	7.12
Deep Well	695.85	8.8	1.7	7.16

Results	Magnitude	Flow Direction	
Screen mid-point value	0.01709	down	
Range of Estimates	0.01183 to 0.03077	down; down	More information...
	Flow directions can be determined. Shallow well is a water table well. Only submerged length used in calculations.		
Gradient Estimate Between Piezometers (screen lengths equal to zero)			
Piezoemeters	0.008696	down	

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 with the drainage rate based on overall soil lithology, 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, ranging from days to potentially months. Wells must be developed adequately after installation, as 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. Use caution when considering averaging a large (and potentially anomalous) gradient into other lower-gradient data as it may misrepresent site conditions. <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 effect 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 discharge (*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 or equal to 50 x 50 m (2,500 m²), 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 (2,500 m²) but less than or equal to 100 x 100 m (10,000 m²), a minimum of two nested wells is required. For total source dimensions of greater than 100 x 100 m (10,000 m²), 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 slough 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 shown below installed within either a fine or coarse soil are considered acceptable.
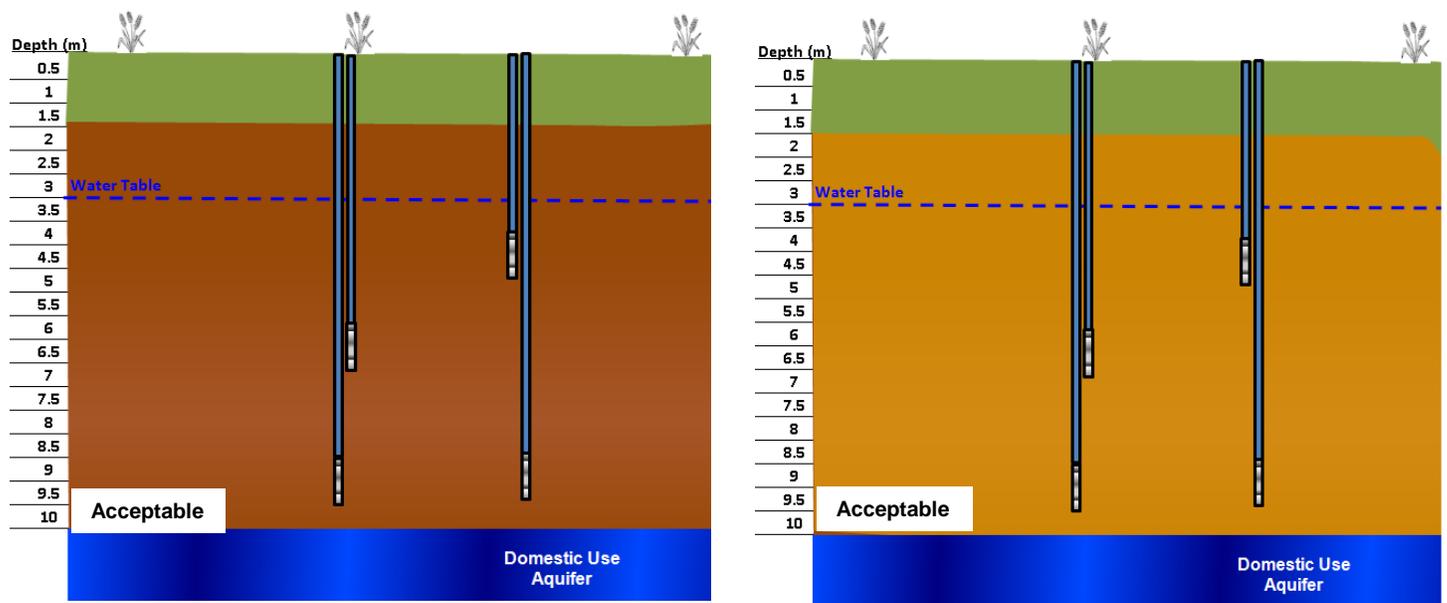
The nested wells shown below in the left panel are <u>not</u> acceptable since the wells are installed either spanning a continuous coarse interval or one of the wells is within the coarse interval.

In the right panel, each individual 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 (for example, installing all the nests shown in the right panel). 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.
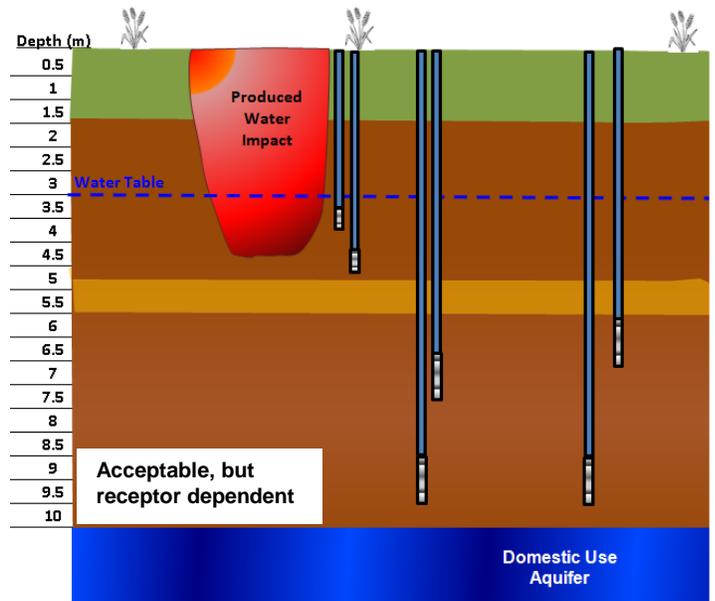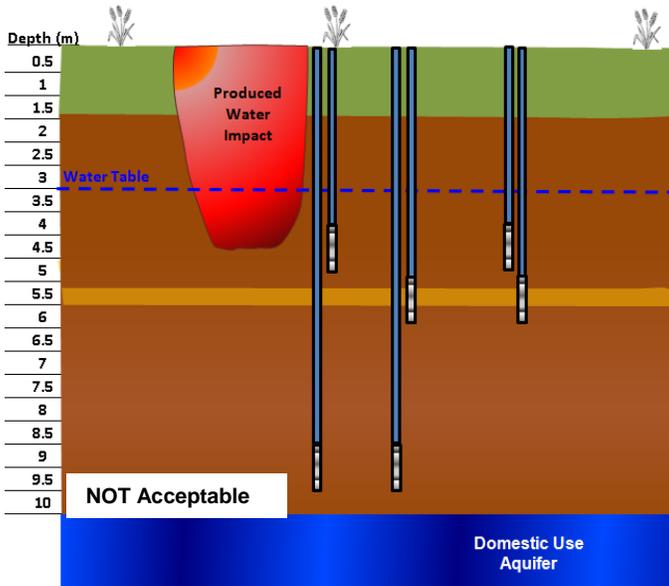
The nested well arrangements below are <u>not</u> acceptable for use in the SST. One of the wells of a nest cannot be screened within or across the DUA. For the panel on the right, one of the wells is installed within a distinct texture, which similarly is not acceptable.
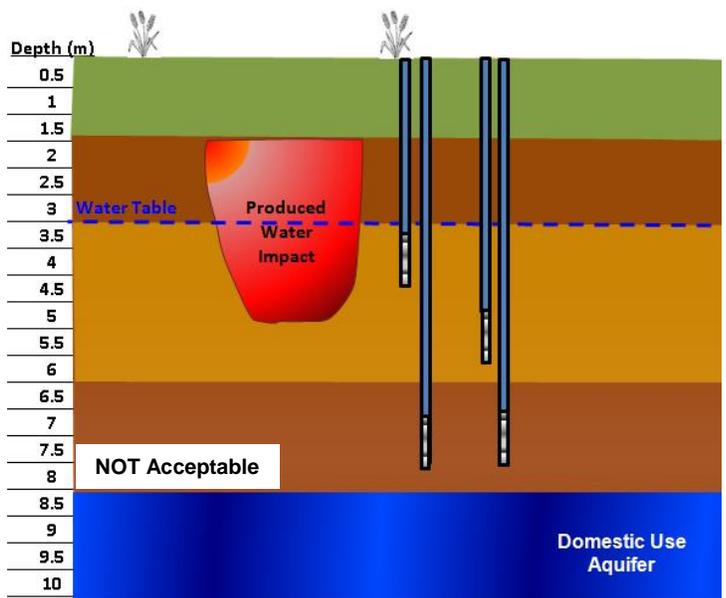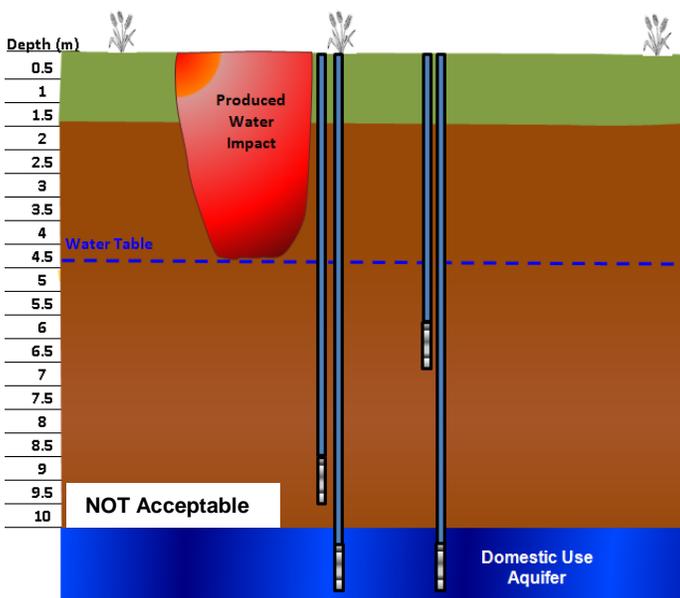
The nested well arrangements below are considered acceptable for use in the SST, but only for a select number of receptors. In the left panel, the wells have been installed within a single porous coarse media with an absence of soils of differing texture between the two screens. The vertical gradient 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 overall 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.
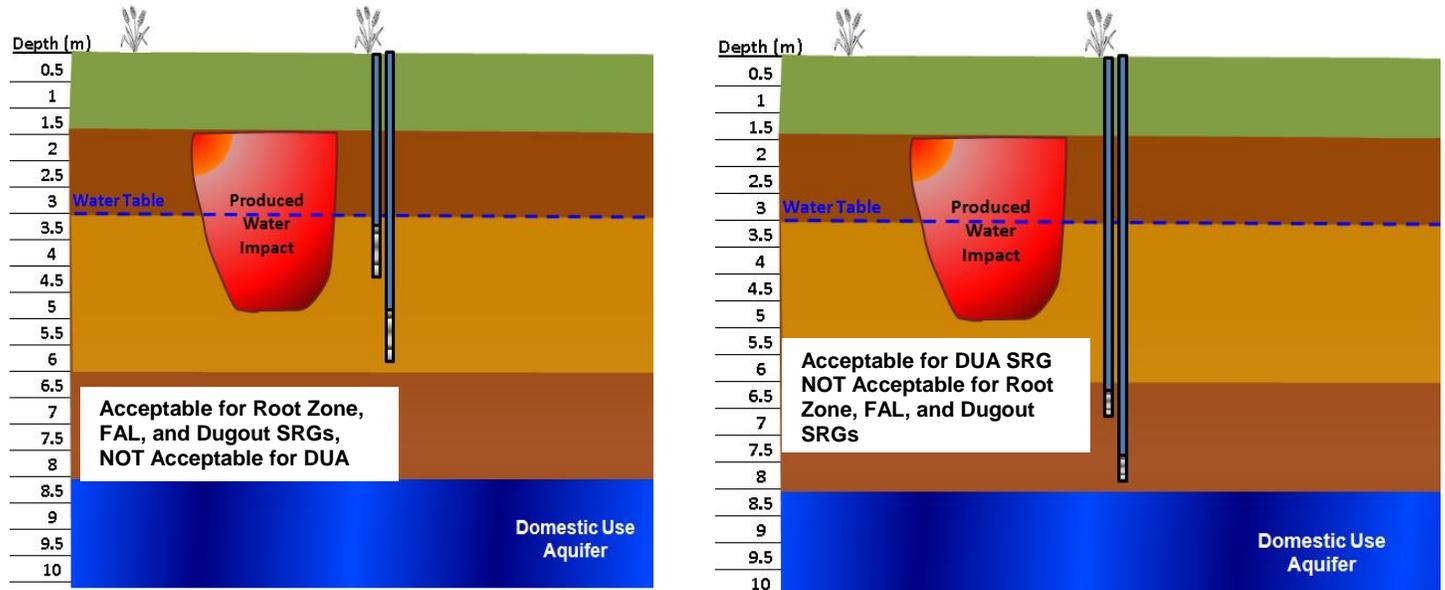
The presence of discontinuous and relatively isolated coarse intervals within a predominantly fine textured soil (and the converse would apply to a predominantly coarse textured soil) will have a relatively minimal influence on the net vertical gradient at a site. An example is provided below. The nested 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.
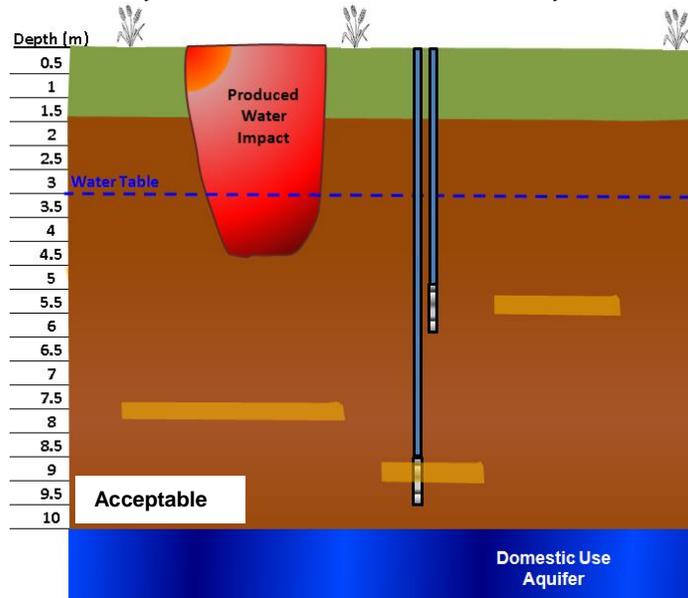
In general, conservative assumptions should be made when using vertical gradient data on sites with complex lithology, or the proponent progresses to a Tier 2C approach. As is discussed in more detail in Section 4.12, the user should always ensure that the input parameters entered into the SST and the resulting drainage rates and other transport parameters imply a logically coherent, consistent conceptual site model (CSM).

Summary

Due to the numerous factors influencing the use of vertical gradient data and its influence on multiple guidelines via drainage rates, the following points provide a brief summary of minimum data requirements and other considerations for using vertical gradients. In general, if any parameters or site conditions preclude the reliable use of the vertical gradient option, it should conservatively be left blank and the tool will use standard default assumptions for drainage rate as a function of climate and overall soil lithology. In all cases, inputs parameters must imply a coherent, logical CSM.

Summary of requirements for vertical gradient

- For sites with total source dimensions of less than or equal to 50 x 50 m (2,500 m^2), 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 (2,500 m^2) but less than or equal to 100 x 100 m (10,000 m^2), a minimum of two nested wells is required. For total source dimensions of greater than 100 x 100 m (10,000 m^2), a minimum of three nested wells is required.
- Additional nested wells are required if lithology or groundwater flow patterns are complex. The use of the 'hydraulic conductivity relevant to drainage' option (Section 4.11) also requires a minimum of one nested pair within any distinct lithology for which that option will be used.
- Nested wells must be constructed within soils of similar lithology, and generally not separated by continuous layers of different lithology (e.g., a sand lense between two wells installed in fine till). In some cases, minor discontinuous pockets of different lithology may be acceptable within or between the two wells of a nested pair.
- Care should be used when selecting locations for nested wells to ensure the resulting vertical gradient is relevant for the impacts at the site. Relevant factors can include topography (e.g., top of a knoll compared to bottom of a hill compared to flat terrain) or proximity to dugouts or surface water features.
- To ensure sufficient accuracy for vertical gradients, 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.
- The user should ensure the wells forming the nested pairs have been surveyed accurately, particularly top-of-casing measurements since these form the basis for the relatively sensitive water level comparisons between shallow and deep wells. Wells should also be periodically inspected for potential signs of damage, particularly those that might influence relative water level measurements between nested wells (such as casing settling or heaving).
- Wells must be developed adequately after installation, as poor well development will lead to incorrect gradients.
- A minimum of two measurements are required during the year outside of the spring snowmelt period. If the gradients are significantly different, additional measurement events are required to produce an annual average gradient. Similarly, fluctuations between weak recharge and weak discharge conditions generally require additional measurements to determine a more consistent pattern over the course of a year.
- Groundwater elevations used for calculating vertical gradient must have sufficiently stabilized after any disturbance (such as well installation, well development, or well testing). This can take a significant length of time in higher clay content soils, ranging from days to potentially months. Groundwater level data taken over time can help determine whether levels at a particular well are relatively stable or continue to experience transient recovery effects.
- The user should ensure records are kept of how vertical gradients were measured, including the time-frame allowed for wells to properly develop to ensure vertical gradient results are representative.
- Vertical gradients should not be used from periods of transient dominant recharge conditions (e.g., spring snowmelt), and the user should ensure that the vertical gradients used are temporally-significant and relevant to typical conditions throughout the year.
- Use caution when considering using a large vertical gradient (or incorporating it into an average with other lower-gradient data) as it may misrepresent site conditions. Large gradients (e.g., > 0.1) may be indicative of anomalous, non-representative results potentially due to poor well development, incomplete recovery, potential well damage, or other factors. Large vertical gradients may also be typical of (and reasonable for) very low conductivity clayey soils, so the presence of a large vertical gradient does not necessary imply unreliable results.
- In some cases, sites with more complex lithology may be analyzed with two distinct runs using vertical gradients relevant to different layers and using the most appropriate guideline for each receptor. More conservative approaches may also used, or more complex approaches considered but those would generally fall under a Tier 2C approach.

4.11 **Hydraulic Conductivity Relevant to Drainage**

The use of vertical gradient data described in the previous section allows improved characterization of vertical transport (drainage rates), primarily as a function of the direction of the vertical gradient (discharge vs recharge) and less as a function of the magnitude. The additional use of hydraulic conductivity relevant to drainage (in combination with vertical gradient) allows further characterization of vertical transport, with drainage rates potentially further refined based on the combination of both. Like vertical gradient, the use of hydraulic conductivity relevant to drainage is a potentially complex process, and requires professional judgement including a thorough understanding of hydrogeological conditions as well as fate and transport processes. Many of the considerations previously described for deep groundwater and vertical gradients are also relevant to hydraulic conductivity relevant to drainage, and at a minimum, reliable vertical gradient information must be available for hydraulic conductivity data relevant to drainage to also be used.

4.11.1 Tier 2A

Under a Tier 2A analysis, no site-specific vertical gradient information is available and thus the option for hydraulic conductivity relevant to drainage is not active.

4.11.2 Tier 2B

Under a Tier 2B scenario where the minimum data requirements have been met for vertical gradient and a value has been entered, the option for entering a 'hydraulic conductivity relevant to drainage' also becomes active. This hydraulic conductivity data is obtained from monitoring wells which characterize the intervals through which water must leach downward toward the DUA, and could potentially include wells from any depth interval from below the water table down to the DUA (but not including the DUA itself). Such wells could thus potentially include wells also used for 'shallow' or 'deep' groundwater, though in this context the data is used for description of vertical transport (drainage) whereas the data used for 'shallow' and 'deep' groundwater is used to describe horizontal transport. Soil lithologies which have uniform properties in the horizontal and vertical directions are considered to be 'isotropic', whereas soils which have different properties in horizontal and vertical directions are defined as 'anisotropic' (Freeze and Cherry, 1979). For the purposes of the SST, soils are considered to be isotropic, and thus hydraulic conductivity data is considered relevant to both horizontal and vertical flow. For clarity of the conceptual model, a brief summary of the differences between these three non-DUA groundwater categories is provided below:

Shallow groundwater
Describes the shallowest saturated intervals below the water table. This interval is relevant to lateral chloride flow toward FAL receptors, and potentially relevant to chloride or sodium flow into a dugout assuming the water table isn't deeper than 6 m.

Deep groundwater
Describes the deeper saturated intervals below the impacts through which chloride impacts must travel as they leach downward toward the DUA. Relevant only to the DUA pathway, and influences only horizontal flow (horizontal smearing during vertical transport) and doesn't directly influence vertical flow.

Hydraulic conductivity relevant to drainage
Describes all saturated intervals through which water must leach downward toward the DUA, and could potentially include wells from any depth interval (but not the DUA itself). Could include wells used as part of the dataset for shallow or deep groundwater, or other wells not included as part of those datasets. Influences both the root-zone and DUA drainage rates, and thus potentially influences guidelines for all pathways for both chloride and SAR/sodium.

In general, the sufficient characterization of hydraulic conductivity relevant to drainage reduces the level of conservatism used in at least one of the two drainage rates. This frequently results in a decrease in the spread between the estimated root-zone and DUA drainage rates used for modeling due to the additional site characterization data available.

The two figures below show examples of wells and associated conductivity data relevant to drainage, including all five wells (two nested pairs plus an additional single well) in example #1 (fine-grained soil), and all four wells (two nested pairs) in the example #2 (coarse-grained soil). Each of these cases show relatively uniform/consistent lithology in the relevant depth interval (between the water table and the DUA), reflected by the relatively consistent hydraulic conductivity values shown next to each well and tabulated to the right.

As a minimum data requirement, three representative hydraulic conductivity values relevant to drainage are required in such cases with relatively uniform lithology throughout the saturated zone. The arithmetic average hydraulic conductivity is used in such cases for entry into the SST. This is calculated as 1.9×10^{-7} m/s in example #1 and 9.9×10^{-7} m/s in example #2 in the tables shown adjacent to each figure. Additional hydraulic conductivity data and more complex analysis is required in cases with more complex lithology, with additional details provided in later examples.

When hydraulic conductivity data relevant to drainage is entered into the SST, the tool internally multiplies this value by the vertical gradient and compares to the resulting product to fixed ranges of typical values for fine and coarse soils. These ranges are shown in the table below, along with the corresponding 'drainage category' ('low recharge, 'mid recharge, or 'high recharge') which provides a high-level refinement of potential drainage rates. These recharge categories are calculated and displayed by the SST directly below the hydraulic conductivity data relevant to drainage, if entered. Note that a 'discharge' drainage category occurs when vertical gradients indicate discharge conditions (negative vertical gradients). Hydraulic conductivity data relevant to drainage does not influence guidelines under such discharge scenarios (and is thus irrelevant).

Recharge category	Fine soil	Coarse soil
High recharge	> 5.6×10^{-9} m/s	> 5.6×10^{-8} m/s
Mid recharge	1.4×10^{-10} to 5.6×10^{-9} m/s	1.4×10^{-9} to 5.6×10^{-8} m/s
Low recharge	< 1.4×10^{-10} m/s	< 1.4×10^{-9} m/s

Note: The boundaries between these ranges are defined by an assumed (default) vertical gradient of 0.028, combined with typical ranges of hydraulic conductivities for fine and coarse soils

The product of hydraulic conductivity and associated vertical gradients are shown below the table for each example, calculated as 6.1×10^{-9} m/s in example #1 ('high recharge' for fine soil) and 1.6×10^{-8} m/s in example #2 ('mid recharge' for coarse soil). This drainage category (assuming recharge conditions) is then combined with climate data (CMI) and overall lithology to determine numerical drainage rates for both the root-zone and DUA pathways as shown in Section 2.7.5. When lithology is consistent throughout, assigning an 'overall subsoil lithology for vertical transport' is clear (*e.g.*, user would select 'fine' in example #1 and 'coarse' in example #2**).**

<u>Example 1. Fine-grained soil</u>
(two nested pairs plus one additional well)
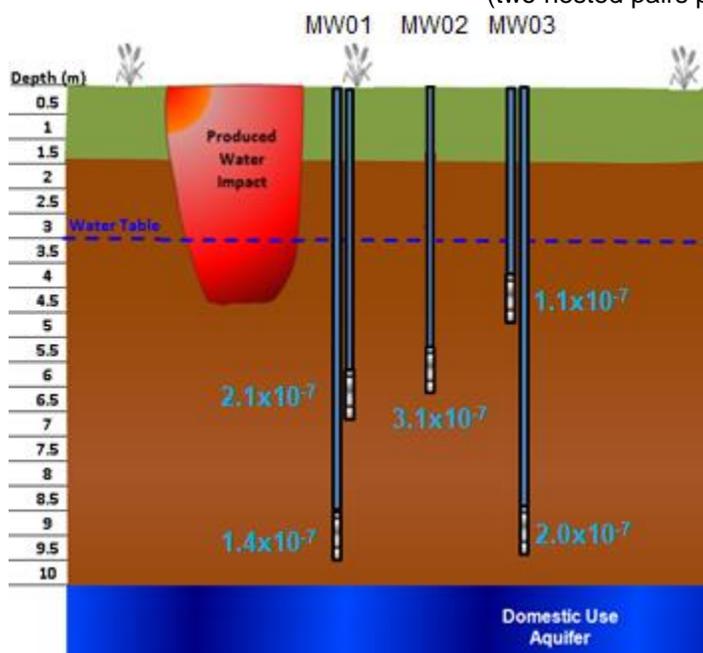
	Hydraulic Conductivity (m/s)	Vertical Gradient (m/m)
MW01a	2.1E-07	
MW01b	1.4E-07	0.019
MW02	3.1E-07	
MW03a	1.1E-07	
MW03b	2.0E-07	0.044
Average	**1.9E-07**	**0.032**

Hydraulic conductivity x vertical gradient **6.1E-09** **m/s**

Drainage category **High recharge**

Overall subsoil lithology for vertical transport = FINE

Example 2. Coarse-grained soil
(two nested pairs)
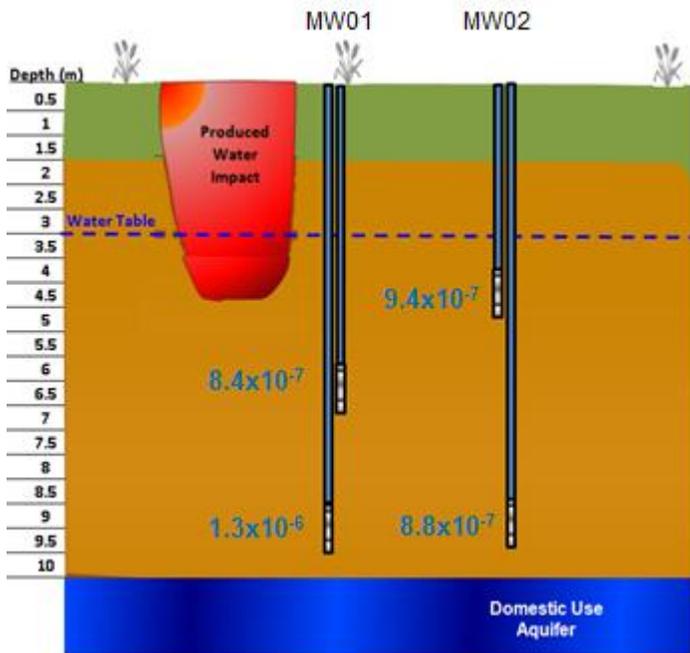
	Hydraulic Conductivity (m/s)	Vertical Gradient (m/m)
MW01a	8.4E-07	
MW01b	1.3E-06	0.012
MW02a	9.4E-07	
MW02b	8.8E-07	0.020
Average	**9.9E-07**	**0.016**

Hydraulic conductivity x vertical gradient **1.6E-08   m/s**

Drainage category   **Mid-recharge**

Overall subsoil lithology for
vertical transport = COARSE

As an alternative to hydraulic conductivity data from monitoring wells, it is also possible for the user to incorporate soil core data in conjunction with (or instead of) the monitoring well data. Monitoring well data (typically from well tests such as slug tests) inherently represents horizontal hydraulic conductivity, whereas data from soil cores (typically referred to as 'saturated conductivity', or K_{sat}) inherently represents vertical hydraulic conductivity. Since soils are considered to be isotropic within the SST, hydraulic conductivity data from both wells and soil cores are considered relevant to vertical flow and drainage rate. However, since soil cores represent a substantially smaller soil volume than the radius of influence of a well test, the hydraulic conductivity results from a well test include more of the macroscopic hydraulic conductivity of the strata (including any preferential flow paths) which is more representative for modeling contaminant movement. To account for these differences in sample size, hydraulic conductivity (K_{sat}) data from soil cores must be multiplied by 10 prior to entering into the tool or combining with hydraulic conductivity data from wells. In addition, two soil core datapoints are considered to be of similar reliability as a single well datapoint, and thus the minimum requirement of 3 monitoring well tests is considered comparable to a minimum of 6 soil core K_{sat} tests, or 2 monitoring well tests plus 2 soil core tests, or 1 monitoring well test plus 4 soil core tests. Soil cores must also be from the saturated interval (below the water table) for this purpose, since unsaturated cores are more prone to changes in bulk density during the collection process (compaction), along with other complicating factors such as potential presence of roots or macro-pores, variable saturation levels, etc.

Example #3 below shows an example of such a dataset including a combination of wells (four wells in two nests) plus soil cores (four). This example is also of uniform lithology (fine soil), with this combination of data equivalent to six wells (four wells plus four soil cores, each of which is equivalent to 0.5 wells) and thus higher than the minimum data requirements of three wells for uniform lithology. The table next to this figure shows both the hydraulic conductivity data from wells, along with the K_{sat} data from soil cores which is first multiplied by 10 (for sample size effects) before incorporating into the hydraulic conductivity arithmetic average. When combined with the example vertical gradients shown in the table, a drainage category of 'mid recharge' is calculated by the tool based on the hydraulic conductivity x vertical gradient product of 3.1×10^{-9} m/s.
Based on the uniform fine texture, this site would be selected as 'fine' for overall subsoil lithology.

Example #4 below shows an example of uniform coarse soils with one nested pair, and additional well, and three soil cores (one of which is not usable since from above the water table). This is thus equivalent to four wells (three wells plus two cores), and is thus also higher than the minimum data requirements. The table next to this figure shows an average hydraulic conductivity of 1.1×10^{-6} m/s (from wells and adjusted core data), and a hydraulic conductivity x vertical gradient product of 9.8×10^{-9} m/s ('mid recharge'). Note that this example assumes the coarse soils do not represent a potential DUA despite their conductivity being in the 1×10^{-6} m/s range, with DUA status typically confirmed in such cases via pump test. Based on the uniform coarse texture, this site would be selected as 'coarse' for overall subsoil lithology.

Example 3. Fine-grained soil
(two nested pairs plus soil cores)
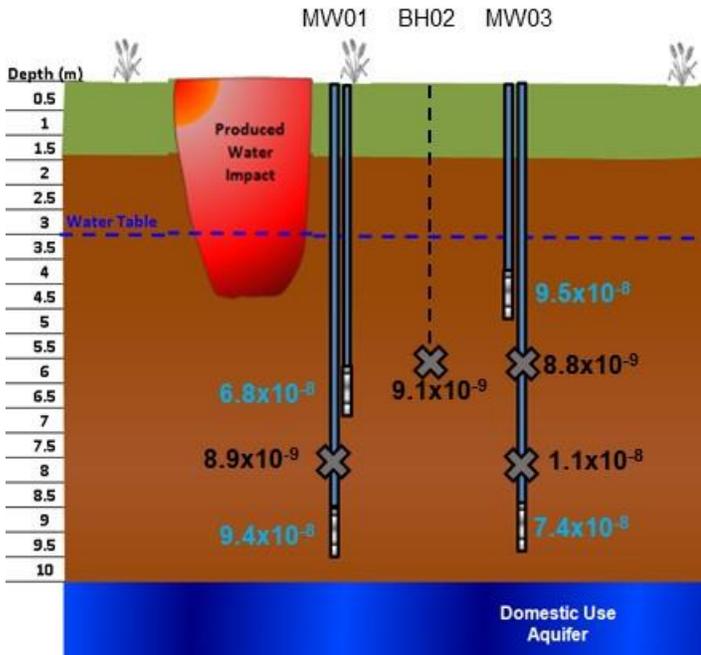
	Ksat from cores (m/s)		Hydraulic Conductivity (m/s)	Vertical Gradient (m/m)
MW01a			6.8E-08	
MW01b			9.4E-08	0.022
MW01 8m	8.9E-09	x10→	8.9E-08	
BH02 6m	9.1E-09	x10→	9.1E-08	
MW03a			9.5E-08	
MW03b			7.4E-08	0.049
MW03 6m	8.8E-09	x10→	8.8E-08	
MW03 8m	1.1E-08	x10→	1.1E-07	
Average			**8.9E-08**	**0.036**

Hydraulic conductivity x vertical gradient	**3.1E-09**	**m/s**
Drainage category	**Mid-recharge**	

Overall subsoil lithology for vertical transport = FINE

Note: X's in the above figure above represent soil core datapoints, with hydraulic conductivity (K_{sat}) values shown in black font. Hydraulic conductivity data from monitoring wells is shown in blue font adjacent to well-screens

Example 4. Coarse-grained soil
(one nested pair, one additional well, plus soil cores)
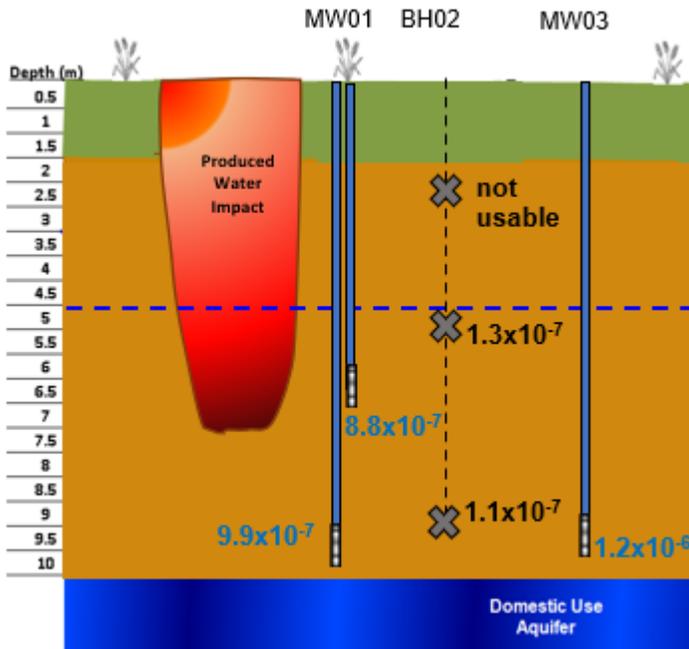
	Ksat from cores (m/s)		Hydraulic Conductivity (m/s)	Vertical Gradient (m/m)
MW01a			8.8E-07	
MW01b			9.9E-07	0.009
BH02 5m	1.3E-07	x10→	1.3E-06	
BH02 9m	1.1E-07	x10→	1.1E-06	
MW03			1.2E-06	
Average			**1.1E-06**	**0.009**

Hydraulic conductivity x vertical gradient	**9.8E-09**	**m/s**
Drainage category	**Mid-recharge**	

Overall subsoil lithology for vertical transport = COARSE

For cases with more complex lithology (more than one distinct lithology above the DUA), three or more representative hydraulic conductivity values from wells (or equivalent) are required for each important relevant layer, and additional results will often be useful. In general, a layer is considered relevant and important if it is continuous, and of sufficient thickness to have a likely substantial influence on drainage rates. In the majority of cases, the most relevant interval will be the shallowest sufficiently thick interval, with data from that interval forming the basis of the main SST run for guideline calculation. Deeper layers may also be relevant to drainage (particularly for the DUA pathway), though in some cases the use of data from deeper layers may be optional (details provided in the provided examples). With three or more monitoring well hydraulic conductivity results (or equivalent) available for any distinct lithology, the arithmetic average may be used for describing that layer.

As in the case of uniform lithologies, two soil core hydraulic conductivity datapoints are considered equivalent to one hydraulic conductivity value from a well, and thus the three representative hydraulic conductivity values from wells could be met by two wells plus two soil cores (or other combinations) as long as other minimum requirements (such as for vertical gradient) are also met. As with the uniform lithologies, soil core data must also be multiplied by 10-fold (for sample size effects) prior to combining with monitoring well data for further calculations.

In this context, a distinct lithology could be represented by a coarse interval overlaying fine soils, or two distinct fine soils (e.g., a silt interval underlain by clay), or other combinations. Note that professional judgement is required in defining and grouping such layered lithologies, where (for example) inconsistent sand pockets observed sporadically over a small proportion of otherwise fine boreholes could be considered to be an effectively uniform (fine-grained) lithology. In general, the techniques described here for characterizing layered lithology within the SST are limited to a maximum of two distinct lithologies overlaying the DUA. More complex scenarios cannot readily be readily modeled by the SST on a Tier 2B basis, and in such cases the user must either not include hydraulic conductivity data relevant to drainage (a conservative approach), or use a Tier 2C approach (less conservative, but more complex).

For sites with more than one distinct lithology, the user must ensure there is adequate proof that each layer exists and that there is support regarding the thickness of each layer. This should generally involve particle size testing (by sieve and/or hydrometer) as a supplement to borehole logs. Bulk density measurements as determined during soil core tests may also be useful in identifying distinct layers.

Vertical gradient must be measured in the same lithology as hydraulic conductivity. This ideally means vertical gradient data should be obtained in both lithologies where more than one is present. In some cases this may not be practical, such as in a thin sand lense (*e.g*, 1 m thick) in otherwise fine soil where monitoring well or soil core data has been obtained but installing a nested pair is not practical or useful. Similarly, where a single deep borehole (ie, for DUA depth identification) indicates a low-permeability deep layer, it may not be practical to install a nested pair to obtain vertical gradients. In such cases, data from the deeper less-conductive layer cannot be used for an additional optional DUA run (due to the lack of vertical gradient data in that layer), but the main run using hydraulic conductivity and vertical gradient data from the shallower, more conductive layer may still be used.

Examples of sites with layered lithology are provided below, including descriptions of whether or not the minimum data requirements have been met for that particular example and other relevant considerations.

Example 5 below first shows an example of a fine-grained site with a uniform silt lithology throughout. Since subsoil is consistently fine, the 'overall subsoil lithology' would be chosen to be 'fine'. The water table is 3 m, with an assumed DUA depth of 15 m (maximum depth of drilling). The two nested pairs plus one soil core is more than sufficient for minimum data requirements, and the table next to the figure shows the average hydraulic conductivity (1.6×10^{-7} m/s, after correcting soil core data), vertical gradient (0.036), hydraulic conductivity x gradient product (5.8×10^{-9} m/s), and drainage category ('high recharge'). If this site was in the Central Parkland natural subregion (slightly dry / semi-arid), this would result in drainage rates of 3 mm/year down (root-zone pathway) and 6 mm/year down (DUA) pathway. In comparison, if no vertical gradient information was available the default drainage rates would have been 1 mm/year up (root-zone pathway) and 6 mm/year down (DUA pathway), and if solely vertical gradient information was available the drainage rates would have been 1 mm/year down (root-zone pathway) and 6 mm/year down (DUA pathway). The inclusion of vertical gradient and hydraulic conductivity relevant to drainage in this case thus reduced the difference between the root-zone and DUA drainage rate assumptions by increasing the RZ drainage rate while keeping the DUA drainage rate constant.

<div align="center">

Example 5. Fine-grained soil with one lithological layer
(two nested pairs plus soil core)

</div>

	Ksat from cores (m/s)		Hydraulic Conductivity (m/s)	Vertical Gradient (m/m)
MW01a			1.4E-07	
MW01b			1.9E-07	0.023
MW02 7 m	1.1E-08	x10→	1.1E-07	
MW03a			2.2E-07	
MW03b			1.5E-07	0.049
Average			**1.6E-07**	**0.036**

Hydraulic conductivity x vertical gradient	**5.8E-09**	**m/s**
Drainage category	**High recharge**	

Examples #5 + #6
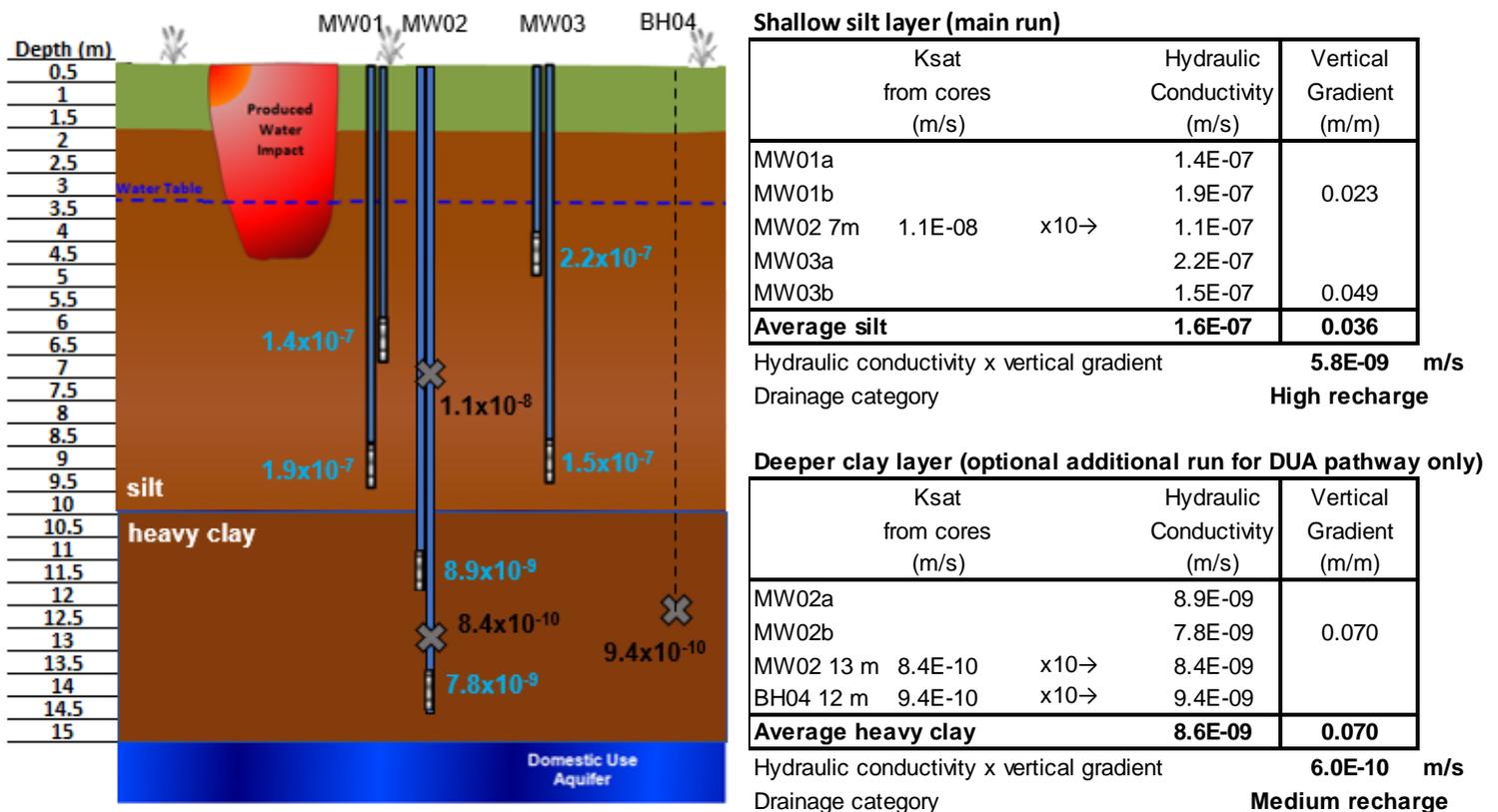**Overall subsoil lithology for vertical transport = FINE**

Example 6 shows a layered version of example 5, where the soft silt extends only to 10 m and is underlain instead by a tighter heavy clay from 10-15 m (as verified by borehole logs and laboratory texture data). Since subsoil is consistently fine despite the layering, the 'overall subsoil lithology' would be chosen to be 'fine'. Each layer has one or two nested pairs (plus supplemental soil cores), and thus both vertical gradient and hydraulic conductivity information is available for each layer (minimum data requirements thus met). The silt has an average hydraulic conductivity of 1.6×10^{-7} m/s, the same as example #5. The firmer, deeper heavy clay has a hydraulic conductivity of 8.6×10^{-9} m/s (after correcting soil core data), thus approximately 20-fold lower than the silty layer and consistent with borehole logs and texture data showing a distinctly different lithology.

The main run performed would be based on the shallower primary lithology since it is thick enough to be highly relevant to drainage. Based on this data, the SST calculates a 'high-recharge' drainage category based the hydraulic conductivity x vertical gradient product of 5.8×10^{-9} m/s. If this site was in the 'slightly dry / semi-arid' CMI (e.g, 'Central Parkland'), this would result in a root-zone drainage rate of 3 mm/year down and a DUA drainage rate of 6 mm/year down. This root-zone drainage rate is considered appropriate for the shallower pathways (root-zone, aquatic life, dugout), and the DUA drainage rate likely conservative since the lithology of the deeper layer suggests likely slower drainage for the DUA.

Assuming sufficient data (as is shown here), the user could optionally perform an additional run for the DUA pathway by using vertical gradient and hydraulic conductivity data for the deeper layer. If this was performed, a 'mid-recharge' drainage category would be calculated based on the hydraulic conductivity x vertical gradient (6.0×10^{-10} m/s), resulting in a reduced DUA drainage rate of 3 mm/year down assuming the same 'slightly dry / semi-arid' CMI. The presence of a well-characterized deeper clayey layer would thus result in increased DUA guidelines in this case due to the reduced DUA drainage rate. Note that the user must ensure that the DUA drainage rate does not become lower than the root-zone drainage rate if using a second DUA run like this.

Note that in this example the vertical gradient is shown as relatively comparable between the shallower and deeper soils (less than a 2-fold difference), whereas in many cases soils with lower hydraulic conductivities may have several-fold higher vertical gradients than soils with higher conductivities. This is part of the reason why obtaining vertical gradients from all important distinct lithologies is important.

Example 6. Fine-grained soil with two lithological layers
(nested pairs and cores in each layer)

Shallow silt layer (main run)

	Ksat from cores (m/s)		Hydraulic Conductivity (m/s)	Vertical Gradient (m/m)
MW01a			1.4E-07	
MW01b			1.9E-07	0.023
MW02 7m	1.1E-08	x10→	1.1E-07	
MW03a			2.2E-07	
MW03b			1.5E-07	0.049
Average silt			**1.6E-07**	**0.036**

Hydraulic conductivity x vertical gradient	**5.8E-09**	**m/s**
Drainage category	**High recharge**	

Deeper clay layer (optional additional run for DUA pathway only)

	Ksat from cores (m/s)		Hydraulic Conductivity (m/s)	Vertical Gradient (m/m)
MW02a			8.9E-09	
MW02b			7.8E-09	0.070
MW02 13 m	8.4E-10	x10→	8.4E-09	
BH04 12 m	9.4E-10	x10→	9.4E-09	
Average heavy clay			**8.6E-09**	**0.070**

Hydraulic conductivity x vertical gradient	**6.0E-10**	**m/s**
Drainage category	**Medium recharge**	

Example 7 shows two such scenarios where the deeper heavy clay lithology from example 6 is not characterized for vertical gradient (either with or without hydraulic conductivity data). In this case, hydraulic conductivity data from the deeper (heavy clay) layer cannot be used for hydraulic conductivity relevant to drainage calculations since no vertical gradient has been obtained from that layer. However, in this case, the shallower data may still be used since it is likely to be conservative (higher drainage rate) compared to the deeper interval and has both hydraulic conductivity and vertical gradient data. This scenario may sometimes occur when a single deeper borehole or well is advanced to identify DUA depth, and an apparently tighter, less-conductive lithology is observed near the bottom of that borehole which is not practical to characterize with nested wells.

Example 7. Fine-grained soil with two lithological layers
(good characterization of shallow layer, but no vertical gradient information for deeper layer)
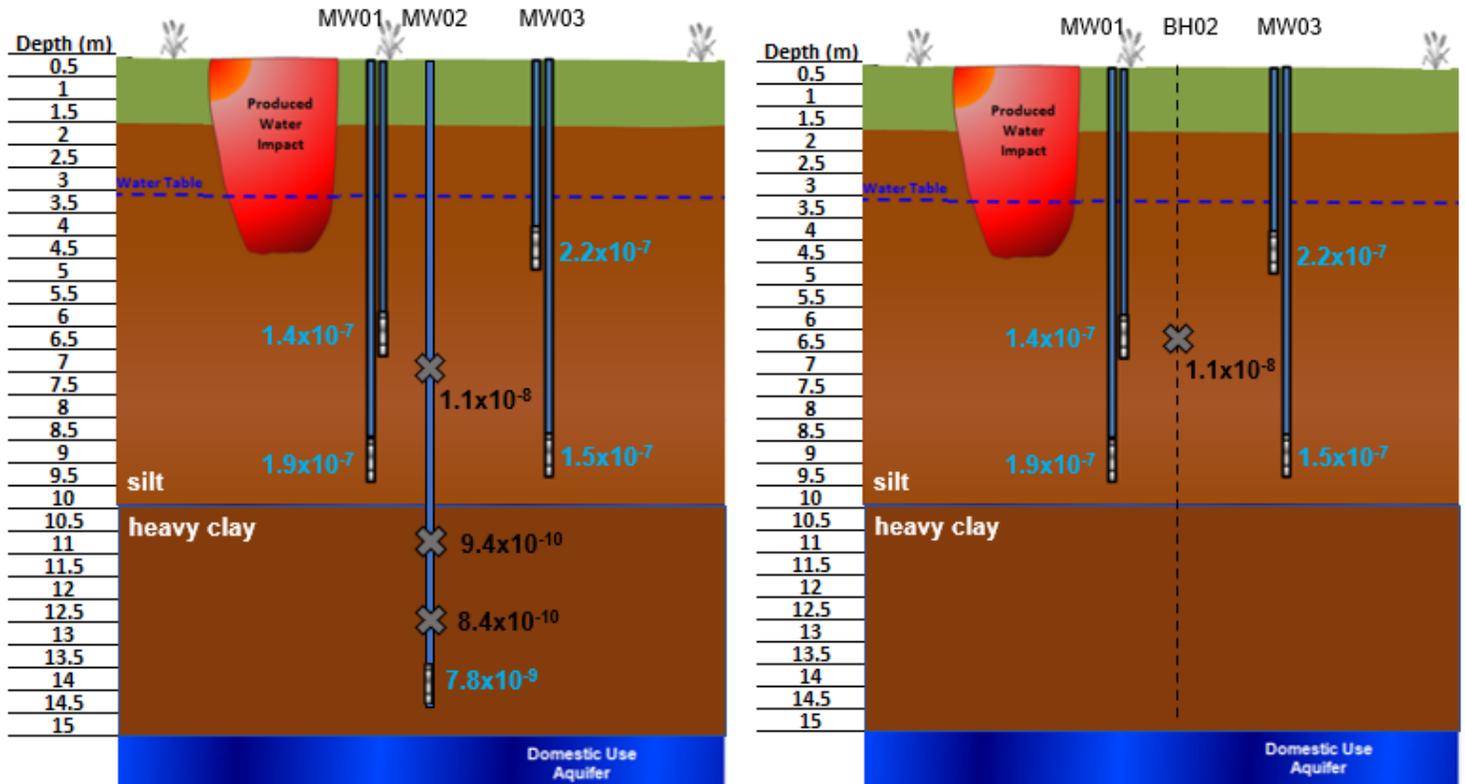
In this case, hydraulic conductivity data from the deeper (heavy clay) layer cannot be used for hydraulic conductivity relevant to drainage calculations since no vertical gradient has been obtained from that layer. However, the shallower data may still be used since it is likely to be conservative (higher drainage rate) compared to the deeper interval and has both hydraulic conductivity and vertical gradient data.

Overall subsoil lithology for vertical transport = FINE

Example 8 shows an example with a 2 m water table and two distinct but similar coarse-grained lithologies – a shallower layer of sandy loam (to 9 m) and a deeper layer of sand/silt (from 9 to 15 m). Since subsoil is consistently coarse despite the layering, the 'overall subsoil lithology' would be chosen to be 'coarse'. Each layer has one nested pair, and thus two hydraulic conductivity values per layer plus one vertical gradient per layer. Hydraulic conductivity for the shallow layer ranged from 9.1×10^{-7} m/s to 2.0×10^{-6} m/s, and for the deeper layer ranged from 9.8×10^{-7} m/s to 2.1×10^{-6} m/s. Since each layer is quite similar in terms of hydraulic conductivity and vertical gradient, these would be considered essentially one layer and thus the data can be combined between layers thus meeting the minimum data requirements. Here, the average hydraulic conductivity is calculated as 1.5×10^{-6} m/s and the average vertical gradient calculated as 0.028.

Using these averages, the SST calculates a 'mid-recharge' drainage category based on the product of hydraulic conductivity x vertical gradient (calculated internally as 4.2×10^{-8} m/s).

As always, and particularly for coarse-grained sites, it is necessary to confirm that the various shallower lithologies do not represent a potential DUA, particularly if they have slug test results above 1×10^{-6} m/s. This is typically done via one or more pump tests, with example #8 assuming that neither of the two lithologies shallower than 15 m represent a DUA based on such pump tests.

Example 8. Coarse-grained soil with two similar lithological layers
(one nested pair for each layer)
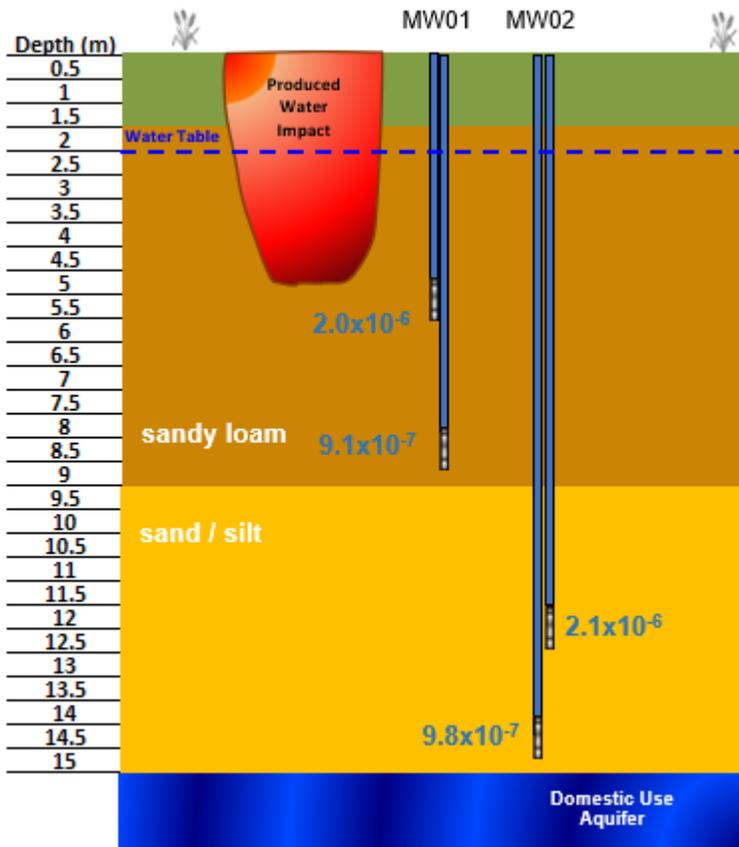
	Hydraulic Conductivity (m/s)	Vertical Gradient (m/m)
MW01a	2.0E-06	
MW01b	9.1E-07	0.027
MW02a	2.1E-06	
MW02b	9.8E-07	0.029
Average	**1.5E-06**	**0.028**

Hydraulic conductivity x vertical gradient **4.2E-08** **m/s**

Drainage category **Mid-recharge**

Overall subsoil lithology for vertical transport = COARSE

Example 9 below shows a more pronounced lithology difference consisting of a medium-textured layer (loam / sandy loam) to 8 m underlain by a fine (c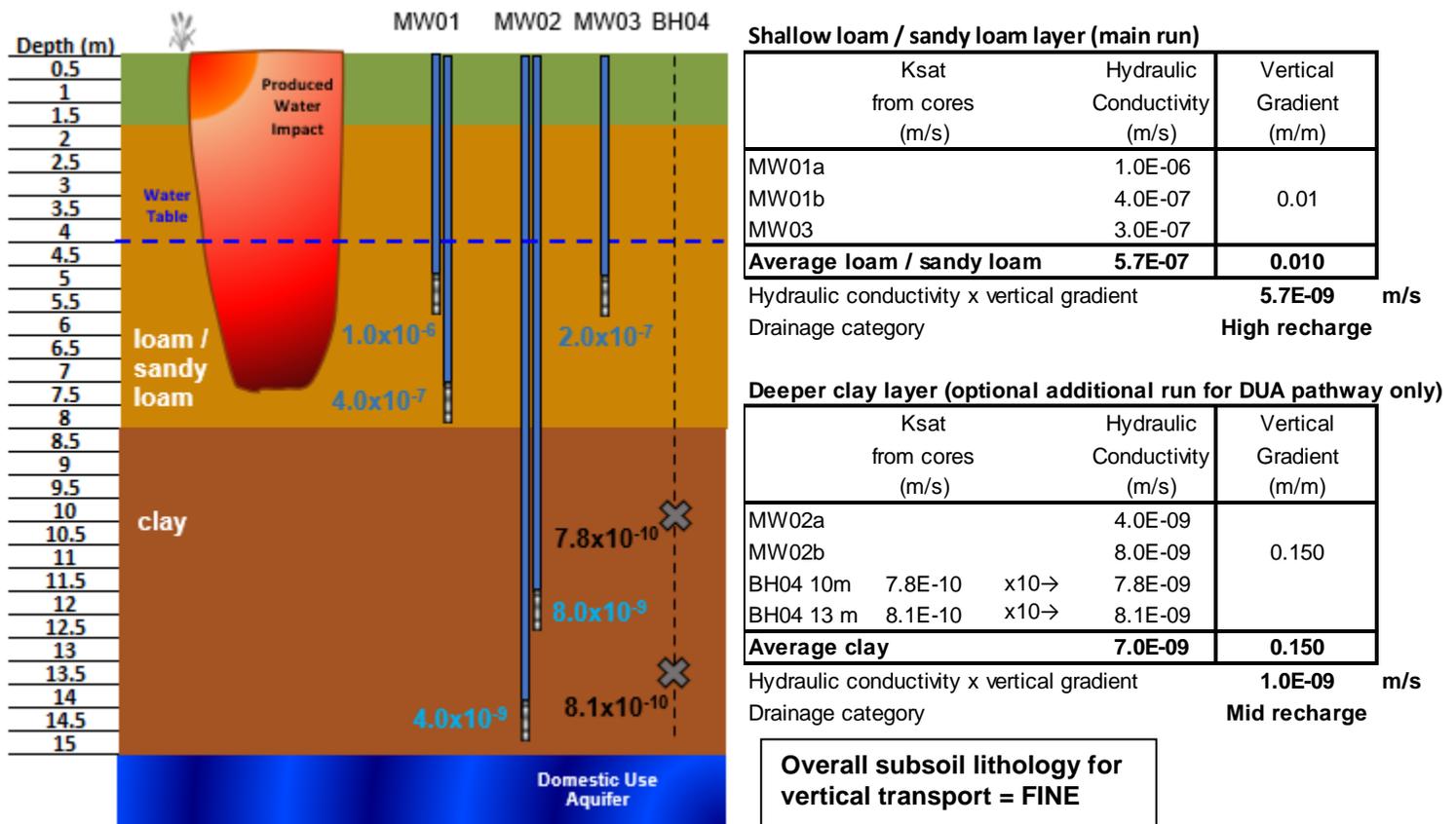lay) layer to 15 m. Since the deeper clay layer will largely determine the drainage rate, the 'overall subsoil lithology' would be chosen to be 'fine'. Each layer has one nested pair (and thus vertical gradient data), plus additional well or soil core data. The average hydraulic conductivity for the shallow layer was 5.7×10^{-7} m/s, and for the deeper layer was 7.0×10^{-9} m/s. As is often the case with large differences in hydraulic conductivity, there is also a large difference in vertical gradient here (0.01 for the shallow layer compared to 0.15 for the deeper layer).

The main run performed would be based on the shallower primary lithology since it is thick enough to be highly relevant to drainage. Based on this data, the SST calculates a 'high-recharge' drainage category based the hydraulic conductivity x vertical gradient product of 5.7×10^{-9} m/s. If this site was in the 'slightly dry / semi-arid' CMI (e.g, 'Central Parkland'), this would result in a root-zone drainage rate of 3 mm/year down and a DUA drainage rate of 6 mm/year down. This root-zone drainage rate is considered appropriate for the shallower pathways (root-zone, aquatic life, dugout), and the DUA drainage rate likely conservative since the lithology of the deeper layer suggests likely slower drainage for the DUA.

Assuming sufficient data (as is shown here), the user could optionally perform an additional run for the DUA pathway by using vertical gradient and hydraulic conductivity data for the deeper layer. If this was performed, a 'mid-recharge' drainage category would be calculated based on the hydraulic conductivity x vertical gradient (1.0×10^{-9} m/s), resulting in a reduced DUA drainage rate of 3 mm/year down assuming the same 'slightly dry / semi-arid' CMI. Note that the user must ensure that the DUA drainage rate does not become lower than the root-zone drainage rate if using a second DUA run like this.

Note that the vertical gradient x hydraulic conductivity products for this example suggest a higher drainage rate through the shallower soils compared to the deeper tighter clays (approximate 6-fold difference). This may be due to factors such as variability/heterogeneity within each layer, the potential presence of soil anisotropy, or differences in lateral flow within the shallower layer balancing out the potential differences in drainage rate. In general, if the textural differences between the two layers are more pronounced (e.g, clearly coarse vs clearly fine) or the difference between hydraulic conductivity x vertical gradient is substantial (e.g., more than 10-fold), then the user should either not use the hydraulic conductivity relevant to drainage option, or use the data but consider it a Tier 2C approach.

Example 9. Medium over fine layered soil
(one nested pair for each layer plus additional well or cores)

Shallow loam / sandy loam layer (main run)

Ksat from cores (m/s)	Hydraulic Conductivity (m/s)	Vertical Gradient (m/m)
MW01a	1.0E-06	
MW01b	4.0E-07	0.01
MW03	3.0E-07	
Average loam / sandy loam	**5.7E-07**	**0.010**

Hydraulic conductivity x vertical gradient	**5.7E-09**	m/s
Drainage category	**High recharge**	

Deeper clay layer (optional additional run for DUA pathway only)

Ksat from cores (m/s)		Hydraulic Conductivity (m/s)	Vertical Gradient (m/m)
MW02a		4.0E-09	
MW02b		8.0E-09	0.150
BH04 10m	7.8E-10 x10→	7.8E-09	
BH04 13 m	8.1E-10 x10→	8.1E-09	
Average clay		**7.0E-09**	**0.150**

Hydraulic conductivity x vertical gradient	**1.0E-09**	m/s
Drainage category	**Mid recharge**	

**Overall subsoil lithology for vertical transport = FINE**

Example 10 below shows a reversed layering compared to example #9, with a shallower fine (clay) layer to 11 m overlaying a deeper medium-textured (loam / sandy loam) layer to 15 m. All hydraulic conductivity and gradient values are the same as example 9 for each layer. This example would also be assigned a 'fine' overall subsoil lithology for vertical transport since drainage would be largely constrained by the shallower clayey layer.

The main run performed would again be based on the shallower primary lithology since it is thick enough to be highly relevant to drainage. Based on this data, the SST calculates a 'mid-recharge' drainage category based the hydraulic conductivity x vertical gradient product of $1.0x10^{-9}$ m/s. If this site was in the 'slightly dry / semi-arid' CMI (e.g, 'Central Parkland'), this would result in a root-zone drainage rate of 3 mm/year down and a DUA drainage rate of 3 mm/year down. This root-zone drainage rate is considered appropriate for the shallower pathways (root-zone, aquatic life, dugout), but in this case the DUA drainage rate would not be conservative since the lithology of the deeper layer suggests potentially faster drainage for the DUA. Consequently, in this example, the user would not have the option of simply using the main run for all pathways, and an additional DUA run using the deeper more conductive soil would be required (rather than optional).

Since there is sufficient data, this additional run for the DUA pathway would use vertical gradient and hydraulic conductivity data for the deeper loam/sandy loam layer. In this case, a 'high-recharge' drainage category would be calculated based on the hydraulic conductivity x vertical gradient ($5.7x10^{-9}$ m/s), resulting in an increased DUA drainage rate of 6 mm/year down assuming the same 'slightly dry / semi-arid' CMI. Note that if the user did not have sufficient data for the deeper layer (e.g, the potentially higher DUA transport was inferred solely from lithology or hydraulic conductivity data but no vertical gradient), then the user would not be able to use the hydraulic conductivity relevant to drainage option for the shallow layer either.

Another difference between example #9 and #10 is the description of lateral transport via shallow and deep groundwater. In example 9 shallow groundwater would be reflective of the medium-grained layer (thus increasing shallow groundwater velocity and risk to aquatic life and dugout pathways), whereas in example 10 shallow groundwater would be reflective of the fine-grained layer (with a lower shallow groundwater velocity and reduced aquatic life and dugout risk). Conversely, hydraulic conductivity data for deep groundwater would be largely reversed for the two sites, resulting in a higher deep groundwater velocity (and more lateral smearing during vertical transport) in example 10 compared to example 9.

Example 10. Fine over medium layered soil
(one nested pair for each layer plus additional well or cores)
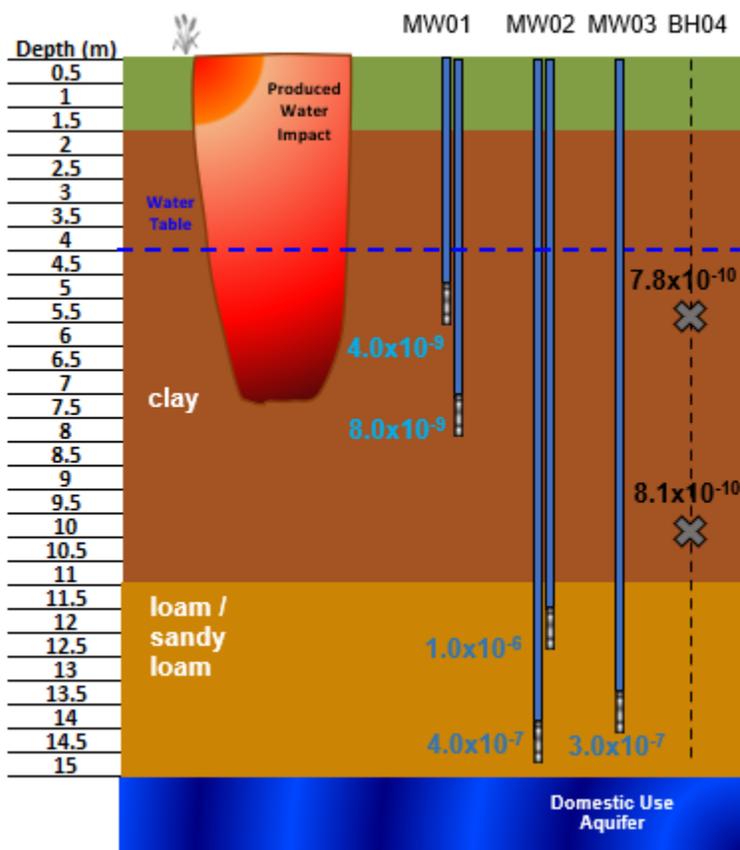
Shallow clay layer (main run)

	Ksat from cores (m/s)		Hydraulic Conductivity (m/s)	Vertical Gradient (m/m)
MW01a			4.0E-09	
MW01b			8.0E-09	0.15
BH04 10m	7.8E-10	x10→	7.8E-09	
BH04 13 m	8.1E-10	x10→	8.1E-09	
Average clay			**7.0E-09**	**0.150**

Hydraulic conductivity x vertical gradient	**1.0E-09**	**m/s**
Drainage category	**Mid recharge**	

Deeper loam / sandy loam layer (required additional DUA run)

	Ksat from cores (m/s)	Hydraulic Conductivity (m/s)	Vertical Gradient (m/m)
MW02a		1.0E-06	
MW02b		4.0E-07	0.010
MW03		3.0E-07	
Average loam / sandy loam	**5.7E-07**	**0.010**	

Hydraulic conductivity x vertical gradient	**5.7E-09**	**m/s**
Drainage category	**High recharge**	

**Overall subsoil lithology for vertical transport = FINE**

Example 11 below shows a typical case with isolated sandy pockets within otherwise fine soil (clay loam). Since the clay layers will largely determine the drainage rate, the 'overall subsoil lithology' would be chosen to be 'fine'. This scenario is considered to be essentially one layer (though non-homogenous) since the sand pockets are not continuous and are not anticipated to substantially alter the flow patterns within the clay.

In this example, the clay lithology is well characterized for both hydraulic conductivity and vertical gradient. One representative sandy pocket also has a single well, potentially used to confirm that the sandy layer was not a DUA based on slug test and/or pump test data. Combining all hydraulic conductivity data together results in an average hydraulic conductivity of 1.3×10^{-7} m/s, influenced upward by the sandy pocket. Using the average vertical gradient of 0.027, the SST calculates a 'mid-recharge' drainage category based on the product of hydraulic conductivity x vertical gradient (calculated internally as 3.5×10^{-9} m/s).

These calculations indicate that the sandy pockets in this example have minimal effect on drainage rate, as the lower average hydraulic conductivity excluding the pocket (1.7×10^{-8} m/s) would still have resulted in a 'mid-recharge' drainage category. These pockets however could potentially play an important role in transport to the FAL receptor or dugout pathways through also being incorporated into shallow groundwater statistics.

Note that this example illustrates one of the few specific cases previously mentioned where it is not practical to obtain vertical gradient data from all lithologies. In this case, installing a nested pair within a thin sand pocket is neither practical nor useful, though if the thickness or lateral extent of this layer was substantially greater then that consideration would likely change.

<u>Example 11. Coarse sand pockets within otherwise fine soil</u>
(two nested pairs plus soil cores within the fine soil, one well within a sandy pocket)
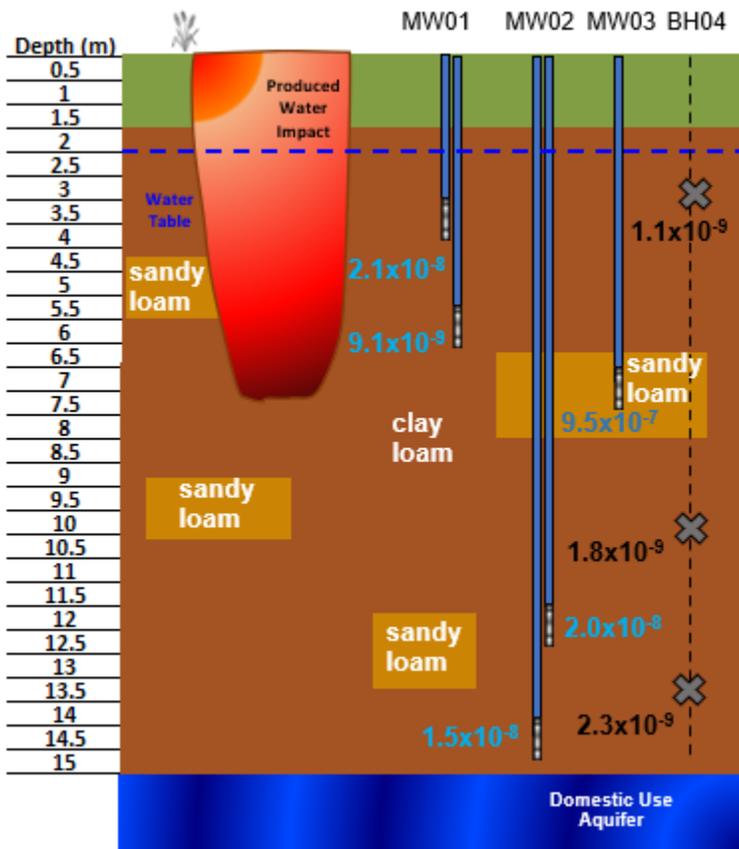
|	Ksat from cores (m/s)		Hydraulic Conductivity (m/s)	Vertical Gradient (m/m)
MW01a			2.1E-08	
MW01b			9.1E-09	0.024
MW02a			2.0E-08	
MW02b			1.5E-08	0.029
BH04 3m	1.1E-09	x10→	1.1E-08	
BH04 10m	1.8E-09	x10→	1.8E-08	
BH04 13m	2.3E-09	x10→	2.3E-08	
MW03			9.5E-07	
Average			**1.3E-07**	**0.027**

Hydraulic conductivity x vertical gradient **3.5E-09** m/s
Drainage category **Mid recharge**

Overall subsoil lithology for vertical transport = FINE

Example 12 below shows two examples of more complex lithology consisting of primarily fine (left) or coarse (right) soil with a continuous lense of opposite texture. Even though there may be two distinct lithologies in each example (clay loam and sandy loam), these examples are considered more complex since they essentially represent three distinct layers (upper, middle, and lower), each of which could potentially have substantially different vertical and lateral flow regimes since the upper and lower layers are separated by a continuous lense. Consequently, regardless of the degree of characterization of each layer, the use of the hydraulic conductivity relevant to drainage option for such sites would be considered a Tier 2C approach (they would also likely require independent runs for the root-zone and DUA pathways). Under a standard Tier 2B approach, the use of vertical gradient information (without hydraulic conductivity) would be permissible, though this may also benefit from an additional run for the DUA pathway due to the potential for differing vertical gradients between layers.

Regardless of the hydraulic conductivity relevant to drainage, the example on the right would generally represent a higher-risk scenario than the example on the left. The overall lithology on the right example would be 'coarse', resulting in generally higher drainage rates than the left example which would be an overall lithology of 'fine'. The example on the right would also predict higher risk to the aquatic life and dugout pathways due to the higher hydraulic conductivity data that would be used for shallow groundwater. Deep groundwater hydraulic conductivity would also be higher in right example, and the resulting increased lateral smearing in deep groundwater may somewhat offset the increased DUA risk caused by the higher drainage rate.

Example 12. Fine or coarse soil with continuous lense of opposite texture
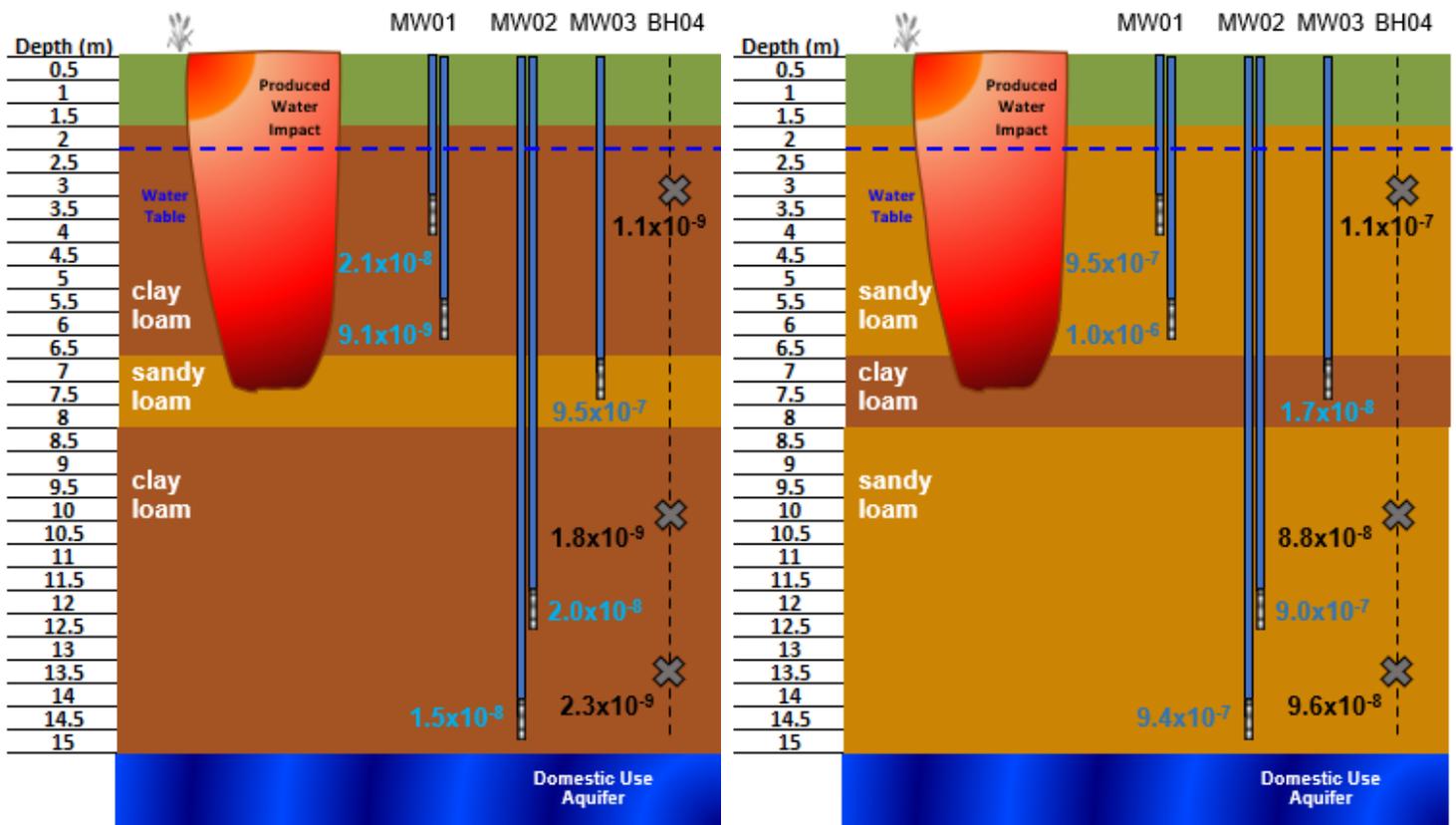
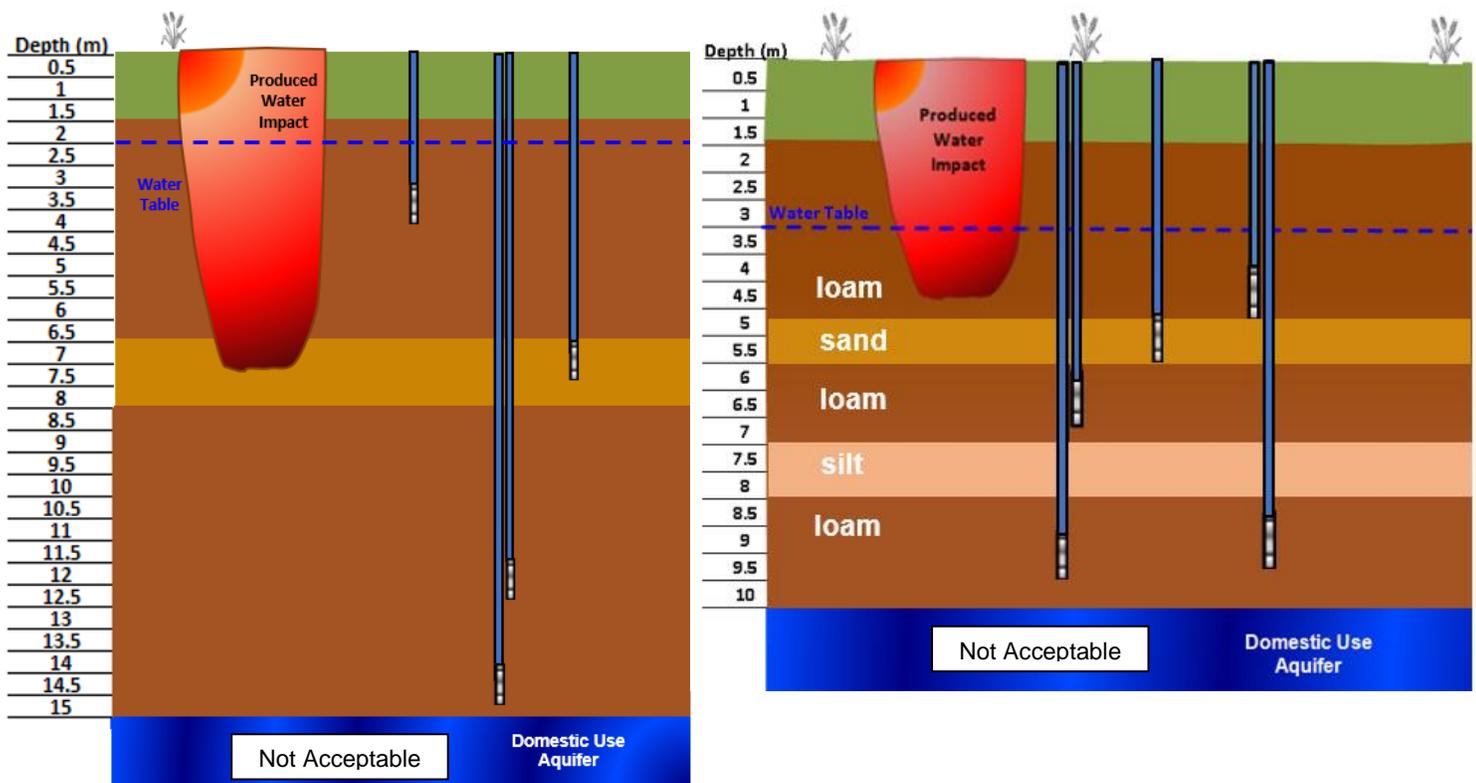Overall subsoil lithology for vertical transport = FINE

Overall subsoil lithology for vertical transport = COARSE

Example #13 shows two non-numerical examples which illustrate other typical factors to consider when determining whether sufficient data is available to allow the use of hydraulic conductivity relevant to drainage data. In both cases, the overall subsoil lithology would be selected as 'fine' since the fine layers would influence drainage more strongly than the coarse intervals.

The left example shows a continuous sandy lense within fine-grained soil, but there is no valid nested pair characterizing the important fine-grained interval above the sand lense. In this case there is thus insufficient vertical gradient data, and the hydraulic conductivity relevant to drainage option thus cannot be used. The ability to use vertical gradient data is also limited in this example as described in Section 4.10.2.

The right example shows excessive lithological complexity, including three distinct lithologies (loam, sand, and silt) and multiple continuous lenses. This example also has no valid nested pairs (since all span more than one lithology), and one important layer (silt) is uncharacterized. This example thus cannot use the hydraulic conductivity option, for any one of these three reasons.

<div align="center">Example 13. Other scenarios</div>

Overall subsoil lithology for vertical transport = FINE (both examples)

As previously discussed, these cases with non-uniform soil lithology generally require professional judgement and an understanding of the underlying conceptual models in order to assign lithologies, thicknesses, hydraulic conductivities, and gradients which accurately describe the physical site. In most cases (such as in the examples previously shown in this section), there is one set of input parameters which can adequately describe the lithologies and hydraulic properties for all receptors at once. In some cases, however, there may not be one set of parameters which can adequately describe all receptors at once, such as (for instance) if an overall lithology of 'coarse' is most appropriate for drainage rates for the DUA pathway but an overall lithology of 'fine' is most appropriate for drainage rates for the root-zone. This could potentially occur if (for instance), a site has fine-grained soil from ground surface to 4 m combined with a 4 m water table and 6 m impact depth, and saturated coarse soils from 4 m down to the potential DUA (see figure below). In this case, the root-zone drainage rate may be best described with a 'fine' overall lithology, but the DUA drainage rate may be best described with a 'coarse' overall lithology. In such cases, the user may need to run the site twice, once with an overall fine-grained lithology and once with an overall coarse-grained lithology, and selecting the guideline most appropriate (or in some cases, most conservative) for each relevant pathway. Due to the substantial lithology differences in this example (coarse underlaying fine with impacts spanning both layers), the user cannot use the hydraulic conductivity relevant to drainage option in this example under a regular Tier 2B approach (though using vertical gradient data may potentially be acceptable under Tier 2B). Any use of the hydraulic conductivity relevant to drainage option in this example would require consideration as a Tier 2C approach. In general, conservative assumptions should be made when describing such sites and the implied CSM (conceptual site model), or the proponent progresses to a Tier 2C approach. As is discussed in more detail in Section 4.12, the user should always ensure that the input parameters entered into the SST and the resulting drainage rates and other transport parameters imply a logically coherent, consistent CSM.
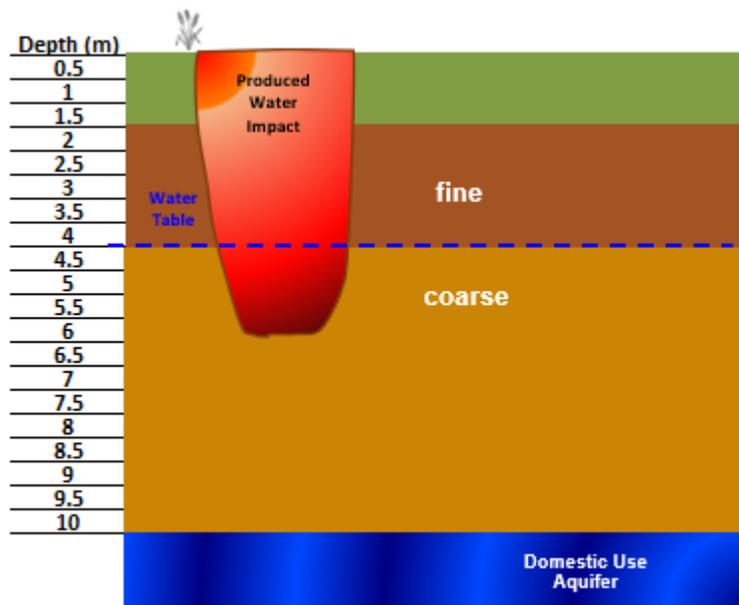
**Overall subsoil lithology for vertical transport is
FINE (for root-zone pathway) and
COARSE (for DUA pathway)**

**May require running site twice, once as overall
FINE and once as overall COARSE and taking
the most appropriate guideline for each receptor**

**Cannot use the hydraulic conductivity relevant
to drainage option under a regular Tier 2B
scenario here (would require consideration as
Tier 2C)**

Summary

Due to the numerous factors influencing the use of the hydraulic conductivity relevant to drainage option and its influence on multiple guidelines via drainage rates, the following points provide a brief summary of the key minimum data requirements and considerations for using this option. In general, if any parameters or site conditions preclude the reliable use of this option, it should conservatively be left blank and the tool will use standard default assumptions for drainage rate as a function of climate, overall soil lithology, and vertical gradient. In all cases, inputs parameters must imply a coherent, logical CSM.

Summary of requirements for hydraulic conductivity relevant to drainage

- Sufficient vertical gradient data must be available and entered in to the SST which meets the minimum data requirements for vertical gradient. The user should also ensure records are kept of how vertical gradients were measured, including the time-frame allowed for wells to properly develop to ensure vertical gradient results are representative. As described in Section 4.10, vertical gradients should not be used from periods of transient dominant recharge conditions (e.g., spring snowmelt), and the user should ensure that the vertical gradients used are temporally-significant and relevant to typical conditions throughout the year.

- Monitoring well or soil core hydraulic conductivity data must be representative of important subsoil lithologies relevant to downward drainage. In general, a layer is considered relevant and important if it is continuous, and of sufficient thickness to have a likely substantial influence on drainage rates.

- Monitoring well hydraulic conductivity data is assumed to be the typical data source, but may be completely or partially replaced by soil core data at the rate of two soil core results per single monitoring result (*i.e*, results from two soil cores are considered equivalent to results from one monitoring well for minimum data requirement purposes). Soil core data must also be multiplied by 10 (outside the SST) before combining with monitoring well data for further calculations.

- For each important distinct layer relevant to drainage, a minimum of three monitoring well hydraulic conductivity results (or equivalent) is required, and additional results will often be useful. The arithmetic average of these results is entered into the SST. This is considered a minimum data requirement applicable to sites with one or two distinct lithologies.

- For sites with more than one distinct lithological layer relevant to drainage, the user must ensure there is adequate proof that each layer exists and that there is support regarding the thickness of each layer. This should generally involve particle size testing (by sieve and/or hydrometer) as a supplement to borehole logs. Bulk density measurements as determined during soil core tests may also be useful in identifying distinct layers.

- In the majority of cases, the most relevant interval will be the shallowest sufficiently thick interval, with data from that interval forming the basis of the main SST run for guideline calculation. Deeper layers may also be relevant to drainage (particularly for the DUA pathway), though in some cases the use of data from deeper layers may be optional.

- In cases where there is an adequately-characterized deeper layer which has a lower hydraulic conductivity x vertical gradient product than the shallower layer, the user may optionally perform an additional run using the deeper hydraulic conductivity and vertical gradient data for the DUA pathway only. Note that the user must ensure that the DUA drainage rate does not become lower than the root-zone drainage rate if using a second DUA run like this.

- Vertical gradient must be measured in the same lithology as hydraulic conductivity. In some cases, this may not be practical, such as in a thin sand lense (*e.g*, 1 m thick) in otherwise fine soil where monitoring well or soil core data has been obtained but installing a nested pair is not practical or useful. Similarly, where a single deep borehole (ie, for DUA depth identification) indicates a low-permeability deep layer, it may not be practical to install a nested pair to obtain vertical gradients in the deeper layer. In such cases, data from the deeper less-conductive layer cannot be used for an additional optional DUA run (due to the lack of vertical gradient data in that layer), but the main run using hydraulic conductivity and vertical gradient data from the shallower, more conductive layer may still be used.

- In some cases, the user may need to run the site twice with different parameters (such as overall soil lithology) if the textural layering does not allow adequate description of all pathways with one set of input parameters. In such cases, the most appropriate guideline for each pathway can be selected from the two runs depending on which describes the scenario for that pathway most accurately.

- If the textural differences between two important lithological layers are too substantial (e.g, clearly coarse vs clearly fine) or the difference between hydraulic conductivity x vertical gradient is too large (e.g., more than 10-fold), then the user should not use the hydraulic conductivity relevant to drainage option, or use the data but consider it a Tier 2C approach.

- If lithology layering is too complex (*i.e*, more than two lithological layers), the user cannot use the hydraulic conductivity relevant to drainage option, though appropriate vertical gradient data may still be used as part of a standard Tier 2B assessment. Or, alternatively, the user may use hydraulic conductivity relevant to drainage data as long as there is sufficient data for each layer and the assessment is considered Tier 2C (to provide additional regulatory interaction).

- The report describing the SST input parameters and assumptions must clearly state if the assessment as a whole is considered a Tier 2C approach or a standard Tier 2A/Tier 2B approach. Being considered a Tier 2C approach may be triggered by complex lithological analysis such as described in this section (more than two lithological layers), or any of the other Tier 2C triggers as described in Section 1.4.2.

4.12 <u>Conceptual Site Model (CSM)</u>

Regardless of whether or not a Conceptual Site Model (CSM) is explicitly developed and identified, the activity of entering input parameters into the SST and generating Tier 2 subsoil salinity guidelines implicitly generates a CSM. A CSM is a visual representation and narrative description of the physical, chemical, and biological processes occurring, or that have occurred, at a site as related to the contaminants and their migration (AEP, 2016). The CSM describes contaminant source and distribution, transport processes, and the impact or potential for impact to receptors. It is developed from data gathered at the site and surrounding area, including soil and groundwater properties, receptor locations, and transport parameters relevant to the site. Consequently, like any CSM, it is important for the user to ensure that the input parameters and corresponding internal SST model are relevant, accurate, consistent, logical, and coherent. As such, it is valuable to frequently be viewing any SST assessment at a higher level, and to ensure that there are no logical inconsistencies between various input parameters and assumptions. This section gives some examples of this type of high-level consideration, along with examples of techniques which can be used to identify potential data problems or inconsistencies. Like any model, the use of inappropriate and/or inaccurate input parameters will result in inappropriate and/or inaccurate model results and corresponding guidelines. The considerations and questions below are not exhaustive and do not all require answers in all cases, but helps provide a useful framework for such thought processes.

Site characteristics and receptors
-is the setting of the site sufficiently understood, including current land use and nearby land use if relevant?
-is this land use likely to change in the near future, either to a more sensitive or less sensitive use?
-have nearby water bodies been identified on maps, and field-evaluated and classified if relevant?
-have distances to the nearest water bodies been measured?
-are there any nearby receptors (DUA or aquatic life) that are already impacted, or will be imminently impacted?
-what is the deepest that has been drilled on the site to-date for potential DUA depth? Is it sufficient?
-has a potential DUA been identified by drilling? Does it require testing by well installation and hydraulic testing?
-are there any site characteristics precluding the use of the SST, or requiring a Tier 2C approach?

Lithology characterization
-has sufficient lithology data by sieve been collected to allow characterization of overall soil lithology?
-is the site simple or complex for lithology? Have all important lithological layers and depths been characterized?
-has sufficient lithology data by sieve been collected to allow characterization of shallow and deep lithology?
-has sufficient hydrometer data been collected to allow a SAR/sodium assessment? Is it consistent with sieve data?
-if the site is coarse-grained, is there the potential that saturated soils may be a DUA? Is further data required to test this?
-is lithology data consistent with monitoring well hydraulic conductivity results, if relevant?
-if soil cores have been obtained, would it be useful to characterize their lithology as well as hydraulic conductivity?
-are borehole logs complete and sufficiently detailed? Are they reasonably consistent with laboratory texture data?

Impact characterization
-is the history of the site sufficiently understood, including a suitable Phase I assessment identifying potential impact sources?
-has an EM survey been performed to help identify potential impact areas and areas of higher natural salinity?
-have other types of geophysical surveys been performed (ERT, VCP, ohm-mapper, etc)? If not, would they be useful?
-have impacts been adequately delineated, both vertically and laterally?
-is there a single impact source, or multiple impacts sources? If multiple sources, are they comingled or separate?
-is the impact distribution generally consistent with likely impact sources? Are there any impact areas with no known source?
-if multiple impact sources, is each one sufficiently characterized to allow splitting into subareas if desired?
-is the site chloride impacted, SAR/sodium impacted, or both?
-will the SST assessment be for chloride only, for SAR/sodium only, or both?
-could elevated SAR be due to historical chloride impacts that have leached away, and not represent background conditions?
-is the distribution of SAR/sodium on the site generally consistent with chloride, but lagging? If not, why not?
-how many years have the impacts been in-place? Were there single, multiple, or continuous impact events?

 Background characterization
-is there sufficient background data to numerically characterize background salinity?
-is this an area of generally high or low background salinity? Is background salinity uniform or patchy?
-does background salinity differ on-lease vs off-lease? Does it differ between impacted and non-impacted areas?
-does background borehole placement adequately and fairly capture the variability of background salinity?
-does background salinity data have adequate refinement by depth? Are root-zone and subsoil adequately characterized?

-are there any complications with marginal chloride impacts in any background locations?
-is there the potential for chloride impacts in the area from non oil and gas sources? (road salt, manure, natural chloride, etc)
-if monitoring wells are present, are any of them in background locations? Are any needed?
-do background sulphate depth profiles provide an indication of discharge vs recharge conditions? Is there sufficient data?
-is background sulphate/TDS data generally consistent with background subsoil EC/SAR data in a SAR/sodium assessment?

Data integrity
-is all the data from the site (soil and groundwater data, if relevant) reliable and organized in a logical manner?
-is some of the data substantially newer than other sets of data?
-is the newer data consistent with older data, or are there substantial differences?
-should both older and newer data be treated comparably, or is newer data more reliable?
-is it reasonable to supersede older soil data with newer data?
-is there the potential that errors may be present in soil or groundwater data? What are the potential sources of errors?
-are there potential transcription errors from field notes to tables? From lab sheets to tables? Between different sources?
-have various data integrity checks been used, such as soil EC vs anion regressions, cation/anion balances, etc?
-are sampling methods consistent from year to year? (eg, bailer vs low-flow sampling). If not, what is the potential effect?
-have original lab data sheets or field notes been consulted to try to isolate sources of potential data issues?
-have reporting units (mg/kg, mg/L, meq/L) and basis (SO4-S vs SO4) been accurately transferred from lab sheets to tables?

Lateral groundwater transport
-are monitoring wells present at the site?
-if not, are the conservative assumptions of a Tier 2A assessment acceptable, or should wells be installed?
-if wells are present, are they adequate to describe the relevant aspects of groundwater flow at the site?
-have monitoring wells been installed in lithologies most relevant toward transport?
-are monitoring wells in good condition, and have sufficiently accurate and relevant survey data?
-have monitoring wells been developed properly after installation?
-have any wells heaved or settled to the point of needing resurveying or repairing / decommissioning?
-have minimum data requirements been met for shallow and deep groundwater, if relevant? Would additional data be useful?
-is groundwater elevation data reliable, and analyzed appropriately to estimate lateral gradient and flow direction?
-is groundwater flow direction and gradient consistent between years? If not, why not?
-is groundwater flow direction consistent with observed impact distribution?
-is groundwater velocity consistent with observed impact distribution and distance from source area?
-were site conditions different historically and potentially influencing transport? (eg, water-filled pit increasing lateral flow?)

Vertical groundwater transport
-are the default drainage rates to be modified using vertical gradient data or hydraulic conductivity relevant to drainage data?
-if so, have sufficient nested well pairs been installed at the site as a function of impact area and lithology complexity?
-have all requirements been met for nested wells? (lithology consistency, equilibrated water levels, non-transient results, etc)
-have sufficient vertical gradient measurements been obtained to capture typical season and annual variability?
-if multiple nests are present, are the results consistent between the nests? If not, why not? Is it appropriate to average?
-do vertical gradients indicate discharge or recharge conditions? Is this consistent with chloride and sulphate profiles?
-is hydraulic conductivity relevant to drainage data from wells or soil cores going to be used? Is there sufficient data?
-if soil cores are being used, or they generally consistent with well data? (taking into account scale effects, etc)
-are current impact depths plausible based on the estimated drainage rates?
-were site conditions different historically and potentially influencing transport? (eg, water-filled pit increasing drainage?)

Guideline generation
-have guidelines been generated for all appropriate scenarios for both chloride and SAR/sodium as needed?
-are input parameters (backfill data, excavation depths, etc) consistent between chloride and SAR/sodium assessments?
-do separate guidelines need to be generated for different receptors using runs with different parameters? (lithology, etc)
-have appropriate guidelines been generated to allow comparison of wall and floor confirmatory data to from different depths?
-have SST output reports been generated and datafiles saved to be able to reproduce, describe, and support guidelines?

Remediation plans
-is there sufficient data to proceed toward excavation or create a Remedial Action Plan (RAP) if necessary?
-is data density sparse (or old) in some areas creating the potential for unexpected results during excavation?
-would additional pre-remediation delineation data be useful to refine excavation depths and volumes?
-has backfill been adequately characterized, and is generally comparable texture and quality (or better) to background soils?

-have options for potential soil reuse been evaluated such as using marginally-impacted soils as subsoil backfill?
-if multiple backfill qualities must be used, has a plan been generated for optimizing its placement by area and depth?
-does the remediation excavation match the assumed depth / extent, or is there a need to review the remediation guidelines?

Four examples are provided below which demonstrate the type of analysis which might be relevant to some of the above questions. The examples are related to consistency of data and coherency of the CSM, and have relevance to a broad range of sites.

Example #1: Soil regressions as a QA/QC and data integrity tool
One useful technique which can be performed on any salinity dataset is the preparation of soil regressions as a QA/QC and data integrity check. There are several ways to generate these regressions, but they are all based on the fundamental concepts of charge balance and the direct relationship between charge and electrical conductivity. In particular, EC (on a dS/m saturated paste basis) is highly correlated with either total anion or total cation charges on a milliequivalent per litre (meq/L) basis. The most useful regression is generally plotting soil EC vs total anions (meq/L), where chloride and sulphate are generally the anions which have the greatest contribution to charge and conductivity at typical produced-water impacted sites. Other anions such as bicarbonate and nitrate may also play a role, but these tend to be either minor and background-related (bicarbonate) or typically associated with fertilizer or livestock impacts (nitrate). To create this regression, chloride and sulphate data in mg/kg must each be converted to meq/L (unless already reported by the lab) by using saturation percentage and equivalent weight. For example, consider a sample with 100 mg/kg chloride and 100 mg/kg sulphate and a 50% saturation percentage. This would convert first to 200 mg/L chloride and 200 mg/L sulphate (dividing by the saturation percentage), and then to 5.64 meq/L chloride and 4.17 meq/L sulphate (dividing by the equivalent weights of 35.45 and 48.0 respectively). The sum of anions would thus be 9.81 meq/L from adding chloride and sulphate together. This would then be plotted with the corresponding EC value (likely in the range of 0.8 dS/m), and a regression generated for all datapoints in the dataset using the same method.

An example of such a regression is shown below, including the best fit line and some typical variability around this line. Two datapoints are identified on this figure as potentially anomalous due to their relative deviation from the best fit. One datapoint has too low an EC given the anions, whereas another point has too high an EC given the anions.
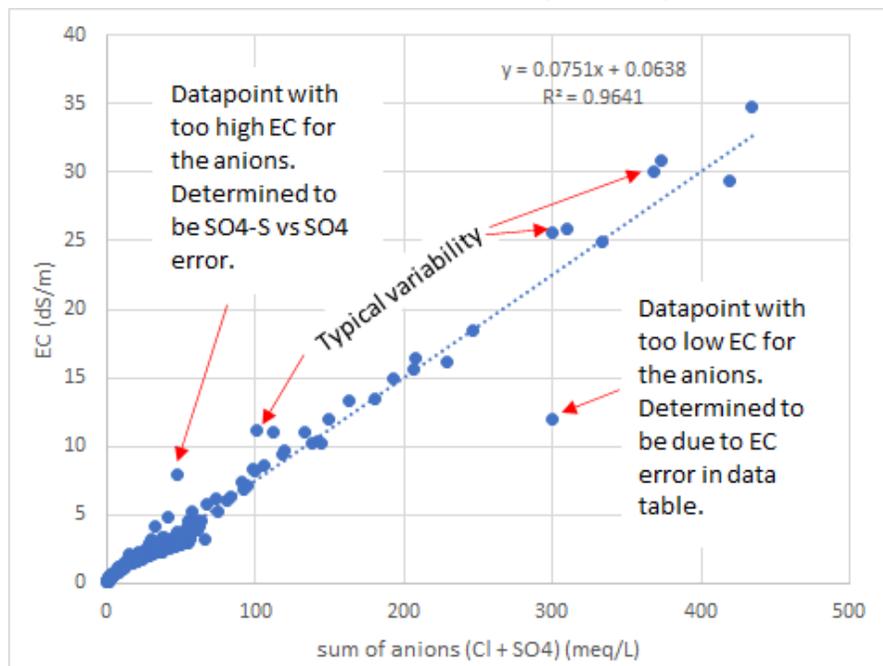
Guided by these findings, the dataset can then be further examined, including checking for transcription errors, reporting errors, or other sources of deviation. For the high EC sample, it was found that the EC value was recorded in the data table as 12 dS/m but should have been 22 dS/m (data transfer error). In the low EC sample, it was found that the sulphate data (in mg/kg) was improperly showing data on a sulphate-S rather than sulphate basis and thus rather than 2100 mg/kg sulphate was shown as 700 mg/kg (the typical 3-fold difference between these measurements as shown in Section 4.2.1.2). When these two errors were corrected, the updated regression is shown below which no longer has any apparent outliers outside

typical variability. The slope of the best-fit line is also within the typical range of 0.06 – 0.10 (0.077 in this case), thus further confirming data validity. This type of regression is especially useful when combining datasets from different labs or different years or different report sources, as there is an increased chance of transcription or reporting errors in such cases. Other useful regressions can also include EC vs total cations (meq/L), and total cations vs total anions (both meq/L). The aspects of the CSM influenced by soil salinity data would thus have a higher degree of reliability after these QA/QC checks.
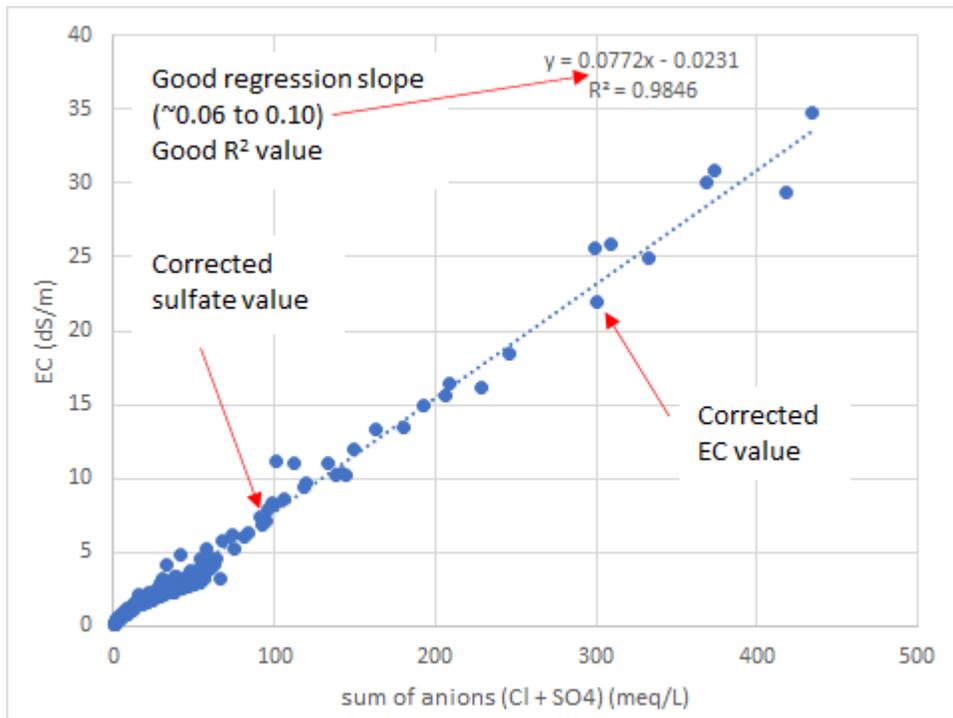
Example #2: Groundwater flow diagrams as a tool to verify groundwater elevation and gradient data

When groundwater elevation data is obtained from monitoring wells, it is useful to analyze the data using the US EPA Lateral Gradient Calculator (US EPA, 2016a) as discussed in Section 4.6.2. While this is a useful tool which can quickly provide an average lateral gradient and flow direction, it does not provide any way to visually confirm that results are reasonable or consistent in the context of other site data.

For example, consider a site with five shallow monitoring wells (MW1 through MW5) with coordinates and groundwater elevations shown below (groundwater elevations calculated from water tape measurements and well survey data). Here, the US EPA calculator generates a lateral gradient of 0.022, with a flow direction of north-northwest (16.3 degrees from north).

Classification: Public

While these results are plausible, they are not consistent with the observed groundwater plume (extending to the southeast) and thus the results are investigated further. Groundwater elevations are contoured in the figure below, showing an unusual pattern with flow direction varying across the site. The blue arrow indicates the average flow direction generated from the US EPA calculator, and the yellow arrows show the local flow directions at various other points at the site (ranging from southeast to northwest).
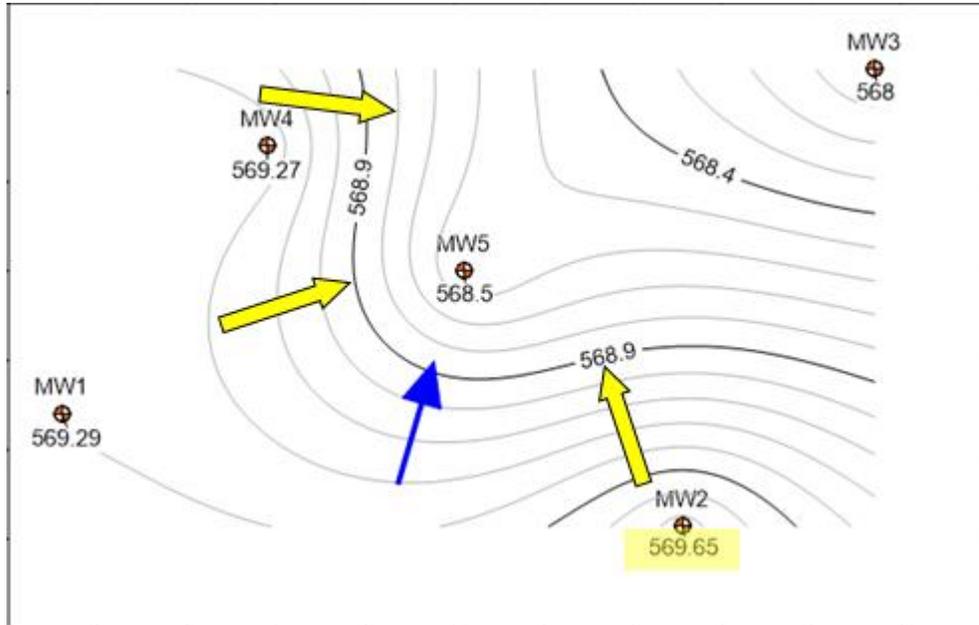
Based on this data, it was found that the MW2 elevation (shaded yellow above) had an error in one digit transcribing results from field notes, with the results of fixing this error shown below. The flow direction is now to the southeast, with a gradient of 0.026 and flow direction of 127 degrees from north. This flow map is now less complex, and more consistent with the observed impact distribution. The CSM implied by this updated data is thus more accurate and representative than the version with the erroneous data.
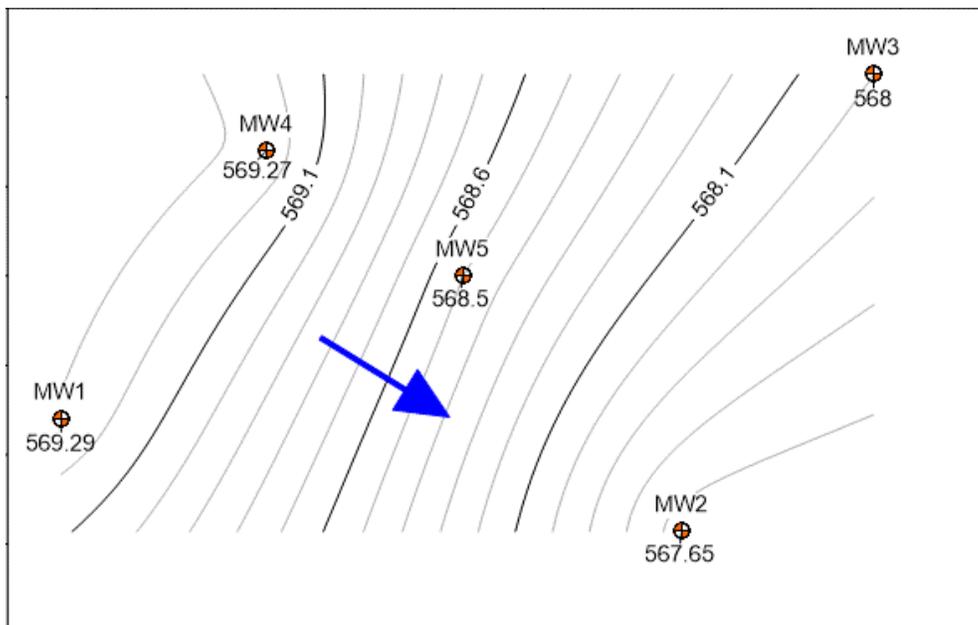
Example #3: Importance of EM surveys and background data being representative of site conditions
When deciding on the placement of background boreholes, it is important to consider the variability and distribution of natural background salinity in and around the site area. EM surveys are important tools to facilitate this, and are required for all SST assessments due to their value in identifying areas of elevated salinity whether natural or impact-related.

The figure below shows a square lease boundary with a known chloride impact near well-center, where the yellow shaded outlines show representations of EM anomalies from an EM survey. EM surveys cannot distinguish between sulphate and chloride-related anomalies, so the descriptions on the figure below of sulphate vs chloride are based on soil chemistry data rather than the EM survey itself.

Potential background borehole locations are shown as either blue or green crosses, with blue crosses located within EM anomalies and green crosses located outside the EM anomalies. From this, it is readily apparent that drilling background boreholes only at the green locations would give a dataset skewed improperly toward low background salinity, whereas drilling background boreholes only at the blue locations would give a dataset skewed improperly toward high background salinity. For background data to be representative, it needs to include a reasonable mixture of the range of salinity across a site, and thus should ideally contain a mixture of blue and green locations in this example. A CSM which includes background data which is inappropriately skewed will result in inappropriate remediation guidelines, whereas a CSM which contains a reasonable representation of background conditions across a site will result in more appropriate guidelines. For a reliable CSM it is also important to ensure that all potential impact sources are characterized, which frequently requires advancing at least one borehole in each distinct, potentially relevant EM anomaly at a Site. This further illustrates the importance of EM surveys and impact characterization to the development of a reliable CSM within the tool.
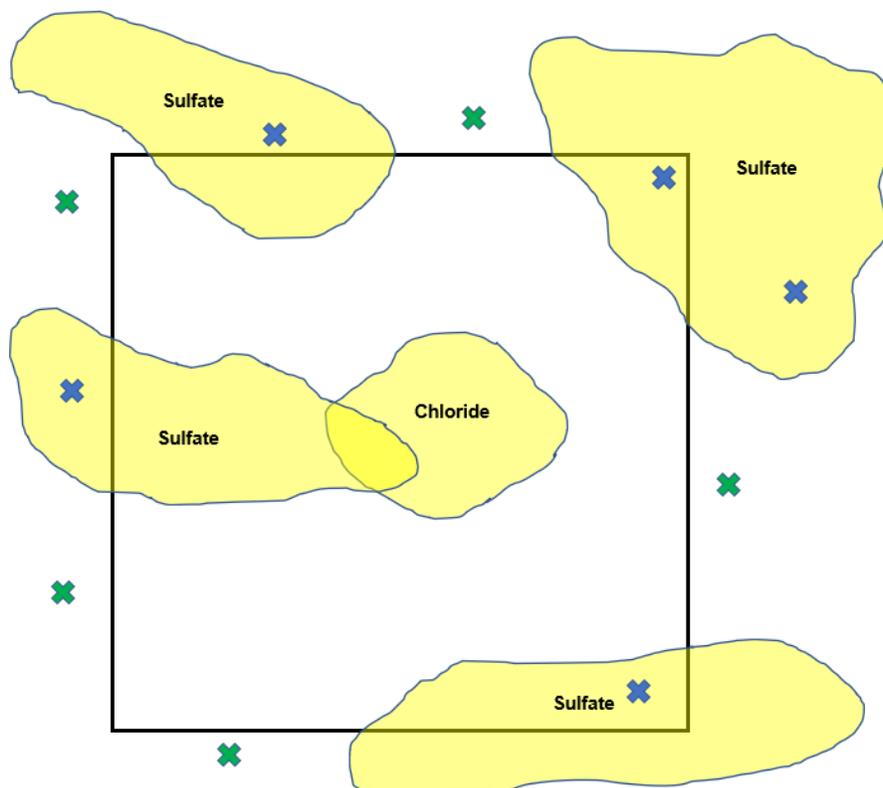
<u>Example #4: Importance of accurate vertical gradients</u>
Vertical gradients can have a strong influence on drainage rates, and thus a substantial influence on the CSM and corresponding guidelines. It is thus very important to ensure vertical gradient data is accurate and reliable, especially when working with potentially small and sensitive differences in water levels between wells. For example, consider a site with three nested pairs (MW01a/b, MW02a/b, and MW03a/b) installed in generally clayey soils, one of which (MW01a/b) is located in the fringe of a nearby wetland to evaluate drainage conditions in that vicinity. The wells were installed and surveyed in early September 2010, developed in mid-September 2010, and monitored in late September 2010 and again in late October 2010. No further assessment work was then done at the site until 2019, at which point water levels were again measured in June 2019 and May 2020 by a different field technician. All shallow ('a') wells were screened from 2-3 m, and all deep ('b') wells were screened from 3.5-4.5 m. Thus, the requirement of a minimum of 0.5 m between the base of the shallow well and the top of the deep well has been met, with an overall difference of 1.5 m between the midpoint of shallow and deep screen depths (relevant to vertical gradient calculations).

Results of vertical gradient calculations are shown in the table below for each of the four events (positive values indicate recharge, negative indicate discharge). The event from late September 2010 showed anomalously high downward gradients (0.06 to 0.34), and were considered non-representative (excluded and shown in faded font) due to the wells not yet being full recharged / equilibrated due to the fine clayey soils. October 2010 results show slight recharge conditions for all nests (0.008 to 0.015 down), and all wells were considered equilibrated at that time. Similar slight recharge results were obtained in 2019 and 2020 for MW02a/b and MW03a/b, but MW01a/b showed stronger upward (discharge) results in the -0.05 to -0.06 range. Based on these values, an overall average of -0.004 (discharge) for all wells for 2010-2020 was obtained. However, since the 2019-2020 results from MW01a/b appear potentially inconsistent with other results, further examination of results was performed to ensure that potentially non-representative values are not entered into the SST and resulting implied CSM.

		Vertical gradients				
Nested pair	Sept 2010	Oct 2010	June 2019	May 2020		
MW01a/b	0.19	0.015	-0.054	-0.06		
MW02a/b	0.34	0.012	0.015	0.010		
MW03a/b	0.06	0.008	0.010	0.009	**Overall average**	
Average	0.197	**0.012**	**-0.010**	**-0.014**	**-0.004**	

First, field notes were carefully checked to ensure that all water level measurements were recorded and transcribed correctly (which they were). Photos of wells were then evaluated, and it was observed that the MW01a PVC casing had heaved upward due to frost heaving cycles at the fringe of the wetland over the previous 9 years (to the point where it was difficult to close and lock the protective metal casing, which was not initially noted as important by the field technician). The well was then physically checked again and resurveyed, and the amount of frost heaving at that well was determined to be 10 cm. Thus, the depth to water measurements at the shallow well were made artificially deeper from the heaved casing, resulting in a false upward gradient when used with the original survey results. When using the corrected casing elevation (relevant to 2020, and assumed to be reasonably relevant to 2019), the anomalous discharge vertical gradients from MW01a/b became slight recharge values consistent with 2010 and consistent with the other well pairs. The corrected vertical gradients for MW01a/b are shown below, along with the updated overall average of 0.011 downward.

		Vertical gradients				
Nested pair	Sept 2010	Oct 2010	June 2019	May 2020		
MW01a/b	0.19	0.015	0.013	0.007		
MW02a/b	0.34	0.012	0.015	0.010		
MW03a/b	0.06	0.008	0.010	0.009	**Overall average**	
Average	0.197	**0.012**	**0.013**	**0.009**	**0.011**	

As further confirmation, undisturbed background sulphate depth profiles at the site were evaluated, and there was no evidence of the site being in a discharge condition based on considerations and example depth profiles described in Section 2.7.6. Thus, these corrected vertical gradients with a slight downward average gradient were considered representative and reliable, and the corresponding downward drainage rates more suitable for the CSM. This confirmation of slightly downward vertical gradients also creates the option of evaluating hydraulic conductivity relevant to drainage (if desired), and potentially further refining the downward drainage rates based on additional site-specific well and/or soil core data.

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. Most of this soil data is relevant to both subsoil chloride and subsoil SAR/sodium assessments, and thus similar data must be collected in either scenario. Soil parameters required by the SST include:

1. Soil Texture and Lithology;
2. Background Root Zone Salinity;
3. Background Subsoil 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 of soil lithology that are less influenced by field investigator judgment, since judgments vary between practitioners and educational backgrounds. (*e.g.*, one practitioners fine silty clay may be another practitioners coarse sandy loam). Soil texture data via sieve are required for:

- boreholes located within the salt impacted area;
- 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,
- material intended to be used as backfill.

While sieve data may be sufficient for chloride assessments, additional hydrometer data may also provide additional insight into lithological transitions and transport potential, and thus may be optionally collected. Hydrometer is required along with sieve data for SAR/sodium assessments due to the importance of clay content in cation transport and exchange reactions.

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 (both root-zone and subsoil), 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 and in subsoil. 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 sieve data should be noted from laboratory results and soils classified into the following general categories for use within the SST:

1. Fine Soil (50% or less retained on 75 µm sieve)
   - generally includes heavy clay, clay, clay loam, silty clay, silty clay loam, silt, silt loam, most loams.
2. Coarse Soil (more than 50% retained on 75 µm sieve)
   - generally includes sandy soils with sand content >50% such as sand, loamy sand, sandy loam, and potentially sandy clay loam or sandy clay

Soil textural information can be recorded in tables or on borehole logs for site-specific SST guideline documents submitted to AEP/AER. 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 <u>receptors of concern</u>. 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 AEP/AER for assistance with determining appropriate salinity guidelines for muskeg/peat layers.

An example of a texture summary table is shown below, including texture by sieve data which is used to define overall lithology in the SST (fine or coarse). It also shows hydrometer data (including clay content) which is required solely for SAR/sodium assessments but may provide useful additional lithological context for chloride assessments as well.

Hydrometer data and clay content
When a SAR/sodium assessment is performed, texture by hydrometer (particularly clay content) is required in addition to sieve data. Average clay content is required for the root-zone (<1.5 m), subsoil (1.5 m to approximately 6 m), and (if relevant) backfill. A minimum of three samples for each interval is required. Each interval is classified as to whether clay content is "low" (<18%), "medium" (18-36%), or "high" (>36%) for SAR/sodium guideline development based on the arithmetic average clay content for each interval.

Borehole	Location	Depth	Texture by Hydrometer				Texture by Sieve	
		(mbgs)	% Sand	% Silt	% Clay	Texture	% Retained (75 µm sieve)	Overall SST Lithology
BH12-14	Impact	0.0-0.3	56	21	24	Sandy Clay Loam	36	Fine
BH12-05	Impact	0.0-0.3	65	11	24	Sandy Clay Loam	24	Fine
Average	**Impact**	**0.0-0.3**	**61**	**16**	**24**	**- -**	**30**	**Fine**
BH11-6	Background	0.0-0.3	60	18	23	Sandy Clay Loam	34	Fine
BH11-77	Background	0.0-0.3	59	26	15	Sandy Loam	52	Coarse
Average	**Background**	**0.0-0.3**	**60**	**22**	**19**	**- -**	**43**	**Fine**
BH12-14	Impact	0.3-0.6	71	20	9	Sandy Loam	57	Coarse
BH12-05	Impact	0.3-0.6	71	13	16	Sandy Loam	61	Coarse
Average	**Impact**	**0.3-0.6**	**71**	**17**	**13**	**- -**	**59**	**Coarse**
BH11-6	Background	0.3-0.6	63	21	17	Sandy Loam	57	Coarse
BH11-77	Background	0.3-0.6	64	21	15	Sandy Loam	53	Coarse
Average	**Background**	**0.3-0.6**	**64**	**21**	**16**	**- -**	**55**	**Coarse**
BH12-14	Impact	1.0-1.5	57	19	25	Sandy Clay Loam	20	Fine
BH12-04	Impact	1.0-1.5	38	18	45	Clay	12	Fine
Average	**Impact**	**1.0-1.5**	**48**	**19**	**35**	**- -**	**16**	**Fine**
BH11-6	Background	1.0-1.5	73	16	12	Sandy Loam	56	Coarse
S10-36	Background	1.0-1.5	58	23	20	Sandy Clay Loam	30	Fine
BH11-77	Background	1.0-1.5	31	18	51	Clay	10	Fine
Average	**Background**	**1.0-1.5**	**54**	**19**	**28**	**- -**	**32**	**Fine**
BH11-26	Impact	2	87	7	5	Sand	65	Coarse
BH09-09	Impact	2	90	7	2	Sand	68	Coarse
BH11-10	Impact	2	75	12	13	Sandy Loam	55	Coarse
BH11-26	Impact	3	31	18	51	Clay	10	Fine
BH09-05	Impact	4	25	22	53	Clay	8	Fine
BH11-10	Impact	4	63	14	23	Sandy Clay Loam	15	Fine
BH11-26	Impact	5	17	26	57	Clay	8	Fine
BH11-26	Impact	6	59	26	15	Sandy Loam	52	Coarse
BH09-09	Impact	6	64	21	15	Sandy Loam	55	Coarse
BH11-26	Impact	7	7	47	46	Silty Clay	10	Fine
BH11-26	Impact	8	19	23	58	Clay	11	Fine
BH09-09	Impact	8	40	18	43	Clay	13	Fine
BH11-10	Impact	9	33	26	41	Clay	15	Fine
BH11-10	Impact	10	2	28	70	Heavy Clay	9	Fine
Average	**Impact**	**1.5-10**	**44**	**21**	**35**	**- -**	**28**	**Fine**
BH11-6	Background	1.75	41	20	40	Clay	12	Fine
BH11-6	Background	2.75	23	34	44	Clay	9	Fine
BH11-6	Background	4.25	20	27	54	Clay	14	Fine
BH11-6	Background	5.75	73	16	12	Sandy Loam	60	Coarse
BH11-6	Background	9.75	13	32	56	Clay	14	Fine
Average	**Background**	**1.5-10**	**34**	**26**	**41**	**- -**	**22**	**Fine**
BF12-01	Backfill		7	47	46	Silty Clay	10	Fine
BF12-02	Backfill		40	20	41	Clay	9	Fine
BF12-03	Backfill		33	22	46	Clay	14	Fine
Average	**Backfill**	**1.0-1.5**	**27**	**30**	**44**	**- -**	**11**	**Fine**

Note that hydrometer data (particularly clay content) are required solely for SAR/sodium assessments, but may provide useful additional lithological context for chloride assessments as well.

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' depending on saturation percentage and other factors). 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.

It should also be noted that in some cases, chloride concentrations may be less than 100 mg/kg throughout a borehole though the location may have previously been impacted by produced water and thus not represent background conditions. Such cases typically involve coarse soils (where chloride has had sufficient time to leach away vertically or laterally) and frequently have elevated SAR left behind as an indicator of past impacts. Such locations require professional judgement to identify (including knowledge of historical impact areas) and should not be included in background root zone salinity statistics.

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 for EC, 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 for EC 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 may be required or further analysis of outliers performed and background data with anomalously high EC potentially excluded (a conservative approach). Alternatively, it may be necessary to divide the site into two distinct areas.

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 exceedance of Tier 1 guidelines at depths shallower than 1.0 m (as well as from 1.0-1.5 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 also 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 exceedance 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.
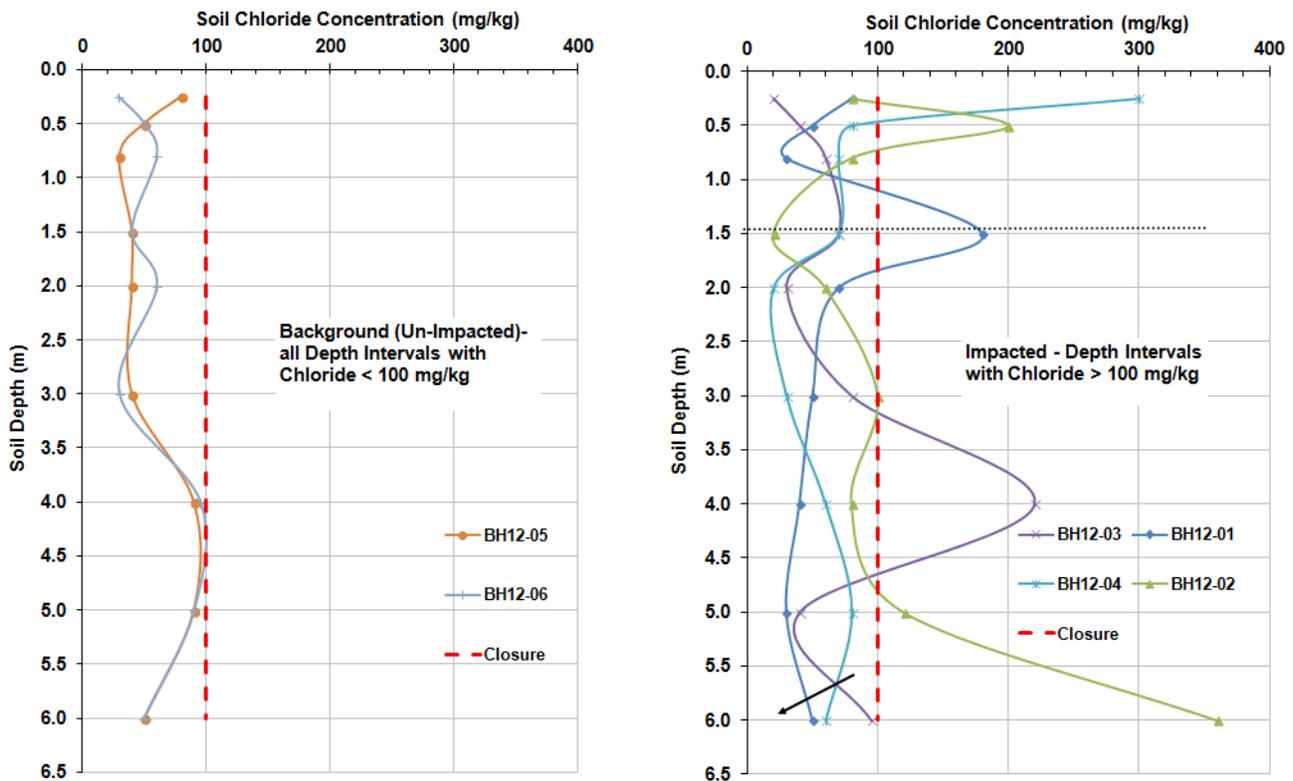

Background boreholes are drilled in locations that are laterally distant from the impacted areas. These boreholes should be drilled at locations that are more distant from the salinity impacts, compared to hydrocarbon impacts, since salts diffuse and disperse to a greater extent into unimpacted soils 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 in 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 ephemeral wet area where the groundwater table is relatively deep. In this case, the ephemeral wet area 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.
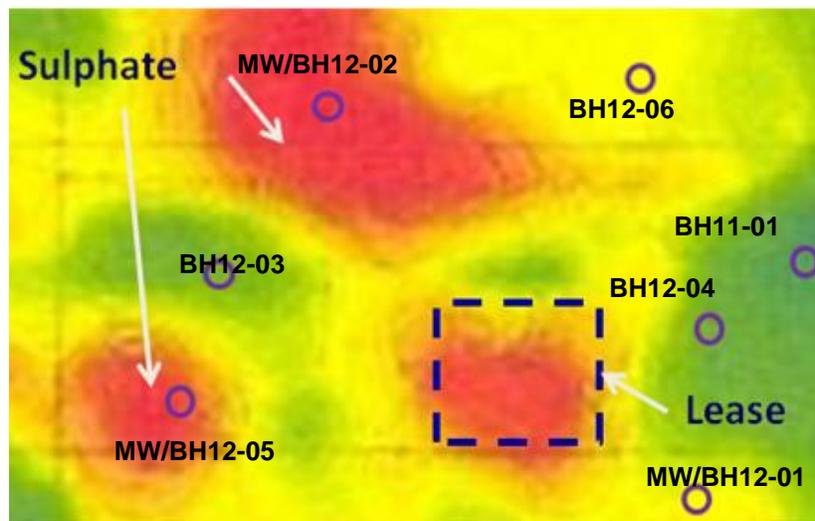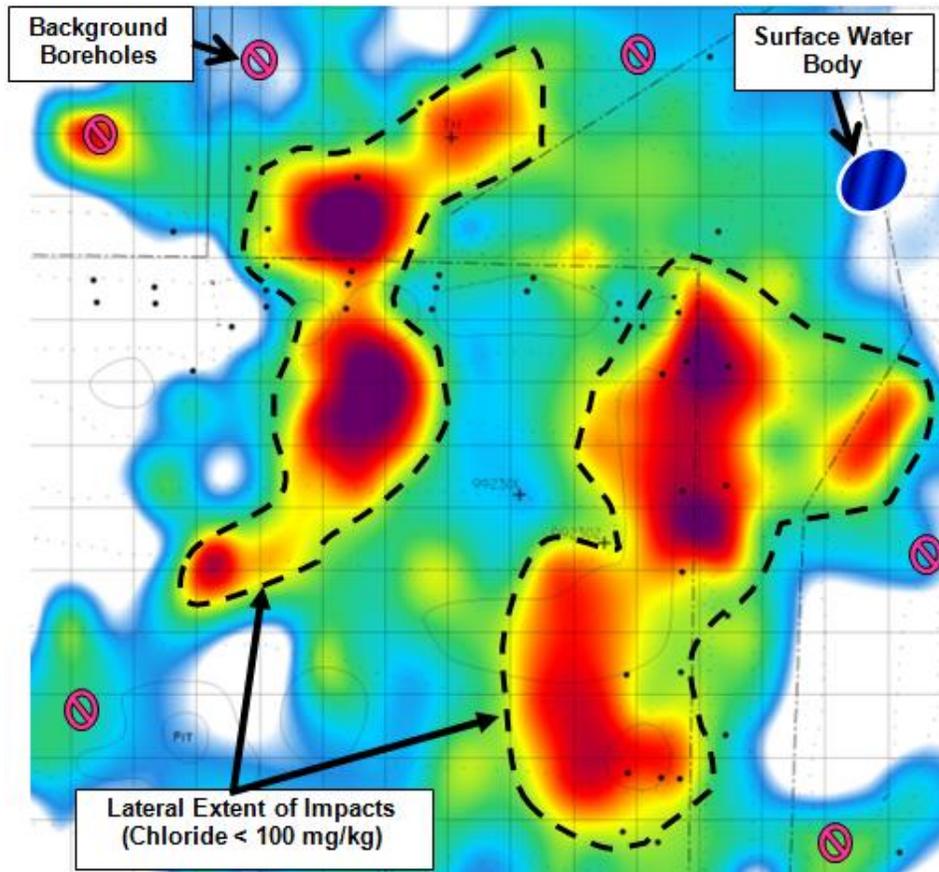
An example is provided below for the proper and improper sighting of background borehole locations, in relation to a chloride impacted area, for salinity environments with greater salinity variability and distinct physiographical features. Airphotos are frequently of use in assisting with background borehole location selection for root zone soil chemistry and texture characterization for this type of grouping. In this example, a pipeline break occurred within an ephemeral wet area, which did not meet the criteria of a wetland / 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 ephemeral wet area is unlikely to be similar to conditions within the boundary of the ephemeral wet area. 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.
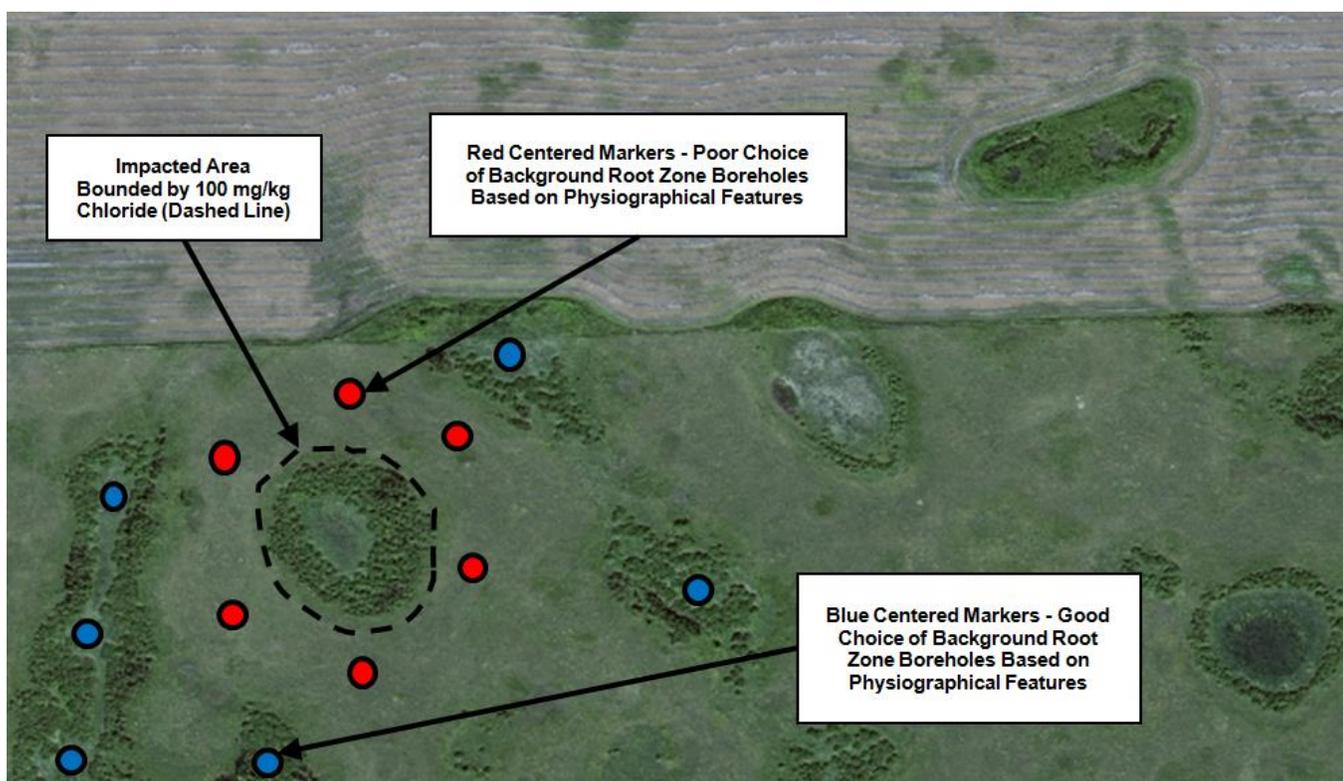
For sites with higher variability root zone salinity and distinct physiographical features and where an impact area extends across different features, multiple datasets of background root zone information must be generated, one for each distinct physiographical feature.

## 5.3 Background Subsoil Salinity

Additional characterization of background salinity into subsoil (below the 1.5 m root-zone) will be required if the following situations occur. The first two are related to the dugout scenario to allow estimation of background TDS from soil data, and the third is related to any subsoil SAR/sodium assessment.

1. A Tier 2A chloride assessment is conducted where the dugout scenario is relevant since the water table is estimated to be 6 m or shallower, and the site is,
   a. Located within an Agricultural Land Use area,
   b. Located on non-Agricultural 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 chloride assessment is conducted where the dugout scenario is relevant (the water table is measured to be 6 m or shallower, and 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 subsoil boreholes drilled are used to estimate background TDS.

3. Any subsoil SAR/sodium assessment is conducted regardless of whether Tier 2A or Tier 2B. Here, background subsoil data is used for all subsoil SAR/sodium pathways (soil structure, upward migration into the root-zone, irrigation water from a dugout) in order to provide the necessary estimates of background subsoil cation concentrations.

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. 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, and sulphate. It may also be useful to optionally include soil carbonate and bicarbonate parameters.since relevant to dugout background TDS calculations.

Soil data for input into the SST for background subsoil salinity are dependent on the water table depth. 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. Since highly relevant to the dugout pathway, samples down to 6 m may be used for background subsoil salinity. Examples are shown below.
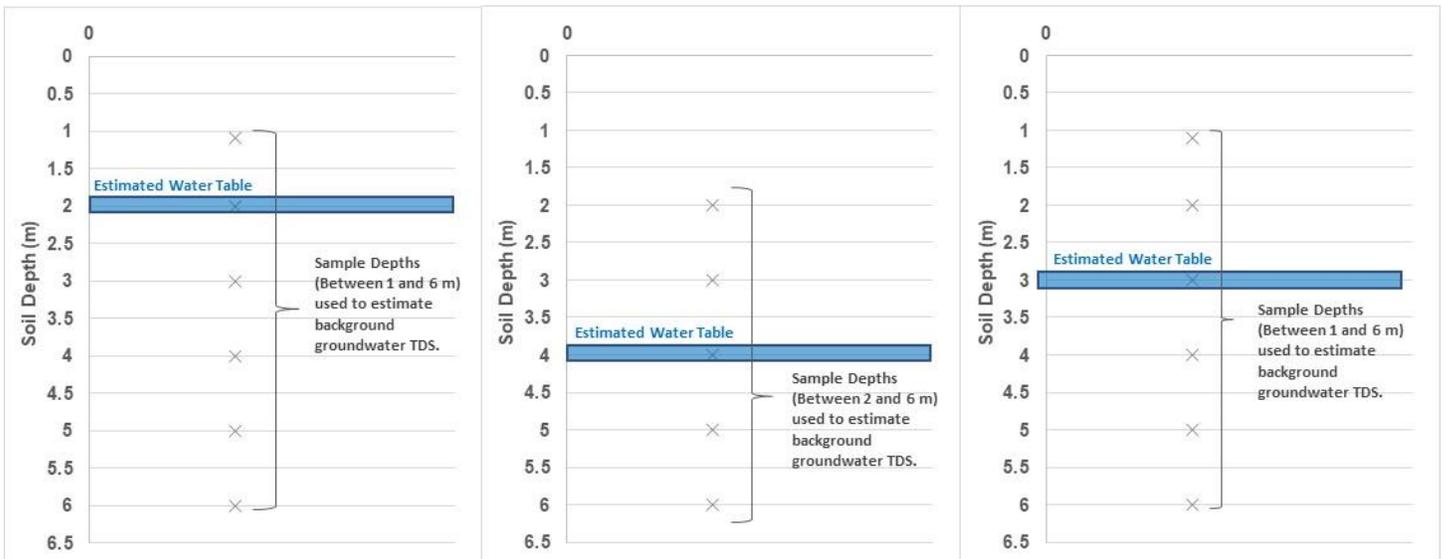

⚠ *Note: Samples within 2 m above the water table are only acceptable if salinity levels (e.g., EC values or sulphate concentrations) are shown to be similar to levels below the water table.*

5.4 Root Zone Salinity in the Impacted Area

Root zone salinity (1.0 to 1.5 m) in the impacted area is determined from samples taken within the salinity impact area (chloride concentrations >100 mg/kg) at some depth interval within the 1.0 to 1.5 m range. When EC and SAR root-zone values are at or below background levels and chloride concentrations are less than or equal to 100 mg/kg, the root zone is considered 'unimpacted'. The root zone is considered 'impacted" if root-zone chloride concentrations are >100 mg/kg or SAR is above background levels, but neither exceeds Tier 1 guidelines. Any exceedance of Tier 1 guidelines at depths shallower than 1.0 m (or from 1.0 to 1.5 m) is a trigger for remediation ('excavation and backfill'), and/or exposure control measures.

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). If multiple SubAreas are considered for a site, a minimum of four boreholes is required per SubArea. An example is shown

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below. For an 'impacted' root-zone scenario (chloride >100 mg/kg in at least one 1.0 to 1.5m sample for a particular SubArea), the 95th percentile of chloride data from 1.0-1.5 m is entered into the SST for updated root-zone buffer calculations.
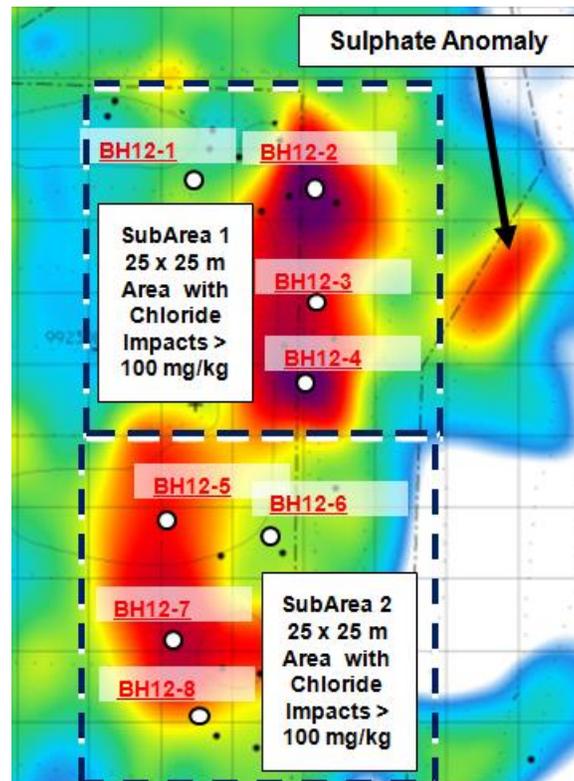

For a SAR/sodium assessment, the same impacted root-zone salinity data requirements apply as for chloride assessments. However, there may not necessarily be chloride >100 mg/kg with the 1.0-1.5 m depth interval since historical chloride impacts may have leached away leaving elevated SAR but not necessarily elevated chloride. For SAR/sodium assessments, the 95th percentile of SAR data for 1.0-1.5 m is required for the impacted root-zone scenario, in conjunction with the average EC from the same impacted root-zone dataset for each SubArea.

As per the characterization of background salinity, it is not acceptable to use data from other depth intervals that overlap the 1.0 to 1.5 m depth interval, such as 0.75 to 1.25 m or 1.25 to 1.75 m. 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 Tier 1 guidelines developed for the site.

## 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 cannot 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.
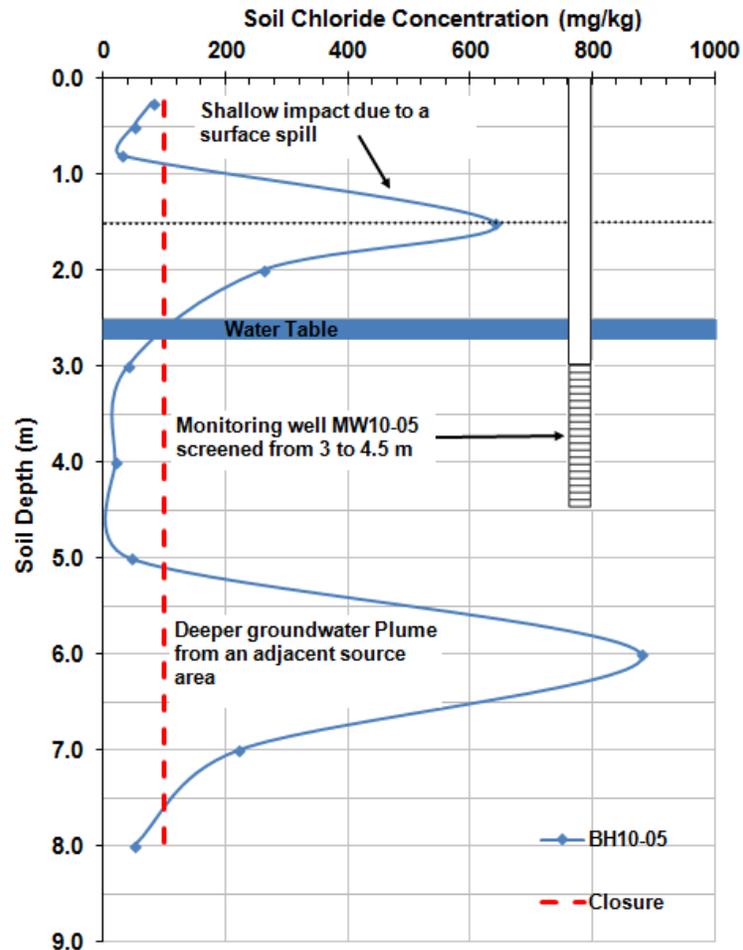
For effective determination of lateral closure, soil samples should be collected at 1 m depth intervals and closure boreholes should be drilled to a sufficient depth that would identify any deeper groundwater plumes originating from source areas at the site. The use of field screening techniques such 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 cumulative in terms of risk to the DUA and FAL receptors, depending on the groundwater flow direction. In such cases, the two areas may be run independently and BAF values are not assigned to each distinct impact area. 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.
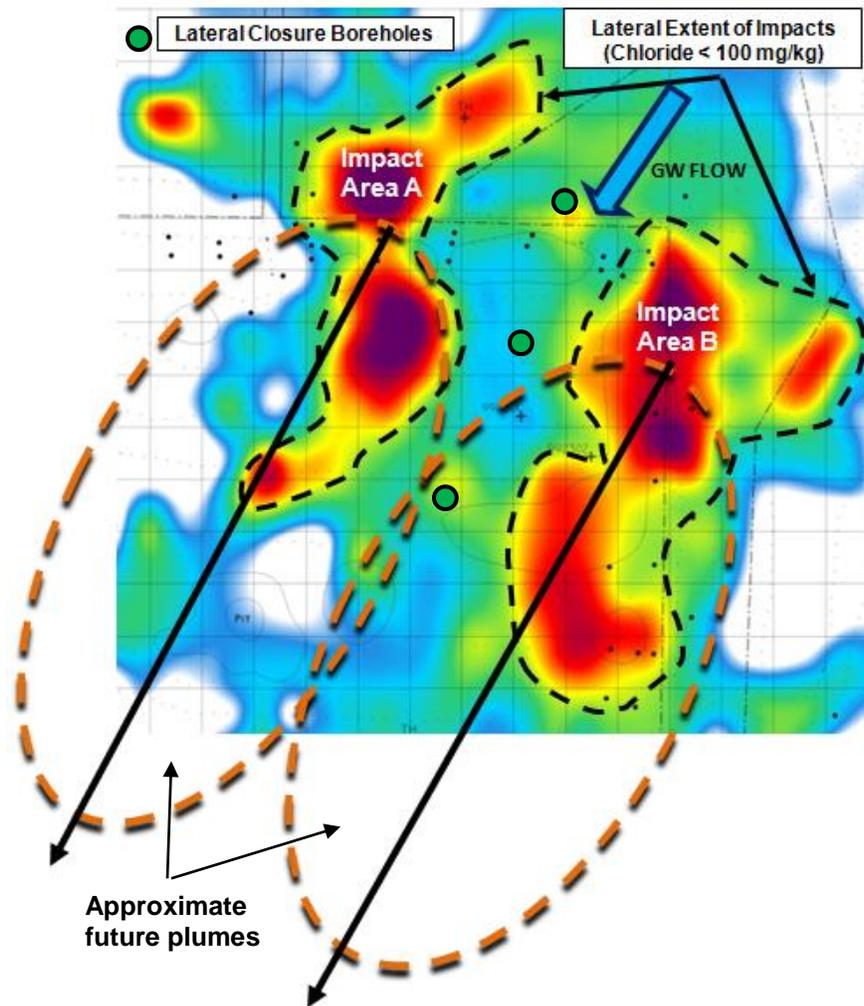
5.6 Source Length and Dimensions

Source length and source dimensions were previously discussed in Section 2.12, with source dimensions defined based on the square-root of the area (in m²) of each SubArea, and source length for the entire site measured linearly across the impacted length of the site. Source dimensions are primarily defined using soil chemistry data and the information is used to develop SRGs for chloride for the FAL and DUA pathways and receptors, which are based on groundwater transport. Source length for the entire site is used to further refine DUA guidelines and is measured linearly across the longest impacted length of the site regardless of groundwater flow direction. *If the source length for the entire site exceeds 300 m, a Tier 2C assessment is required.* There are six default source dimensions in the SST Version 3.0: 15 x 15 m; 25 x 25 m; 35 x 35 m; 50 x 50 m; 75 x 75 m; and 100 x 100 m, though any source dimension up to 100 m can be entered into the SST with internal interpolations performed. Multiple SubAreas can be run to represent an impact or for assessing source dimensions greater than 100 x 100 m, but the maximum total area of SubAreas with the potential for cumulative risk (*i.e.*, overlapping plumes) cannot exceed 200 x 200 m. *If the total combined source dimension exceeds 200 x 200 m, a Tier 2C assessment is required.* Source length and dimensions are not required input parameters for a subsoil SAR/sodium assessment since long-distance transport and interactions between SubAreas are less relevant than for chloride.

Lateral closure (chloride concentrations <100 mg/kg) must be obtained around the perimeter of 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 3.0, the chloride impacts may be divided into one source area or multiple source SubAreas. SRGs are developed based on the potential for source areas (or SubAreas) to have a cumulative 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 square source area of 35 x 35 m was determined for a site with a single SubArea, the source dimension would be entered into the SST as 35 m for that SubArea,

and the source length for the entire site entered as approximately 50 m (49.5 m, the longest distance across the entire impacted area). Additional examples of source dimensions and source lengths when more than SubArea is present are provided in Section 2.12.

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 manure, 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 as a single SubArea with a source dimension of 60 m. 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 could be run as a smaller 45 m source dimension for the single SubArea. Source lengths for the entire site would also be similarly reduced in each case.

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 (VCP). ***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.

Classification: Public
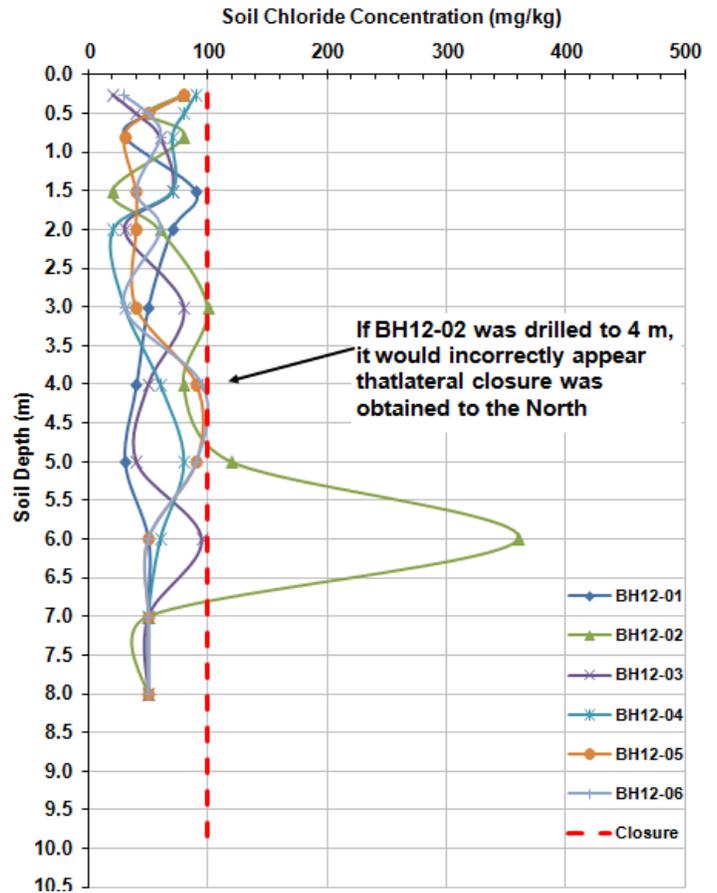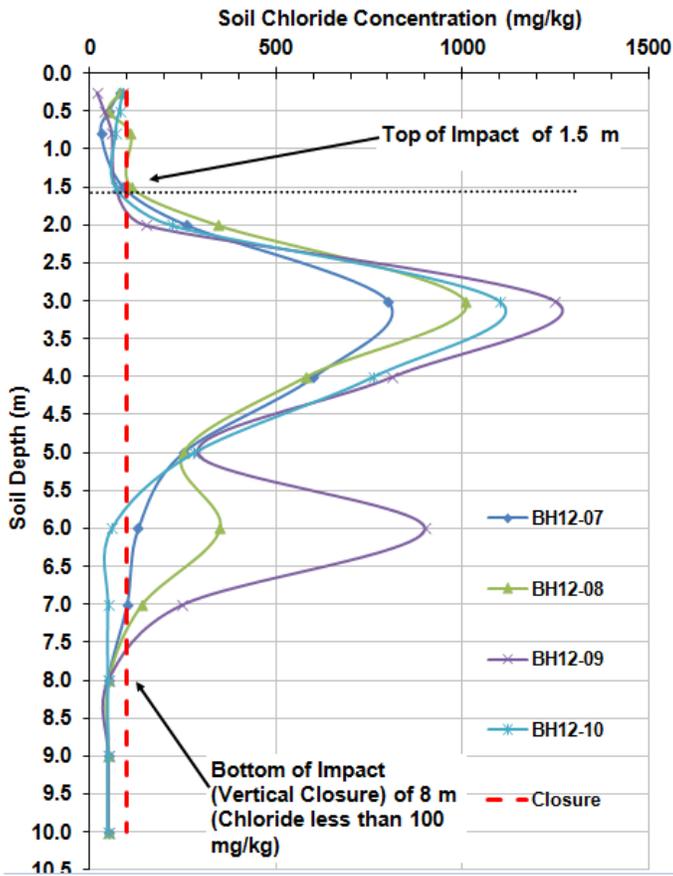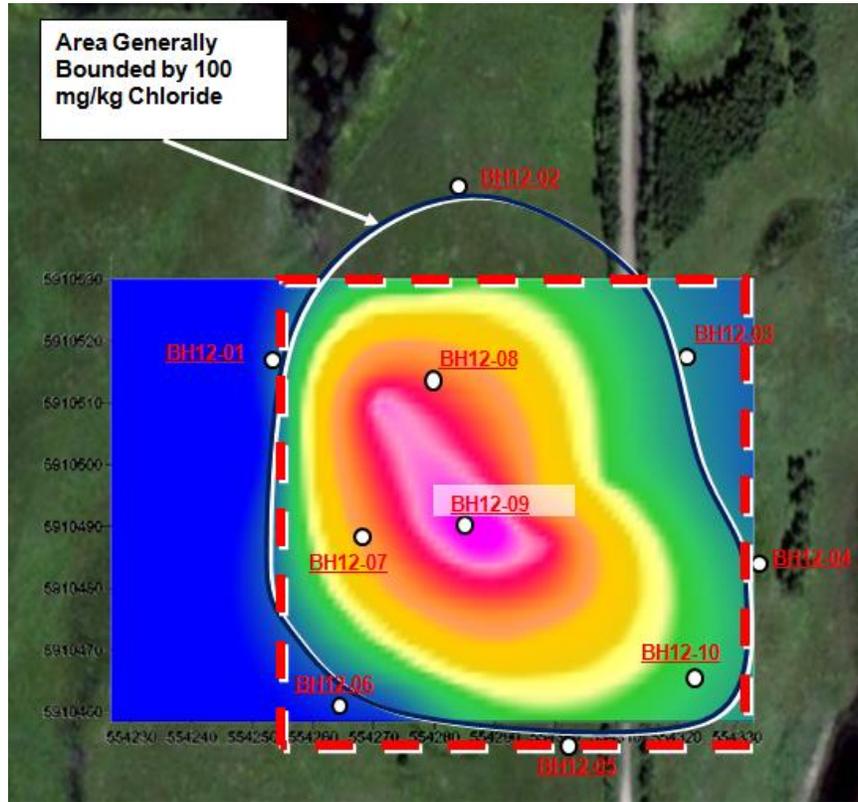
Impacts within the root zone, but lacking subsoil impacts, are not included in source length calculations. For example, in the figure below, the area circled by the black dashed oval (a former flare pit) has both root zone and subsoil chloride impacts with concentrations > 100 mg/kg. Within the red dashed 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. If the area of the black oval was measured to be approximately 1600 m^2, a source dimension of 40 x 40 m would be selected for calculating SRGs providing lateral impact closure was obtained. A source length for the entire site of approximately 50 m would be measured linearly across the black dashed oval as shown by the white arrow.
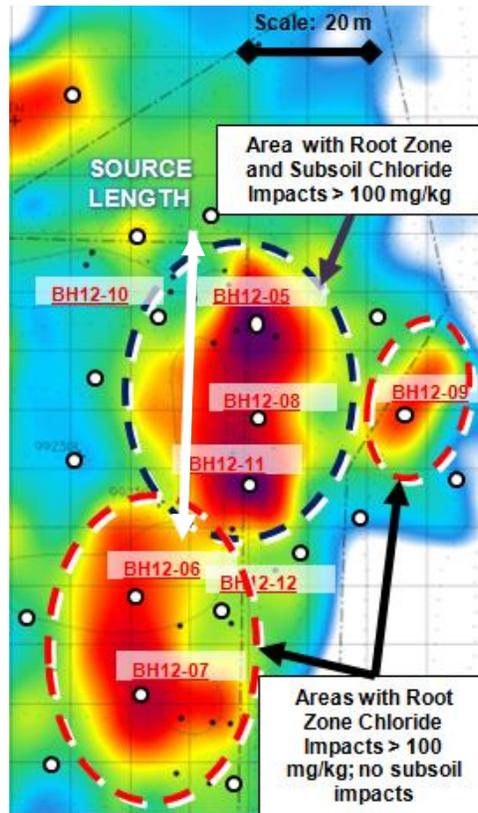
⚠️ *Proper documentation of lateral chloride closure is required for all SST submissions*

In the upper panel of the figure below, investigation work has been completed with multiple boreholes to determine a boundary of the 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), so a source dimension of 100 m may be conservatively entered into the SST. The chloride impacted area may also fit within a smaller 75 x 75 m area (yellow dashed line), so a calculation may also be made to estimate the area (m^2) 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 area impacted by chloride does not exceed the 75 x 75 m area, a 75 m source dimension can be entered into the SST, resulting in less conservative DUA and FAL chloride guidelines than if a 100 m source dimension was entered. 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 chloride impacts vary 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 dimension of 75 m could 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 m²). 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 impacts vary in terms of chloride concentration, as well as top and bottom of impact, between the SubAreas.

In each of these cases, the source length for the entire site would be determined by measuring the longest linear length across the entire impacted area, regardless of groundwater flow direction (not shown on the figures below).

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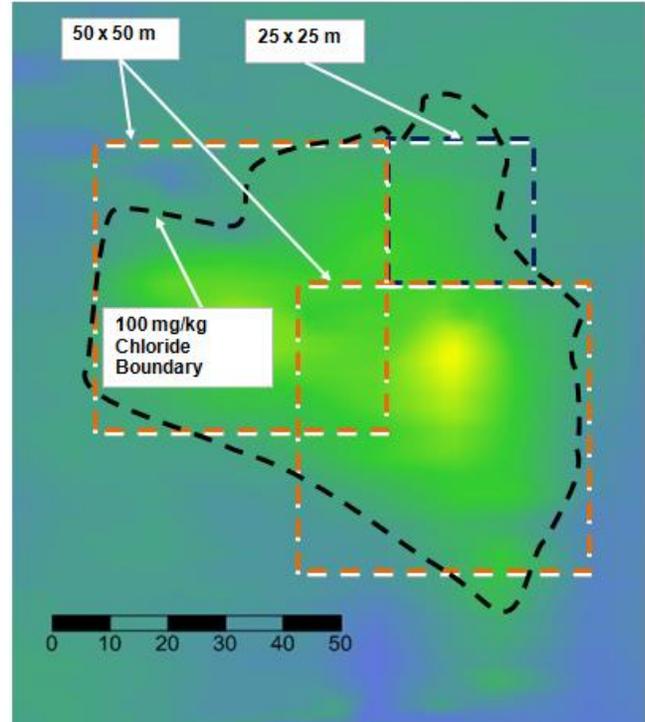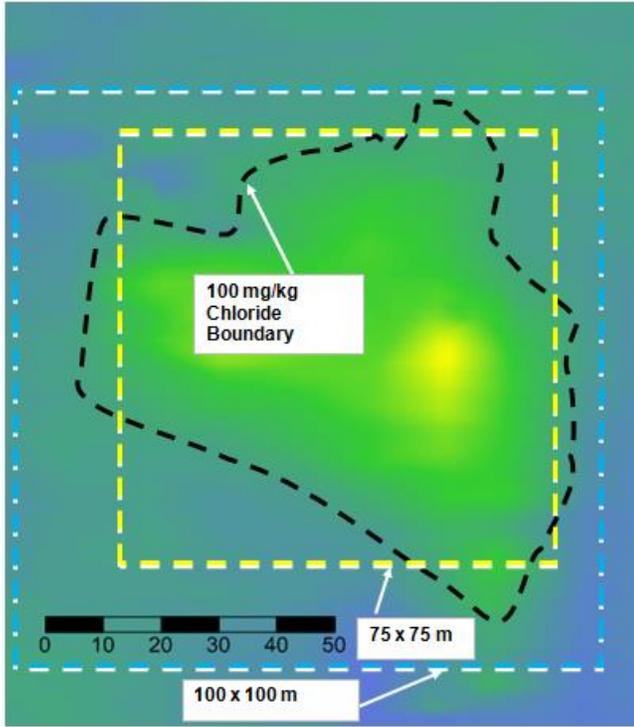
LOWER PANEL
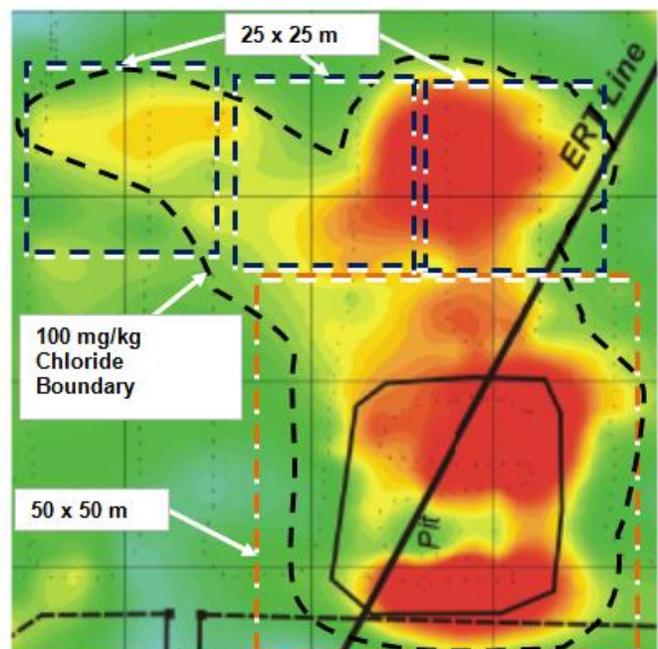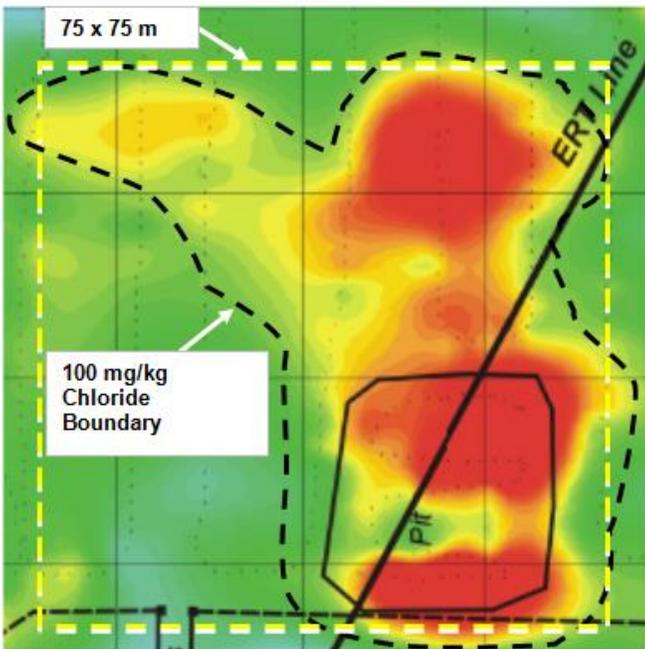
⚠ *The area bounded by chloride ≤ 100 mg/kg must be measured and it must be demonstrated that this area is encompassed by the sum of square source areas entered into the SST*

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 where impacts have leached downward over time, particularly in coarse soils;
2. 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,
3. Excavations that remove salt impacts in shallower soils.

For chloride assessments, 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 elimination of sample collection for some depth increments 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 large vertical gaps within which soil samples were not collected. This can result in subsoil impacts not being identified and the resulting SST inputs underestimating chloride mass leading to incorrect 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.

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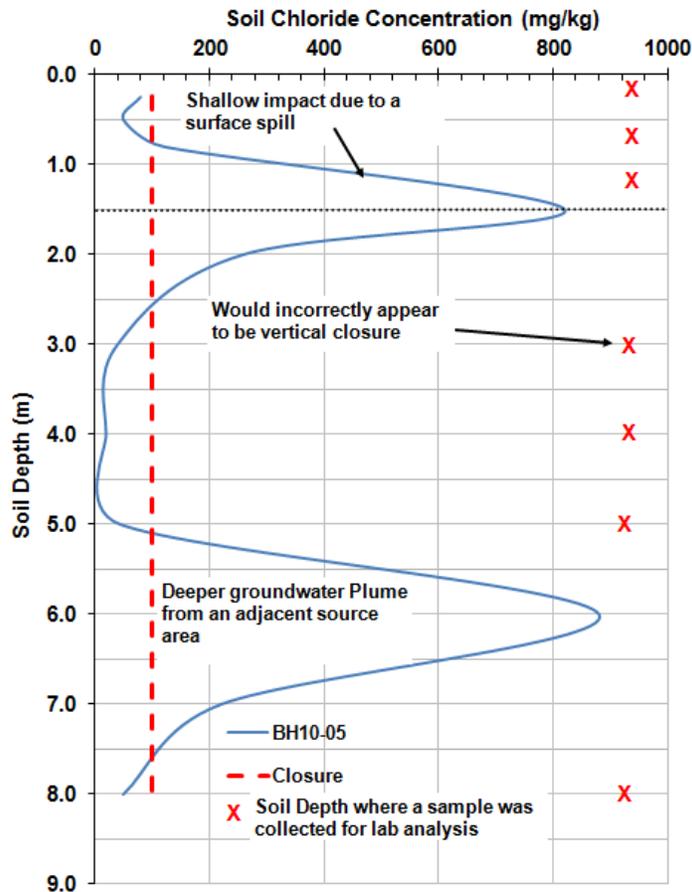
In situations where sands are encountered in the vadose zone beneath an impact and chloride concentrations are less than 100 mg/kg, it is possible that the impacts may have travelled through the coarse material and concentrations greater than 100 mg/kg may be found in deeper underlying fine till, as shown in the example below.   Additional vertical drilling and sample collection must be used to ensure closure is obtained in this situation.
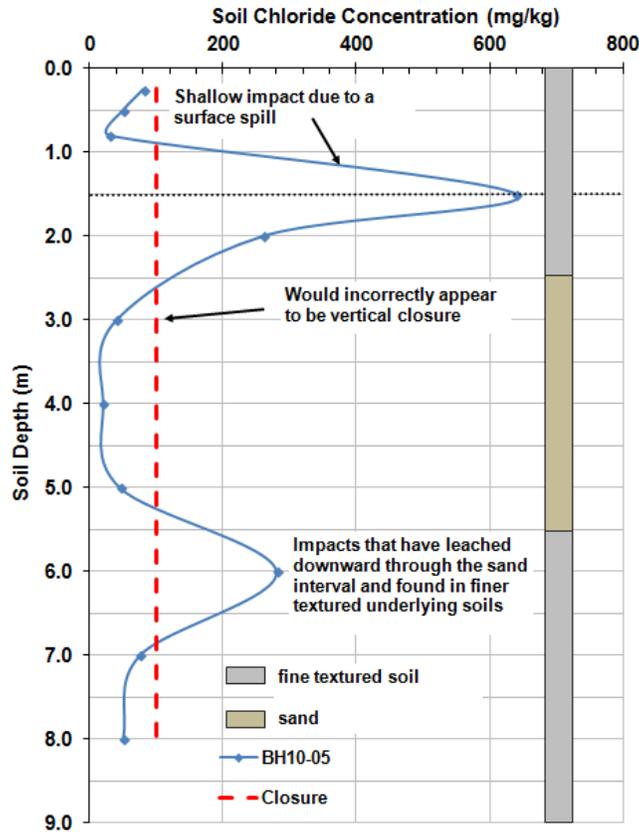
For SAR/sodium assessments, the top and bottom of impacts may not necessarily be associated with elevated chloride concentrations since chloride may migrate/leach away from the initially impacted area and potentially leave elevated SAR behind. In general, however, sodium will transport more slowly than chloride, and thus the bottom of SAR/sodium impacts will generally be similar to or shallower than the bottom of chloride impacts. Due to the variability of background sodium concentrations and the consequent lack of a standard background sodium level, vertical closure in SAR/sodium assessments is defined by SAR values dropping to (or below) the relevant background SAR levels and Tier 1 category for that depth interval.

5.8   Backfill Material Information

SST assessments for either chloride or SAR/sodium involving excavation and backfill require that the texture of backfill material is similar to the native material that was removed through excavation. This requires laboratory texture data for the backfill, including hydrometer data (for clay content) for SAR/sodium assessments.

Laboratory chemistry data is also required from the backfill to determine EC and SAR values (as well as saturation percentage and ion concentrations such as chloride, sulphate, sodium, calcium, magnesium, *etc.*) of fill material placed in the root zone (< 1.5 m soil depth) for excavate and backfill scenarios. Backfill used for the root-zone needs to be within the root-zone Tier 1 EC and SAR guidelines as determined by the 95th percentile of background root-zone statistics as previously discussed. Within this acceptable range, the use of backfill with somewhat higher or lower EC or SAR values can influence the subsoil chloride and sodium guidelines for the root-zone pathway via modified EC and SAR buffers.

In subsoil, though not as critical as in the root-zone, efforts should be made to use unimpacted backfill with salinity levels also within the same Tier 1 EC and SAR categories as background subsoil. To optimize soil conservation, in some cases it may also be possible to use less-impacted soils from the root-zone which exceed Tier 1 root-zone EC guidelines but may potentially be used as subsoil backfill. Since chloride concentrations of the backfill are elevated in such cases, the backfill would be considered impacted and the top of impact would need to be adjusted to a shallower depth to take into consideration the depth interval over which the impacted backfill material was placed. In this case, the user would need to ensure this re-used backfill is meeting the relevant subsoil chloride guidelines after adjusting the top of impacts. Similarly, root-zone soils which exceed Tier 1 SAR guidelines may potentially be suitable for reuse as subsoil backfill, provided the top of impacts are adjusted appropriately and the soil meets both subsoil chloride and subsoil SAR/sodium guidelines.

It is important to note that the backfill parameters entered into the SST are applied solely to the root-zone, and primarily influence the upward migration pathway for chloride and sodium. The SST assumes that sulphate, calcium, and magnesium concentrations in subsoil are similar between impacted locations and background locations, with these values determined by background TDS/sulphate parameters and background subsoil EC/SAR values for SAR/sodium assessments.   If an excavation extends into subsoil and these subsoil backfill parameters are substantially different than background conditions (including partially-impacted backfill from other excavation areas), the user should be aware that the assumptions for upward sulphate/calcium/magnesium transport into the root-zone might be affected.   In such cases, additional SST runs (including potentially adjusting background subsoil EC/SAR values based on backfill values) may be warranted for the root-zone pathway.

A visual representation of some of these aspects is shown below, whereby highly-impacted soils from the root-zone and subsoil are landfilled, and replaced with a combination of clean imported backfill and less-impacted root-zone soils. In such cases, it is generally most efficient to place the highest salinity backfill (impacted or not) at the deepest depths, and place the lowest salinity backfill in the root-zone (particularly from 1-1.5 m). At the completion of backfilling, all soils must meet the relevant Tier 1 guidelines for root-zone soils and SST-generated subsoil chloride/SAR/sodium guidelines for subsoils. Some of these backfill considerations are further illustrated in the following section.

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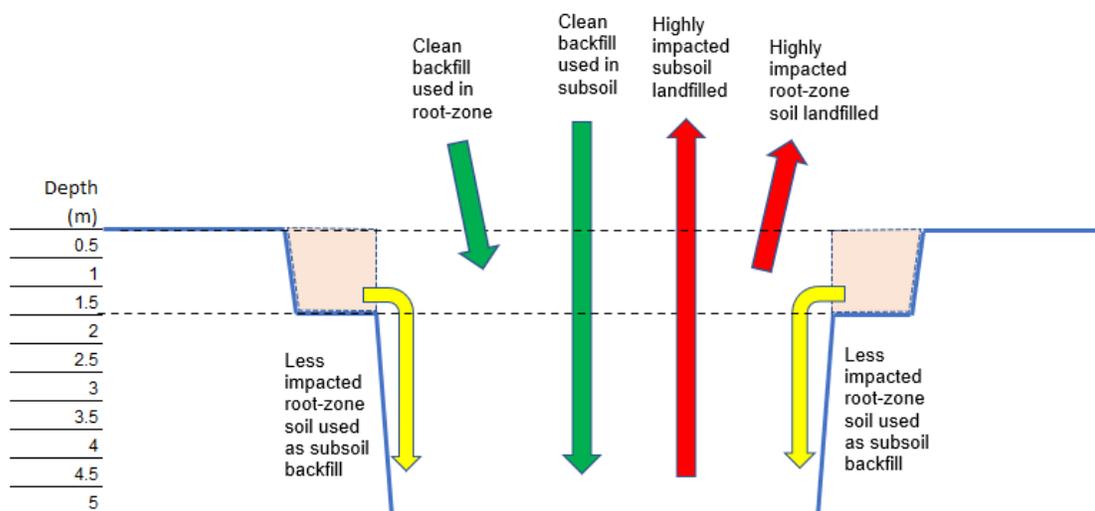
6   SRG ANALYSIS AND EXCAVATION RESULTS INTERPRETATION

Following the development of subsoil chloride Tier 2A or 2B SRGs for a site, they are then compared with measured concentrations of chloride, sodium, or SAR in soil to identify whether an exceedance has occurred. For a chloride assessment, 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 chloride SRGs are calculated for all relevant receptors (root zone, dugout pathways, FAL, and DUA). Examples of a chloride assessment 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. Analysis of a SAR/sodium assessment is also performed in a similar manner, though generally simpler due to the lack of the FAL and DUA pathways and associated BAF factors. When both a subsoil chloride and subsoil SAR/sodium assessment is performed, it is generally most efficient to first determine the excavations required for subsoil chloride (including root zone Tier 1 EC or SAR exceedances), and then evaluate whether additional excavation is required for subsoil SAR/sodium.

6.1   SRG Analysis

Measured values of EC and SAR within the root zone (<1.5 m) at a site must similarly be compared against appropriate guidelines, which for the root zone is AEP (2019a) Tier 1 EC and SAR guidelines. Such root-zone exceedances 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 AEP (2019a) 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 depth within the root zone, 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). Separate EC and SAR guidelines can be developed for each depth interval (shown graphically below by the dashed red line). For this example, it is assumed that Tier 1 guidelines for SAR are used for both the root-zone and subsoil, thus representing a case where the SST was used to generate solely Tier 2 guidelines for chloride but not for SAR/sodium. In cases where using Tier 1 guidelines for subsoil SAR would result in substantial additional remediation requirements beyond those required for chloride, Tier 2 (SST) subsoil SAR/sodium guidelines can be developed and compared in a similar manner to data from the impacted area.

In Example 1 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**
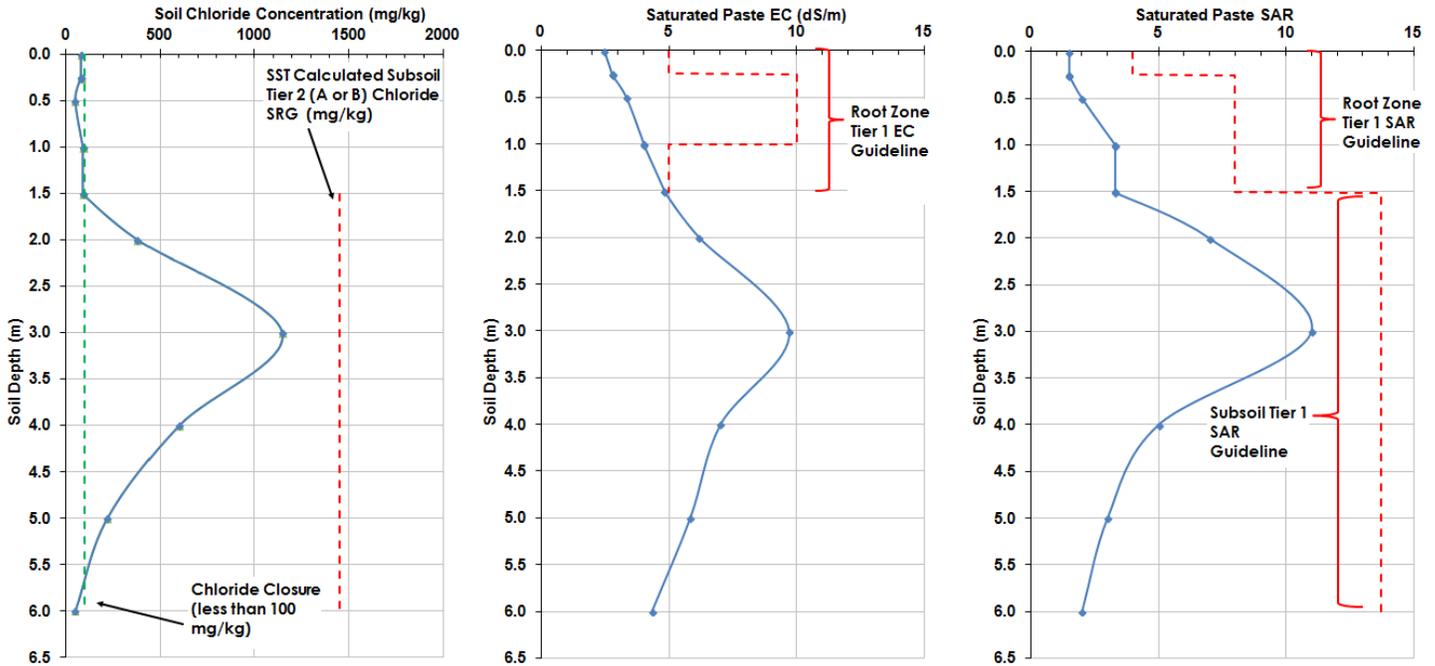
Leftmost panel – root zone and subsoil chloride; middle panel – root zone and subsoil EC; rightmost panel – root zone and subsoil SAR Subsoil chloride, root zone EC, and root zone as well as subsoil SAR SRGs shown as dashed red lines. A single vertical profile of chemistry data within the impacted area is shown as a blue line. 100 mg/kg chloride closure is shown as a dashed green line.

In Example 2 below, 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 exceedance 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 exceedances 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
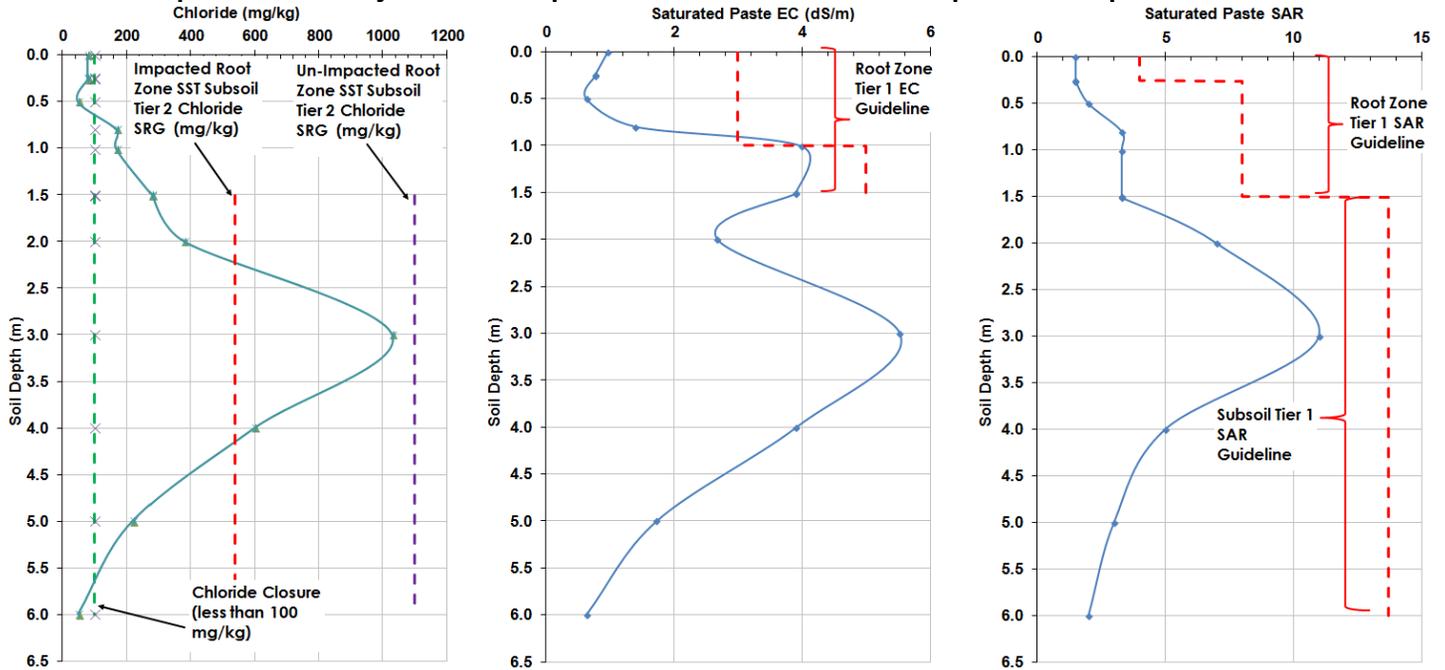
In Example 3, the appropriate SST root zone scenario would be Excavate and Backfill, because chloride concentrations were greater than 100 mg/kg over the depth interval of 1.0 to 1.5 m (leftmost panel) **and** EC and SAR values within this depth interval (as well as shallower soils) exceeded Tier 1 guidelines (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 exceedances.

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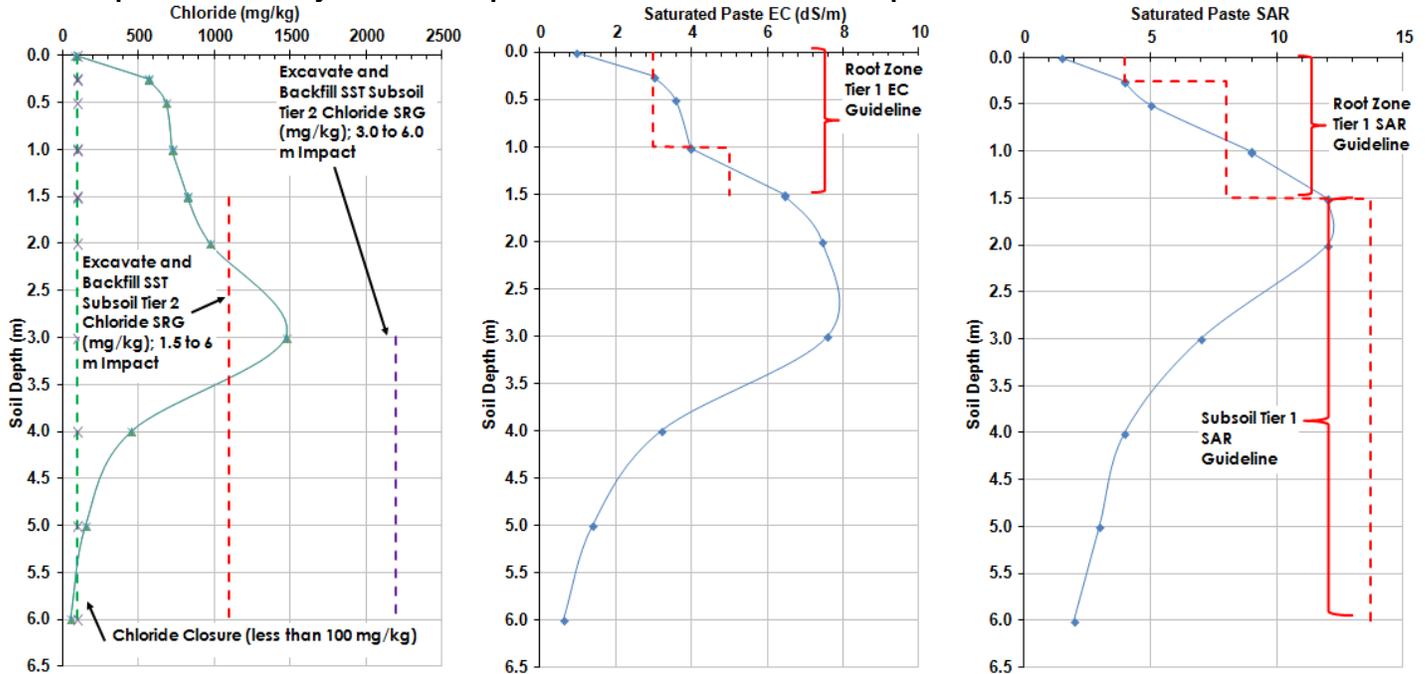

6.2   Excavation Confirmatory Sampling Analysis

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 to subsoil Tier 1 SAR guidelines. A similar process would be used if subsoil SAR/sodium guidelines were derived in the SST in addition to (or instead of) subsoil chloride guidelines. The examples below are based on the assumption of SST-derived subsoil chloride guidelines and 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 Tier 1 subsoil SAR guideline of 12 was developed for application at soil depths greater than 1.5 m based on background statistics. 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
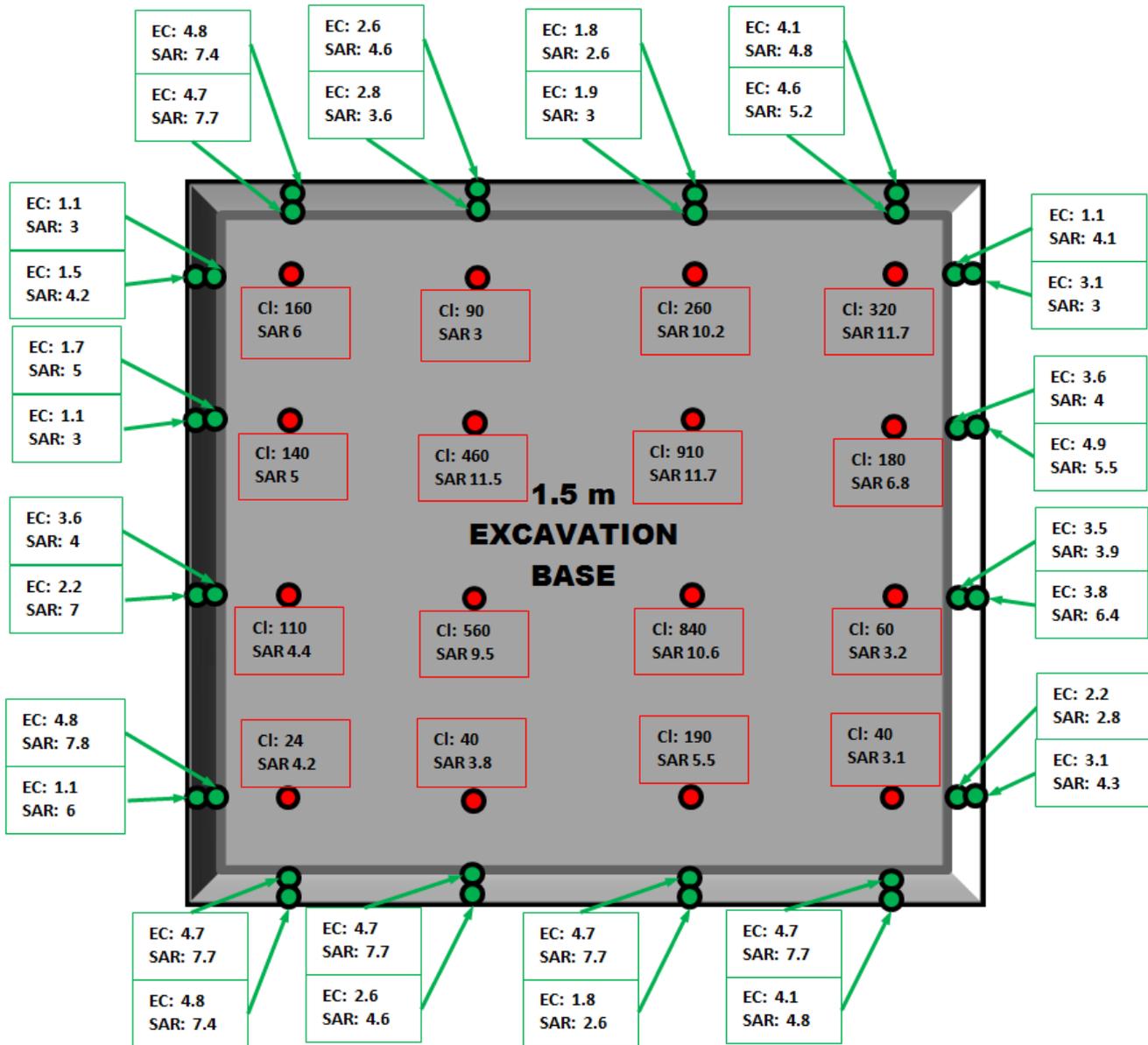
EC values are in dS/m; SAR values are unitless; Cl (Chloride) concentrations are in mg/kg soil

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 exceedance 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 exceedance was observed, it is possible to get facility-related SAR exceedances 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 Exceedances 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. Exceedances were identified within the root zone (Excavate and Backfill scenario was required) and exceedances of Tier 2 SRGs were observed in subsoil for chloride and Tier 1 exceedances 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, leaving impacts from 2 to 4 m, 4 to 6 m, and 6 to 7 m in each SubArea respectively. 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 based on background statistics. The excavation diagram below the table 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)._

SubArea #1
2.0 m
EXCAVATION
BASE

SubArea #2
3.0 m
EXCAVATION
BASE

SubArea #3
6.0 m
EXCAVATION
BASE
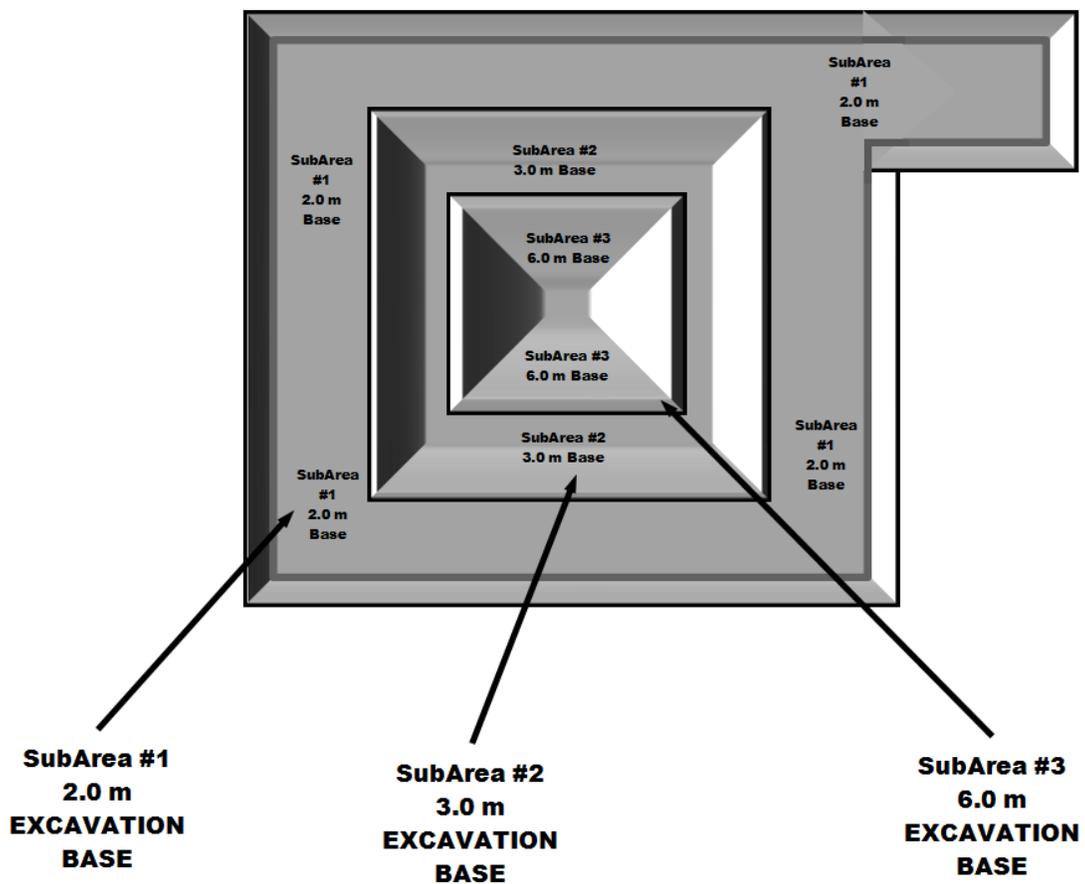
Summary of SRGs for Example #3

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
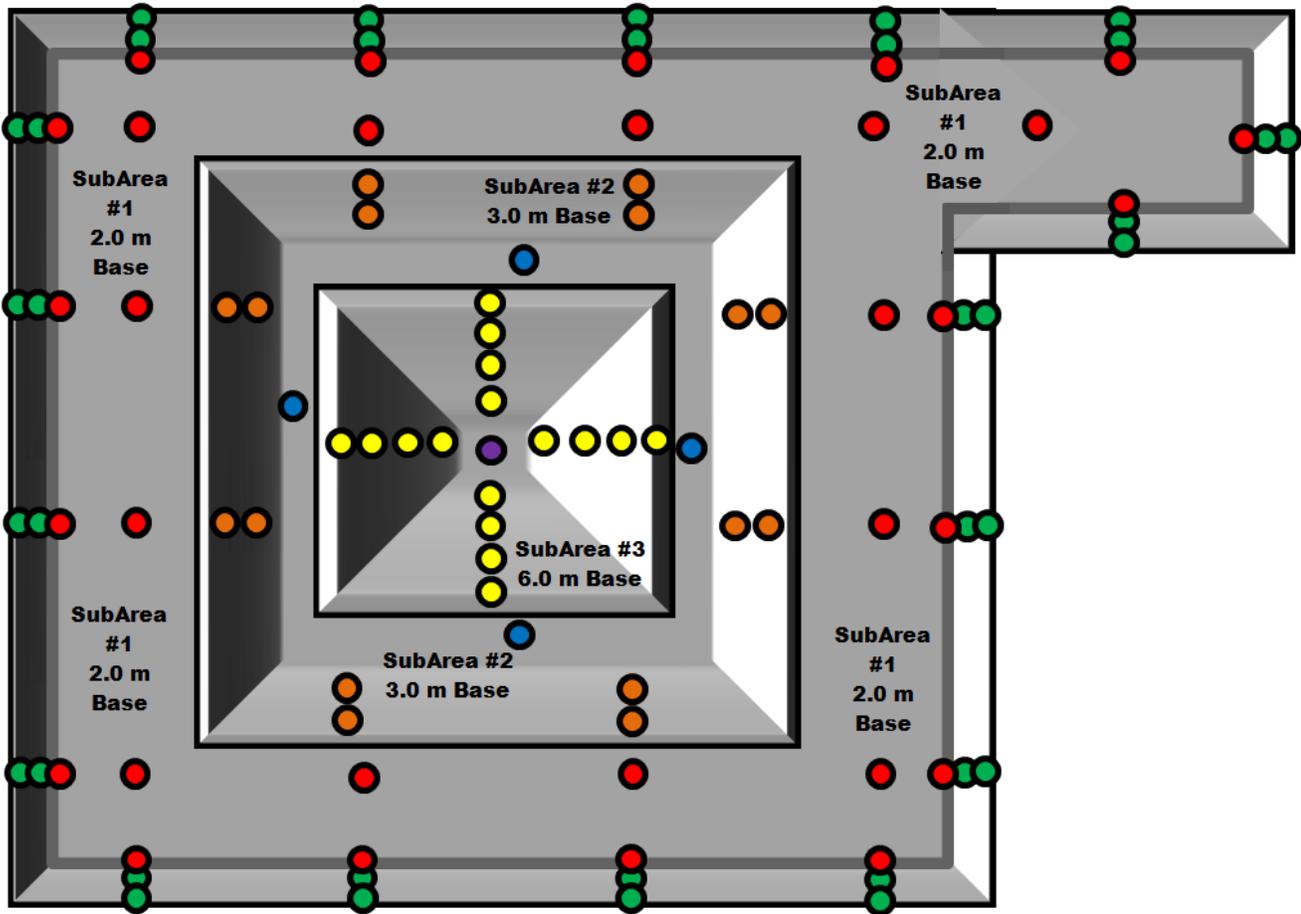
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8   GLOSSARY

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, 2000).

Buffer: The difference between background concentrations and applicable guidelines.

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

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

Climate Moisture Index (CMI): The CMI is a climate-based estimate of water balance based on the difference between precipitation and evapotranspiration (Hogg et al, 2013). It provides 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.

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 (for a chloride assessment) or SAR values fall to or below background levels (for a SAR/sodium assessment).

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 area and may escape as a spring, seep, or baseflow, or by evaporation and transpiration (Fetter, 2001).

Domestic Use Aquifer (DUA): A hydrostratigraphic unit with one or more of the following properties: 1) a hydraulic conductivity of $\geq 10^{-6}$ m/s with a minimum thickness of 0.5 m and yield of 0.76 L/min or greater, or; 2) is currently being used for domestic purposes, or; 3) any aquifer determined by Alberta Environment to be a DUA (AEP, 2019b).

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 direct contact with contaminated soil or groundwater, or organisms that ingest contaminated soil, water, or food. 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; AEP, 2019a).

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, 2000).

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: In a chloride assessment, any soil with chloride concentrations appreciably above background. For the purposes of the Subsoil Salinity Tool, 100 mg/kg is used for screening purposes. In a SAR/sodium assessment, impacted soil is indicated by SAR values appreciably above background levels for that depth interval.

Natural region: Extensive land mass (of the order of 20,000 km^2) characterized by permanent geographic boundaries (geological, physiographic, etc.) and a certain uniformity and individuality of climatic, topographical, geomorphological and biological conditions. There are six Natural Regions recognized in Alberta (Natural Regions Committee, 2006).

Natural subregion: Large land mass (of the order of 10,000 km^2) 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 (Natural Regions Committee, 2006).

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

Perched water table: An aquifer that occurs above the main water table. This occurs when there is a relatively impermeable layer of rock or sediment above the main aquifer but below the surface. Water percolating downward is trapped above this relatively impermeable layer.

Porosity: 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%. $\left(1 - \frac{Bulk\ Density}{Particle\ Density}\right) \times 100$

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).

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, 2000).

Root Zone: Defined in the SST as the top 1.5 m of soil, and generally requires remediation to Tier 1 salinity guidelines for both EC and SAR. The SST can be used to derive subsoil salinity guidelines for below the root-zone (>1.5 m).

Salinity: The measure of the total soluble salts in soil. Salinity levels of the soil can be determined by determining the electrical conductivity (EC) of a saturation extract of the soil. EC measures the influence of all dissolved ions (cations and anions) and does not differentiate between them.

Sand: Soil particle between 0.05 and 2 mm in diameter (Agriculture and Agri-food Canada, 2013).

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, 2000).

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

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:

$$SAR = \frac{[Na]}{\sqrt{\frac{[Ca]+[Mg]}{2}}} \quad \text{(AENV, 2001)}$$

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 animal 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 dimension: An effective dimension determined for each individual SubArea which represents the length of an equivalent square area. For irregularly shaped SubAreas, can be calculated by measuring the area (in m^2) of that SubArea and calculating the square-root to obtain the effective source dimension.

Source length: The greatest length across the impacted area in any direction regardless of the direction of groundwater flow. Measured from boreholes that have chloride concentrations of less than 100 mg/kg (indicative of an unimpacted borehole), across impacted boreholes, back to boreholes that have chloride concentrations of less than 100 mg/kg.

Standard deviation: A measure of the variability of the dataset.

Subsoil: For Tier 1 salinity guidelines, the soil material beneath the topsoil (A horizon); includes the B and C soil horizons. Roughly, the part of the soil profile below plow depth. (AENV, 2001). For other Tier 1 guidelines, generally considered deeper than either 1.5 m or 3.0 m depending on the context (AEP, 2019a). In the SST, defined as soils deeper than 1.5 m and for which Tier 2A or Tier 2B subsoil salinity guidelines can be derived.

Surface runoff: The portion of water supply to the surface which neither is absorbed by the soil nor accumulates on the surface, but which runs downslope (Hillel, 1982).

Surface soil: For Tier 1 guidelines other than salinity, represents ground surface to a depth of either 1.5 m or 3.0 m depending on the context (AEP, 2019a).

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, 2000).

Tier 1: 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 (AEP, 2019a).

Tier 2: The Tier 2 approach allows the consideration of site-specific conditions through the modification of Tier 1 guidelines and/or removing exposure pathways that may not be applicable to the site (AEP, 2019a).

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 additional site information, and therefore fewer conservative assumptions, compared to a Tier 2A approach. Tier 2B requires additional investigation efforts, primarily in the realm of groundwater data which is generally not available with a Tier 2A approach.

Tier 2C analysis: Tier 2C analysis is for complex and/or sensitive sites such as those that have deep impacts (>15 m), highly complex soil stratigraphy, complex hydrogeology, large impact areas, very nearby aquatic receptors, gravel or muskeg/peat soil lithology, or other parameters outside the stated limits of the Subsoil Salinity Tool. Tier 2C analysis typically falls outside the scope of the Subsoil Salinity Tool, but may include application of the SST to scenarios, such as interacting sources, that require additional discussion with the regulator.

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

Total Dissolved Solids (TDS): 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): Land that is saturated with water long enough to promote formation of water altered soils, growth of water tolerant vegetation, and various kinds of biological activity that are adapted to wet environments (ESRD, 2015).