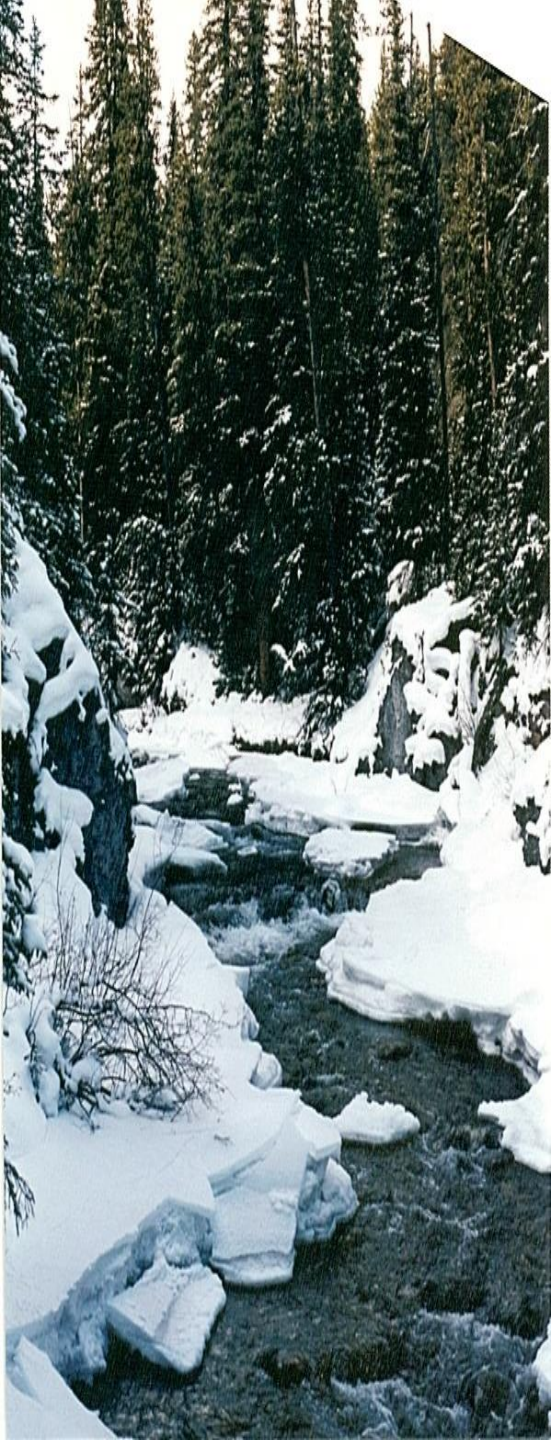

Equilibrium Environmental Inc

Subsoil Salinity Tool (SST)
Update Version 3.0

Key Changes to Guideline Calculations, Software Tool Use, and Data Collection

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EnviroTech 2019

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Calgary, Alberta

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- Alberta Energy Regulator (AER)
- City of Calgary

Presentation Overview

- **Introduction to SST Version 3.0**
  - General information and conceptual model
  - Changes from Version 2.5.3
- **Chloride module**
  - Key changes to aspects of chloride model
- **SAR / sodium module**
  - General information and conceptual model
  - Case study
- **SST certification course**
  - Information and dates

Introduction to SST Version 3.0

Subsoil Salinity Tool

- Subsoil Salinity Tool (SST) allows generation of Tier 2 subsoil chloride guidelines for below the root-zone (>1.5m)
  - Tier 1 guidelines for EC and SAR applicable in root-zone
- Introduced in 2008, several versions since then
  - Most recent is Version 2.5.3 from 2014
  - Version 3.0 to be released in 2019
- Considers key receptors for salinity to ensure minimal levels of risk both current-day and in future
- Generates subsoil chloride guidelines for up to 5 pathways
  - Overall guideline determined by most constraining pathway
  - Similar process as used for many Tier 1 guidelines

SST Conceptual Model

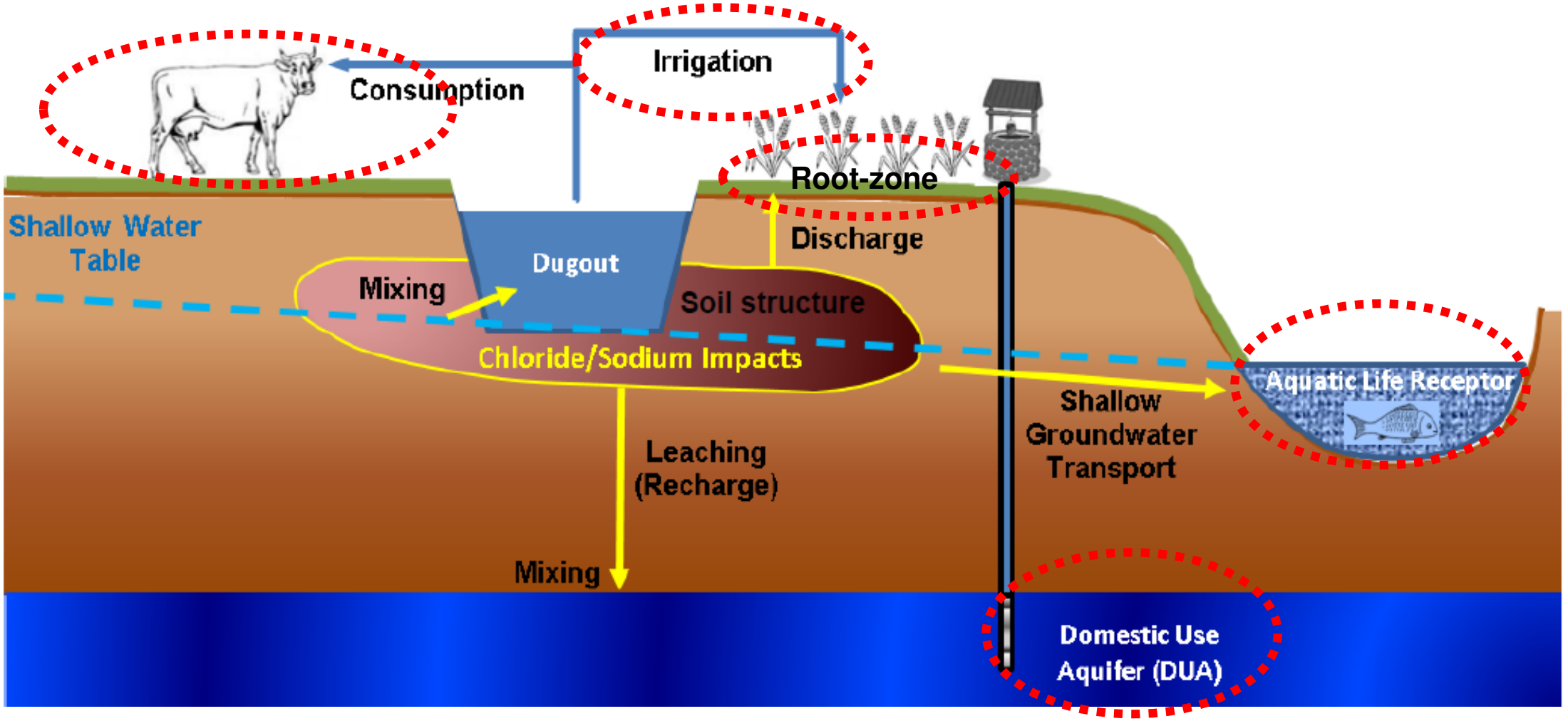
- **Five relevant pathways for subsoil chloride**
  - Root-zone (upward transport)
  - Livestock watering (migration into dugout)
  - Irrigation water (migration into dugout)
  - Aquatic life (lateral transport to aquatic receptor)
  - Domestic use aquifer (downward transport to DUA)

- **Same five chloride pathways for both Version 2.5.3 and 3.0**

- **Which pathway is most constraining a function of many factors**
  - Soil properties
  - Groundwater properties
  - Nearby aquatic receptors
  - DUA depth

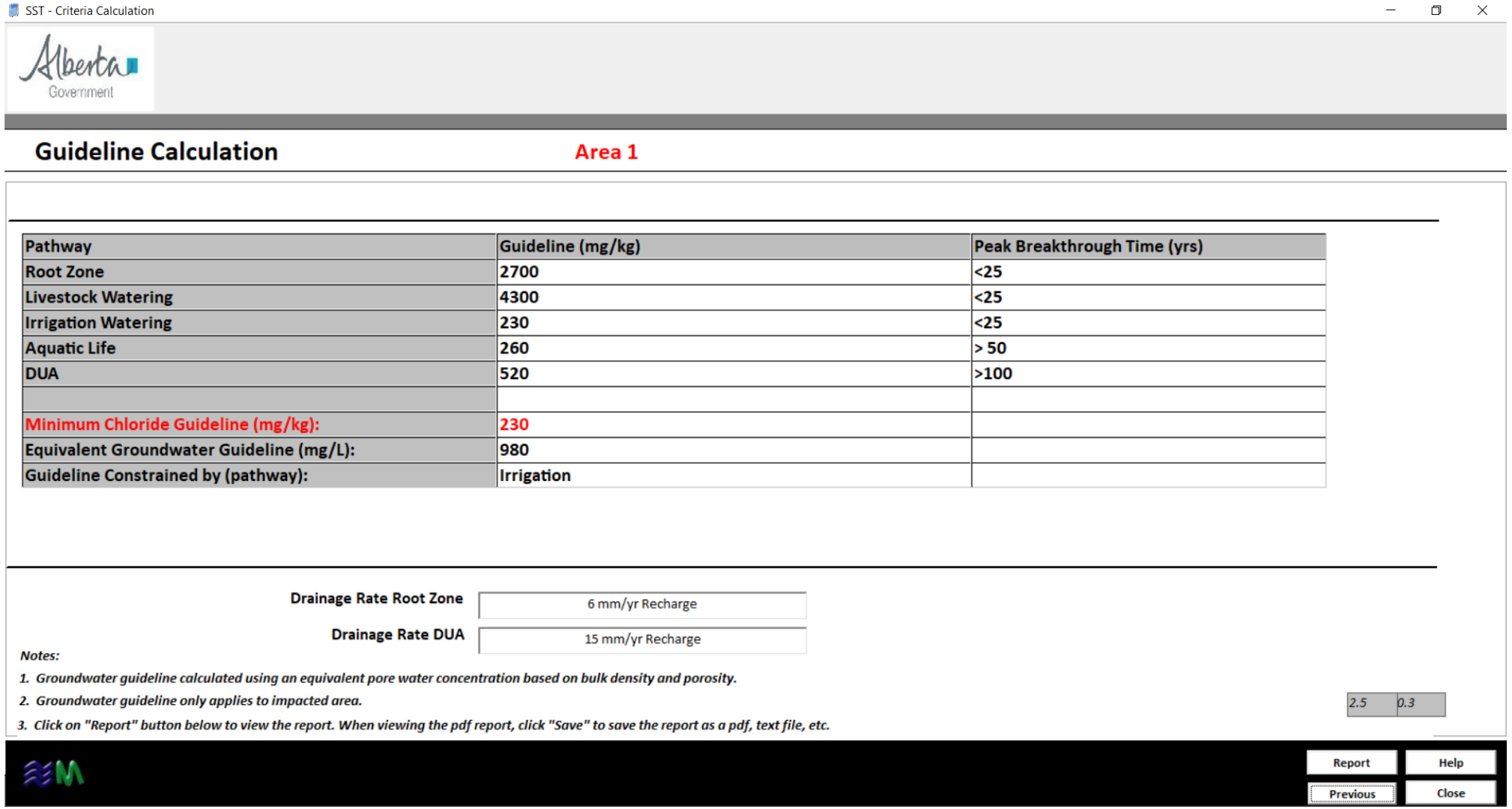
SST Conceptual Model

- **Versions 2.5.3 and 3.0 both consider chloride transport from impact area to each of five receptors**



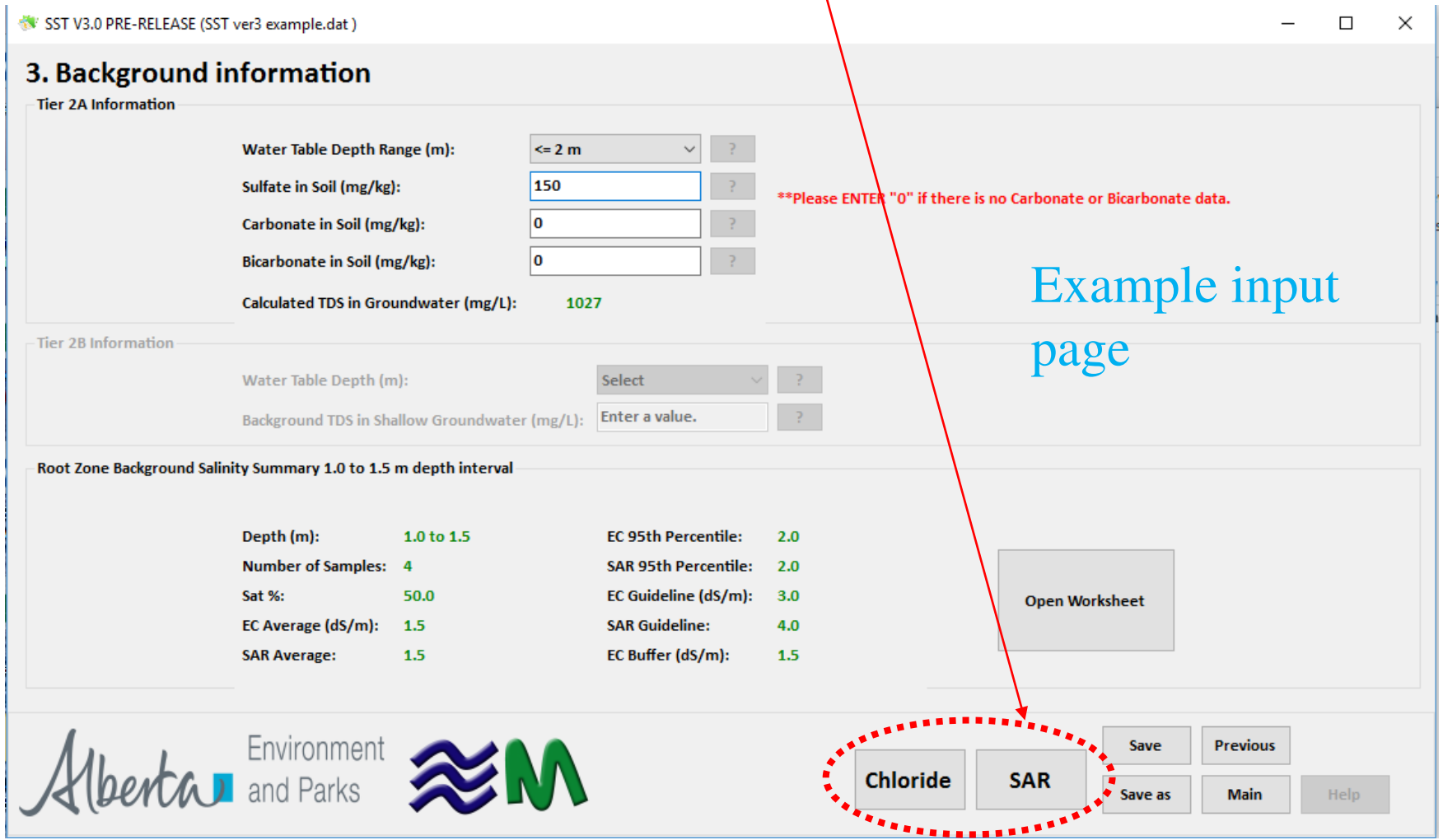
SST Version 2.5.3 (example output)

- **Here, irrigation water is most constraining pathway**



SST Version 3.0

- Numerous updates to chloride module
  - Updated protocols and calculations
  - Updated documentation
  - Expanded capabilities
- SAR and sodium module now included along with chloride



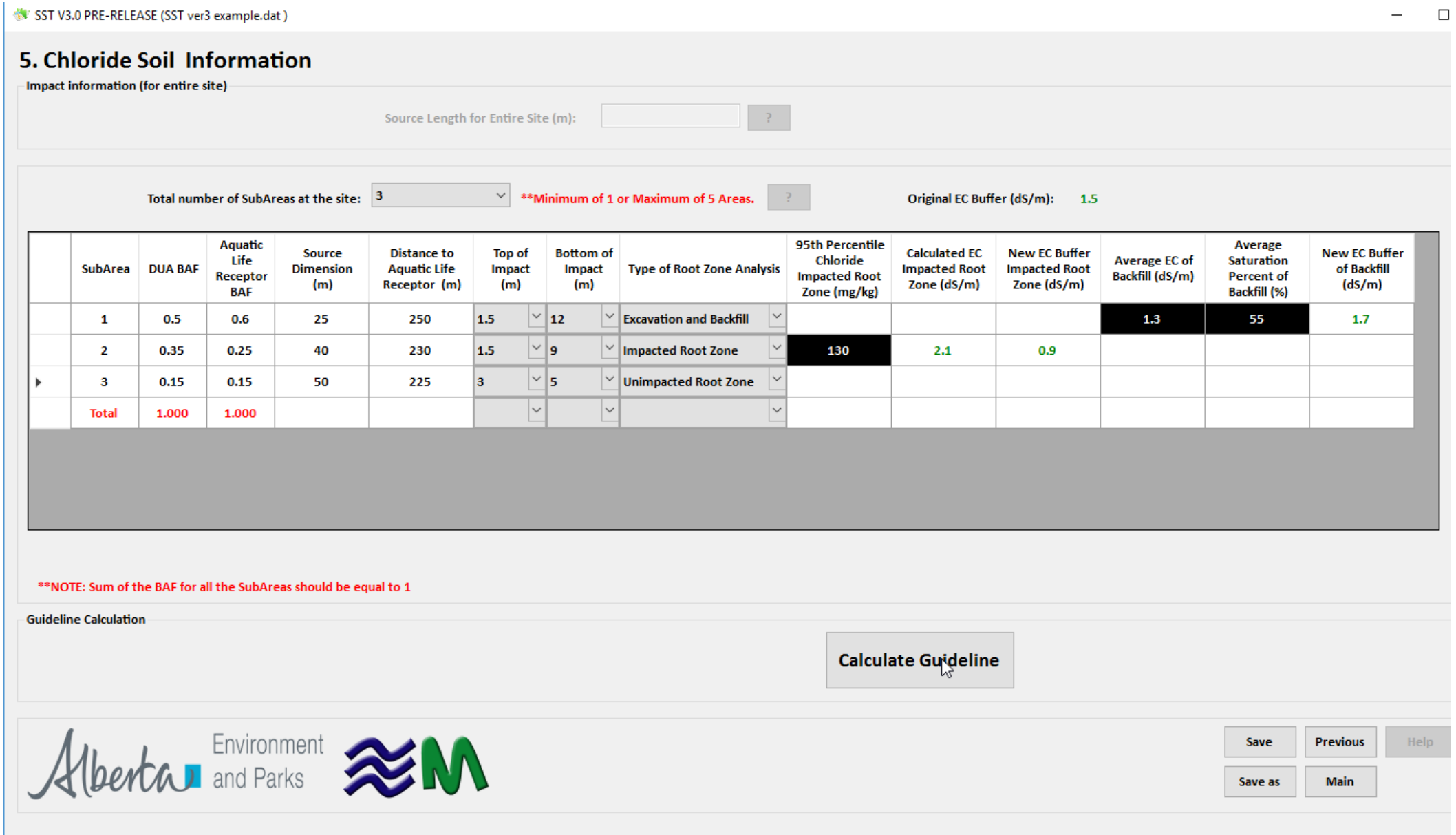
Example input page

SST Version 3.0 General Info and Model Updates

- Numerous updates to protocols and functionality
- Maximum chloride impact depth now 15 m
  - Previously 10 m
- Maximum water table depth now 15 m
  - Previously 10 m
- Maximum DUA depth now 25 m
  - Previously 20 m
- Soil properties now harmonized with Tier 1
  - Fine vs coarse soils now determined by sieve, not hydrometer
  - 1.4 bulk density for fine soils, 1.7 bulk density for coarse
  - Hydraulic conductivity defaults harmonized to $1x10^{-6}$ and $1x10^{-5}$ m/s
- Drainage rates now more harmonized with Tier 1
  - Selected drainage rates adjusted to match 12 and 60 mm/year
- Enhanced handling of subareas
  - Simultaneous calculation of up to five subareas rather than sequential for more streamlined guideline development

SST 3.0 Example Chloride Input Screen

- **Example of three subareas for chloride**



**Layout, protocol details, and guidelines all subject to final adjustments*

Chloride Module

SST 3.0 Chloride Modeling Updates

- Transport modeling calculations updated / enhanced for several pathways
- Root-zone pathway
  - refined upward transport modeling through unsaturated soils
  - Reduces conservatism via more refined diffusion estimates
- Aquatic life pathway
  - Enhanced transport modeling
  - Sentinel well option
- DUA pathway
  - Enhanced transport and dilution modeling
- Dugout pathways
  - Enhanced mixing calculations
- In some cases, 100 mg/kg closure criteria is not sufficient
  - consistent with new 2019 Tier 1 guidance

Aquatic Life Pathway Updates

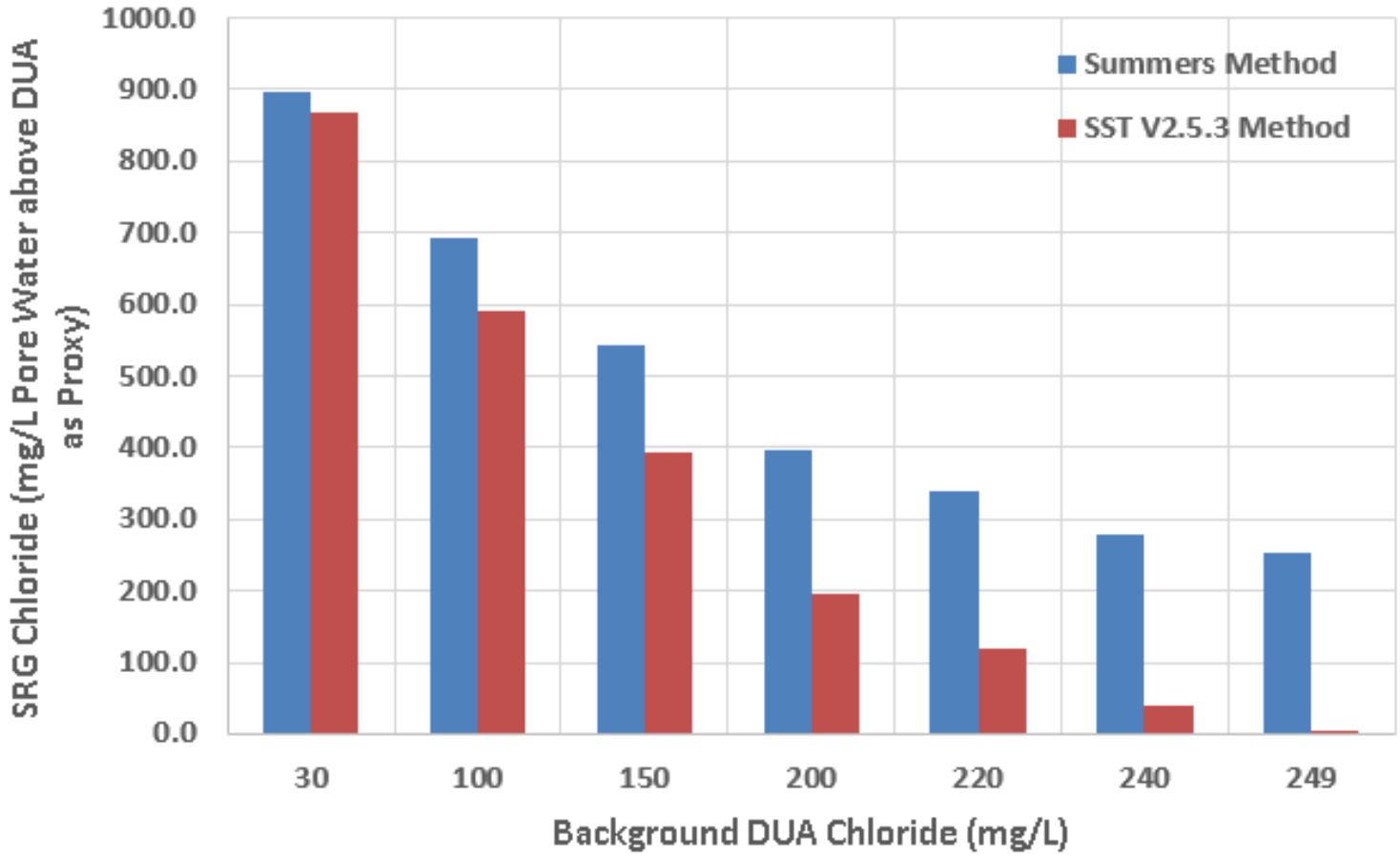
- Additional modeling performed to handle the faster potential groundwater velocities in coarse soils
  - Up to approximately 25 m/year
- Effective porosity of 0.25 no longer used
  - now uses Tier 1 total porosity of 0.47 (fine) and 0.36 (coarse)
- Pore water conversions for fine soils now give lower concentrations due to lower bulk density / higher porosity
  - Results in higher soil guidelines, all else equal
- Refined transport modeling for multiple subarea interactions
  - Reduces conservatism via use of neural network algorithm
- Sentinel well option provides for additional monitoring options

DUA Pathway Updates

- Additional smoothing of guidelines introduced via intermediate drainage rates
- Pore water conversions for fine soils now give lower concentrations due to lower bulk density / higher porosity
  - Results in higher soil guidelines, all else equal
- Dilution into DUA ('Dilution Factor 3') now uses more flexible 'Summers' mixing model
  - Mass balance on background and impact concentrations
- Improved handling of subarea interactions
  - Some similar subarea over-conservatisms to be corrected as for aquatic life
  - Uses stepwise dilutions for subareas with multiple mixing calculations (less conservative, more accurate)
- Improved handing of background DUA chloride concentrations

DUA Mixing Model

- **Improved handling of background DUA chloride via Summers mixing model**
  - **Improved accuracy compared to previous 'buffer' method, particularly when background DUA chloride concentrations are high (approaching 250 mg/L drinking water guideline)**



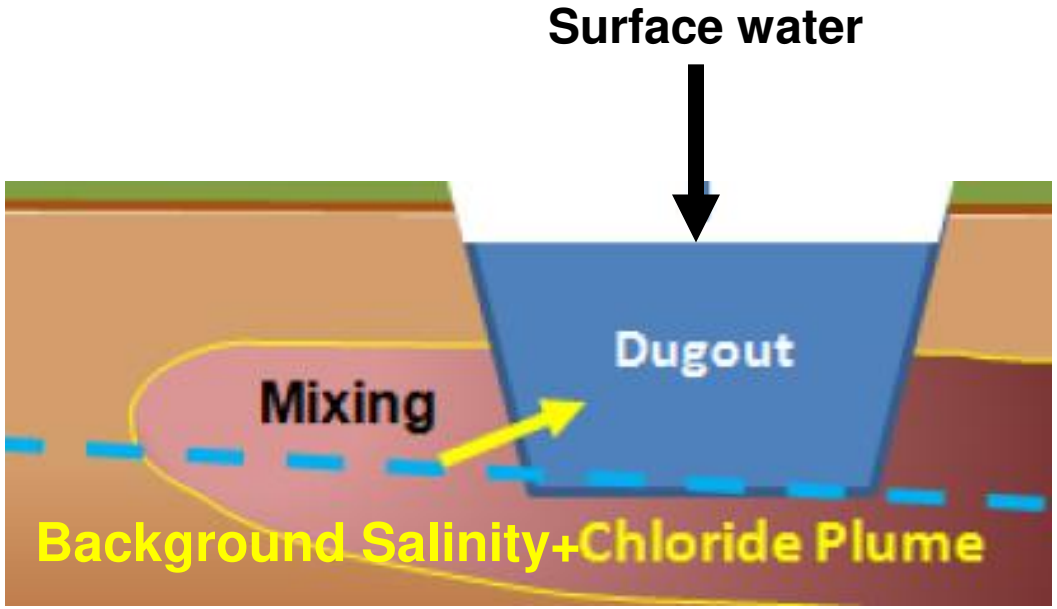
Dugout Pathway Updates

- **Improved handling of background salinity via mixing model**
  - Improved accuracy compared to previous buffer method
  - Reduces frequency of highly-constraining irrigation guidelines
- **Refined final dugout water targets**
  - 3,000 mg/L TDS for livestock water (consistent with Tier 1)
  - 355 mg/L chloride for irrigation water

    (from an Alberta-relevant range in chloride irrigation guidelines, equivalent to approximately 1 dS/m EC contribution from chloride)
- **More elaborate mixing model including stronger effects from important input parameters**
  - water table depth
  - climate information
  - shallow groundwater hydraulic gradient and conductivity
  - replaces the previous generic 3-fold and 10-fold mixing factors for coarse and fine soils

Dugout mixing model

- **Background salinity in shallow groundwater mixes with surface water in dugout, along with chloride impacts**
  - **Use of 'Summers' mixing model results in smoother and more refined guidelines than previous buffer method (and generally less conservative)**



- **Dugout depth now assumed to be 6 m rather than 4 m based on Alberta Agriculture sizing guidelines**

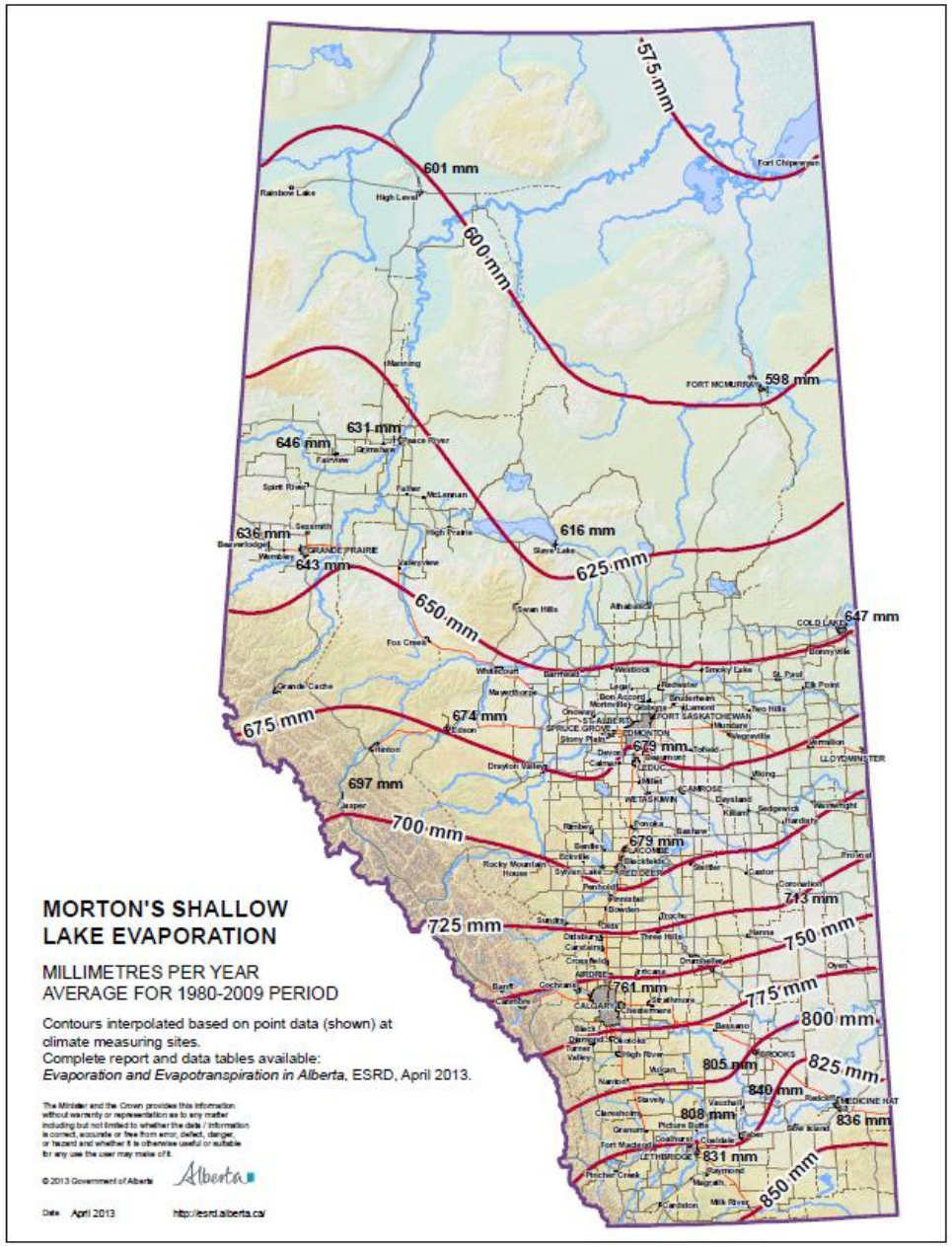
Dugout mixing model

Step 8-11 Dimensions and Capacity (cubic yards)

Chart for 21 Foot Depth

Width (feet)	70	80	90	100	110	120	130	140
Length (feet)								
80	1700	2100	2500					
100	2300	2800	3400	3900	4400			
120	2900	3600	4300	5000	5700	6300	7000	
140	3500	4400	5200	6000	6900	7700	8600	9400
160	4100	5100	6100	7100	8100	9100	10100	11100
180	4700	5900	7000	8200	9300	10500	11600	12800
200	5300	6600	7900	9200	10500	11900	13200	14500
220	5900	7400	8800	10300	11800	13200	14700	16200
240	6500	8100	9700	11400	13000	14600	16200	17900
260	7100	8900	10700	12400	14200	16000	17800	19500
280	7700	9600	11600	13500	15400	17400	19300	21200
300	8300	10400	12500	14600	16700	18700	20800	22900
320	8900	11100	13400	15600	17900	20100	22400	24600
340	9500	11900	14300	16700	19100	21500	23900	26300
360	10100	12600	15200	17800	20300	22900	25400	28000
380	10700	13400	16100	18800	21500	24200	27000	29700
400	11300	14200	17000	19900	22800	25600	28500	31400
420	11900	14900	17900	21000	24000	27000	30000	33000
440	12500	15700	18800	22000	25200	28400	31600	34700
460	13100	16400	19800	23100	26400	29800	33100	36400
480	13700	17200	20700	24200	27600	31100	34600	38100

- **Dugout sizing and mixing calculations taken from ‘Quality Farm Dugouts’ combined with updated Alberta evaporation info**



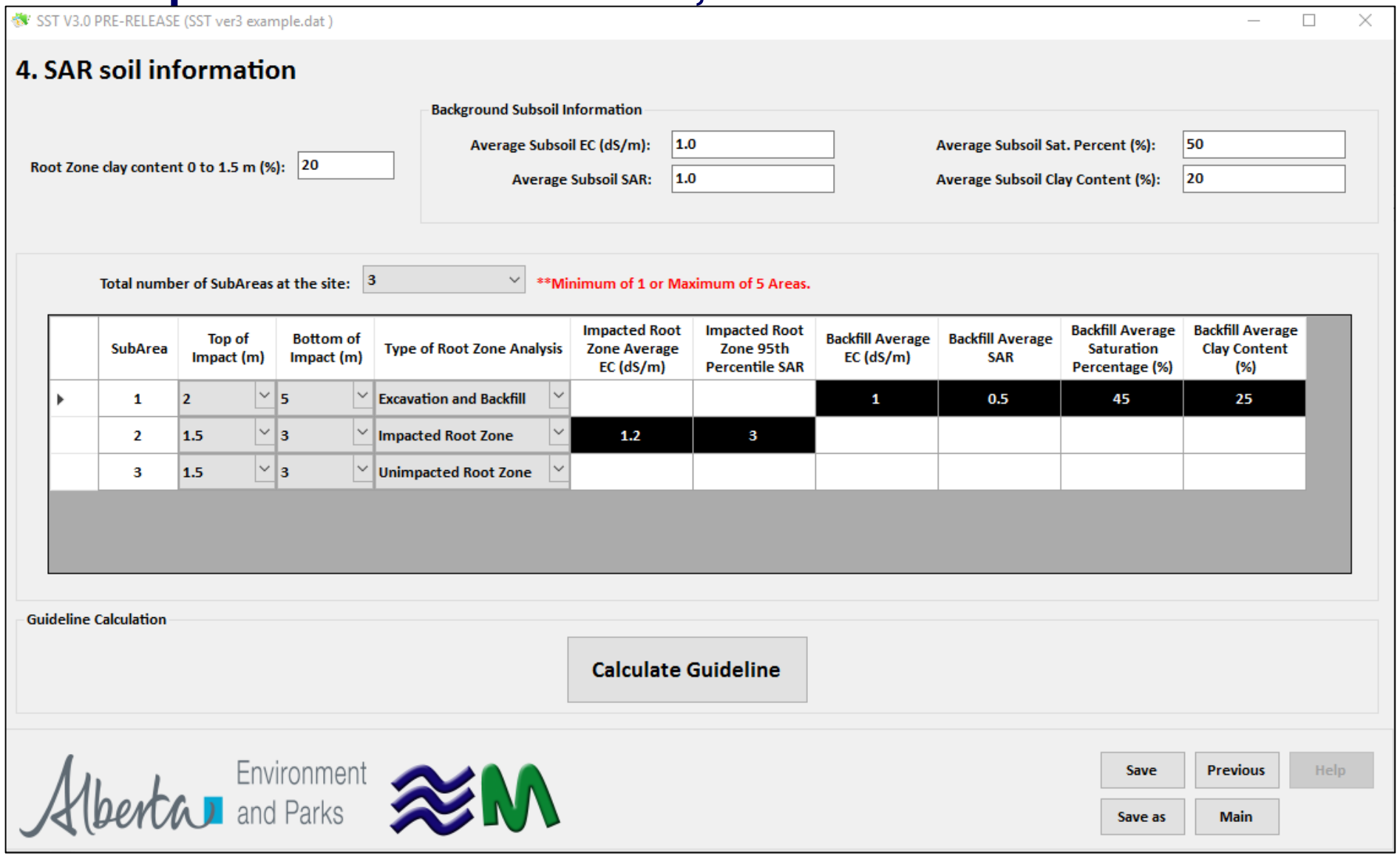
SAR / Sodium Module

SAR / Sodium Module

- Introduced to SST in Version 3.0
- Allows generation of standardized Tier 2 SAR and sodium guidelines for subsoil
  - Previously, only options for subsoil SAR were Tier 1 or Tier 2C
  - Tier 2A or Tier 2B depending on if monitoring wells are present
- Can be done in conjunction with chloride guidelines, or separately
- Accommodates up to five subareas (as per chloride)
- Same root-zone scenarios as chloride
  - Unimpacted root-zone
  - Excavation and backfill
  - Impacted root-zone

SAR / Sodium Module Inputs

- **Example with three subareas, three root-zone scenarios**



SAR / Sodium Module Outputs

- **Output screen shows subsoil SAR guideline plus subsoil sodium guidelines for two pathways**
  - **Displays guidelines for up to five subareas**
  - **Constraining sodium guideline and pathway identified for each area**

SAR Summary Output

	Pathway	Guideline - SubArea 1	Guideline - SubArea 2	Guideline - SubArea 3	Guidel
▶	Rooting Zone (mg/kg Sodium)	454	493	493	
	Irrigation Watering (mg/kg Sodium)	596	971	971	
	Constraining Pathway for Sodium	**Root Zone**	**Root Zone**	**Root Zone**	
	Constraining Guideline for Sodium (mg/kg Sodium)	**454**	**493**	**493**	
	SAR Guideline for Soil Structure	22	19	19	

SAR / Sodium Conceptual Model

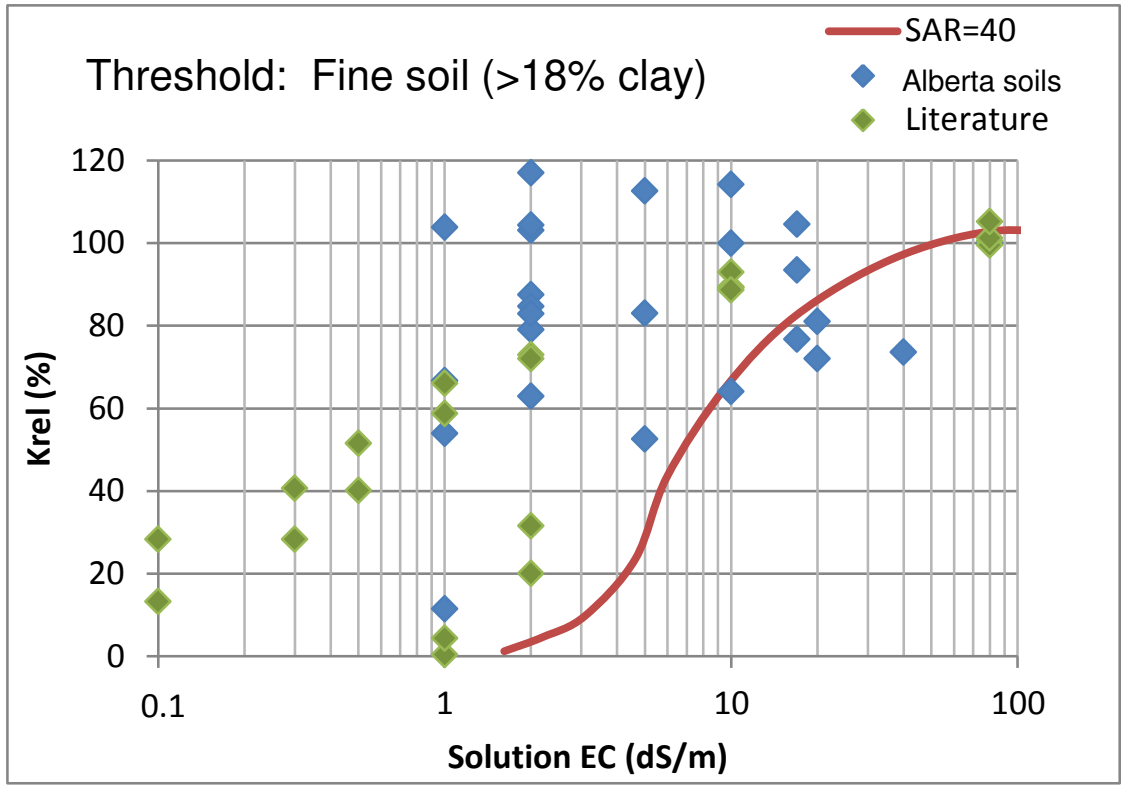
- Three pathways considered for subsoil SAR/sodium:

- Soil structure pathway
  - Potential for elevated subsoil SAR to cause excessive hydraulic conductivity loss current-day or in future
- Root-zone pathway
  - upward sodium migration potentially causing future root-zone SAR exceedance
- Irrigation water pathway
  - Sodium impacts mixing into dugout potentially causing SAR exceedance in irrigation water

- Other potential pathways such as DUA, livestock water, or aquatic life either sufficiently protected by chloride guidelines, or have no relevant SAR/sodium guidelines

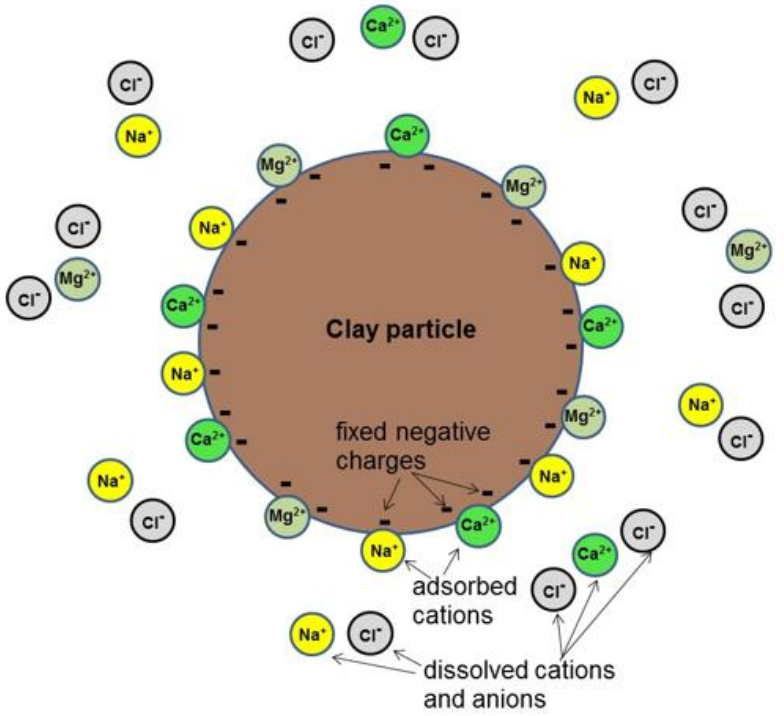
Soil Structure Pathway

- Based on evaluating potential for excessive hydraulic conductivity (K_{sat}) losses due to SAR
  - Eg, K_{rel} of 25% indicates a 4-fold K_{sat} loss
- Relative K_{sat} losses a function of both SAR and EC
  - Higher EC reduces Ksat losses, but EC levels may reduce over time
- SAR threshold curves derived for fine and coarse soils based on combination of literature results and Alberta soils
  - Used to derive SAR guideline for soil structure based on background EC



Root-Zone Pathway

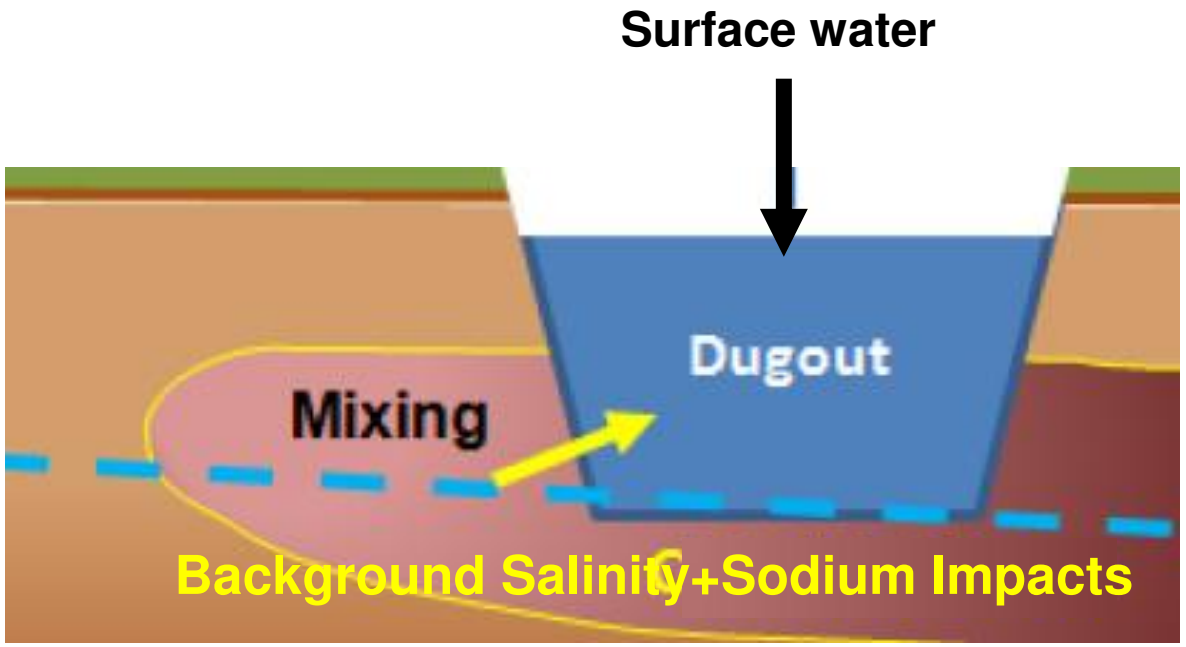
- Elevated subsoil sodium has potential to migrate upward into root-zone and cause future Tier 1 SAR exceedance
  - Function of drainage rate, impact depth, root-zone characteristics
- Sodium transport similar to chloride, but generally slower and more attenuated due to cation exchange reactions
  - Modelled extensively with 'LeachC' software suite
- Migration of sodium into low SAR soils results in sodium exchanging onto clay particle and releasing calcium or magnesium
  - Results in slower sodium transport and more gradual SAR increase than would otherwise be predicted



Irrigation Water Pathway

- Elevated subsoil sodium has potential to migrate into dugout water and cause irrigation water SAR exceedance
- Irrigation water SAR calculated via updated mixing model
  - same updated mixing calculations as for chloride
  - also influenced by background subsoil cation concentrations and surface water runoff concentrations

- Background subsoil cations (eg, Ca+Mg) estimated based on background subsoil EC and SAR
  - new data requirement

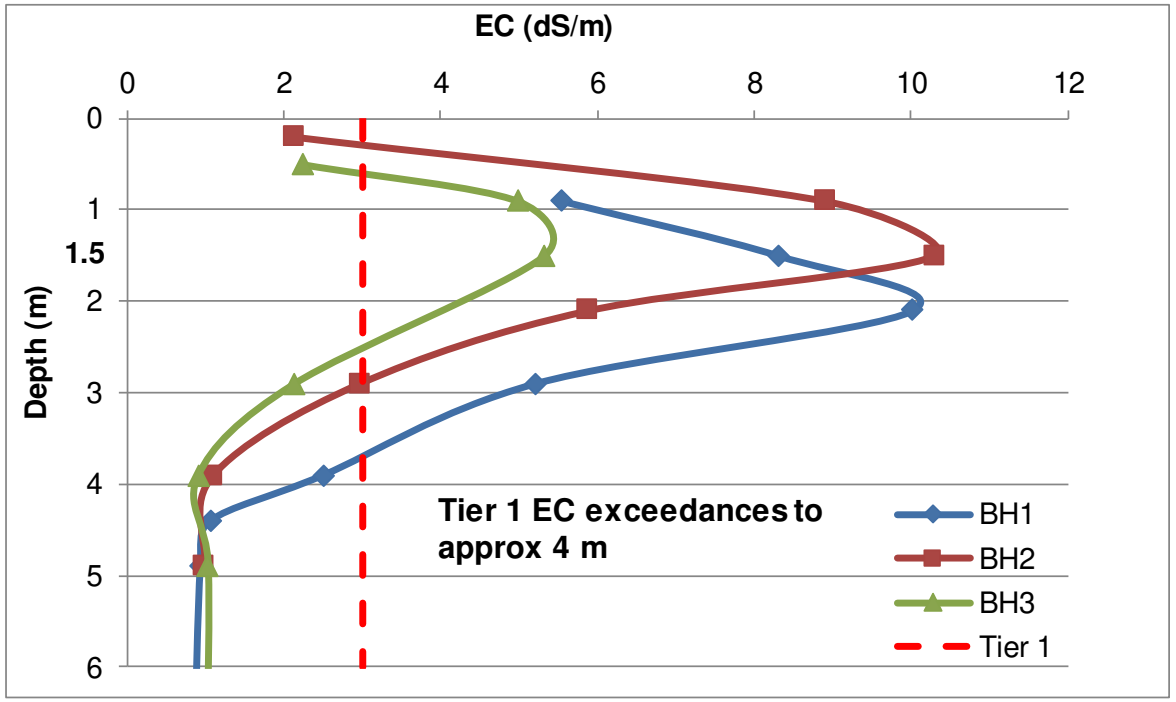


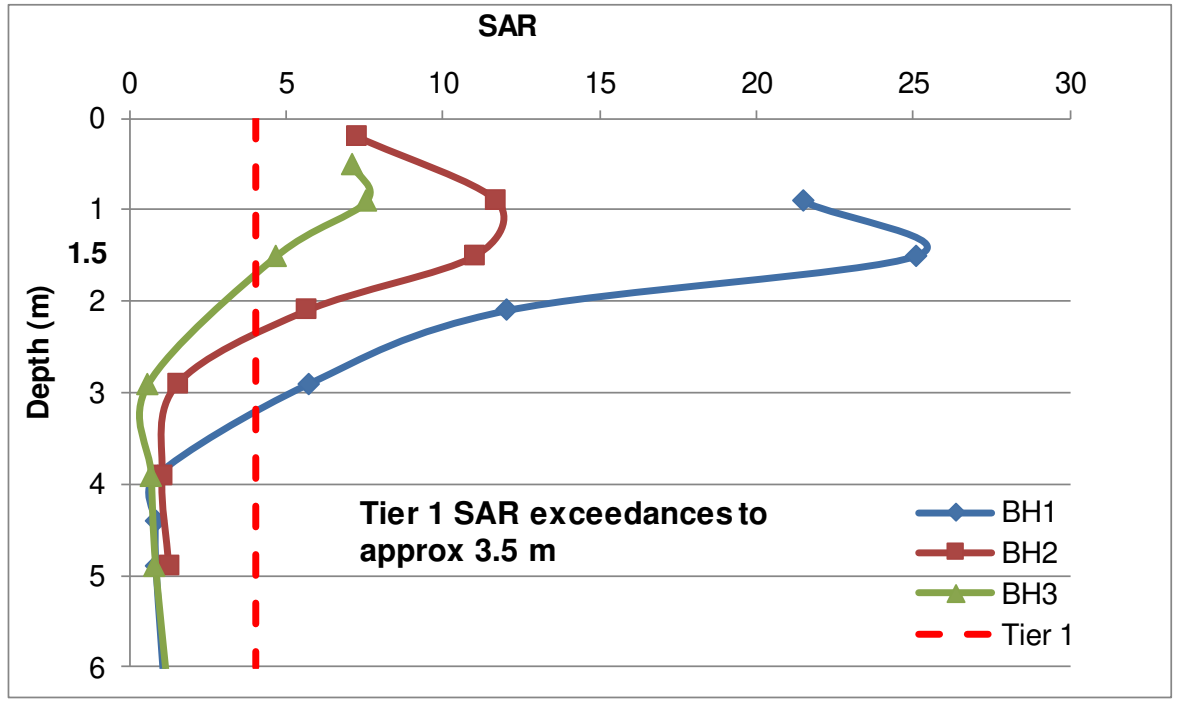
Additional SAR/Sodium Data Requirements

- **Same site data generally required for SAR/sodium as for Cl**
  - Site location and climate
  - Land use
  - Soil texture (coarse vs fine)
  - Vertical and lateral delineation
  - Root-zone background data (including SAR)
  - Water table depth (measured or estimated)
  - Vertical gradients (if available)
  - Backfill data (assumed or measured)
- **Additional subsoil background data also required**
  - Required for all subsoil SAR / sodium assessments (Tier 2A/2B)
  - Background subsoil data required to 4.5-6 m depth
- **Additional texture data also required**
  - Clay content data required for root-zone, subsoil, backfill

Case Study

- **Fine-grained agricultural soil with Tier 1 EC and SAR exceedances due to produced water**
  - **Tier 1 exceedances extend to 3.5-4 m**





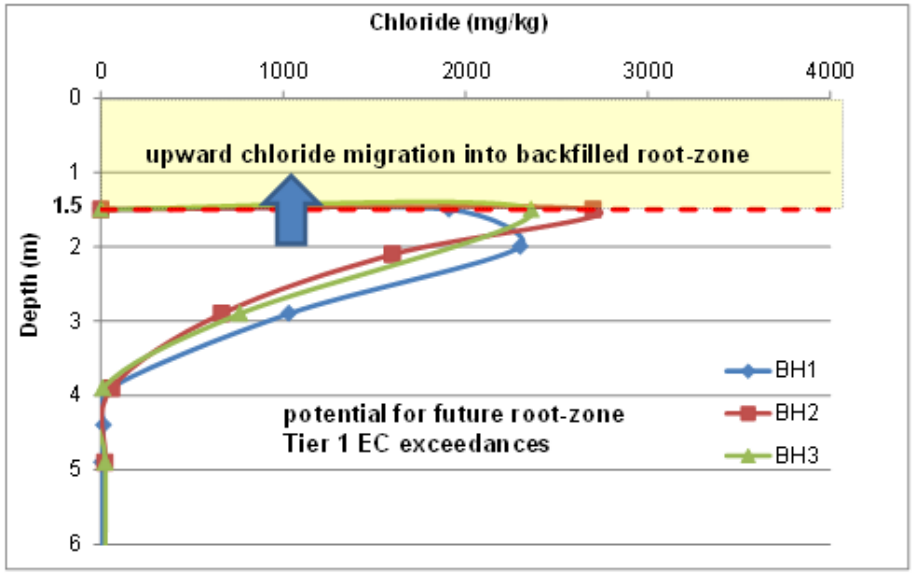
- **Root-zone at minimum must be remediated to Tier 1**
  - **How deep to remediate subsoil to protect backfilled root-zone?**

Case Study (cont'd)

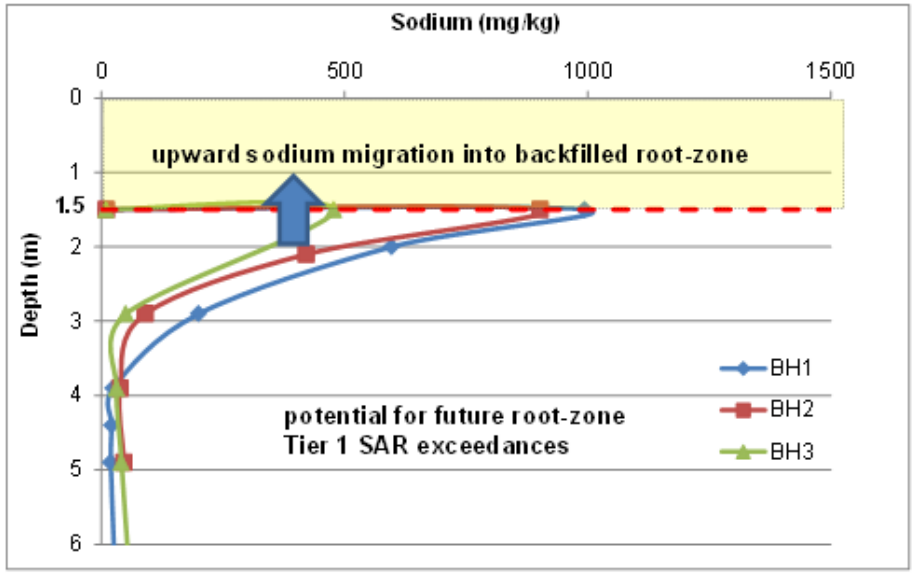
- **Other inputs**
  - 1.5 m preliminary excavation depth — Slight recharge (1 mm/year↓)
  - 4 m bottom of impacts — Backfill EC=1 dS/m, SAR=1
  - 7 m water table (dugout pathway excluded)

- **Preliminary subsoil guidelines for root-zone pathway**

Chloride: 1,300 mg/kg



Sodium: 475 mg/kg

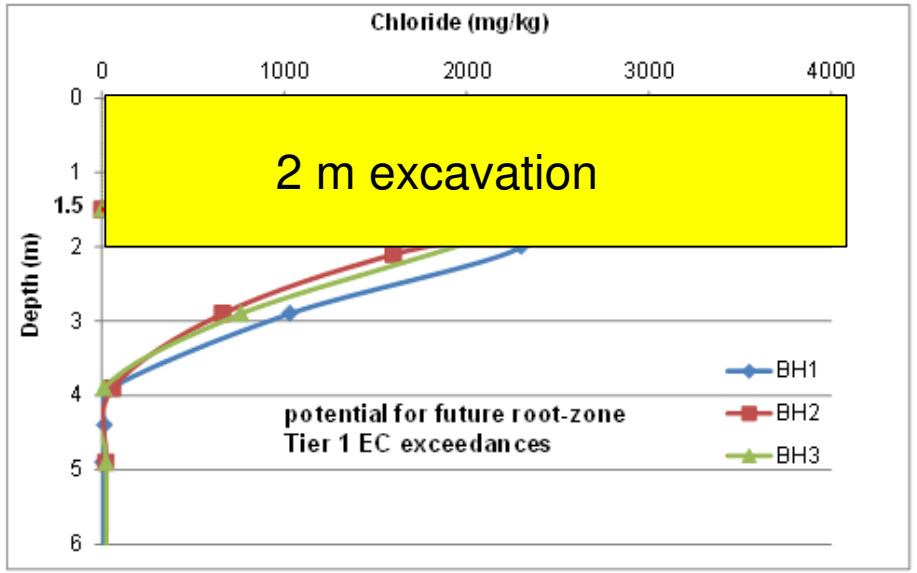


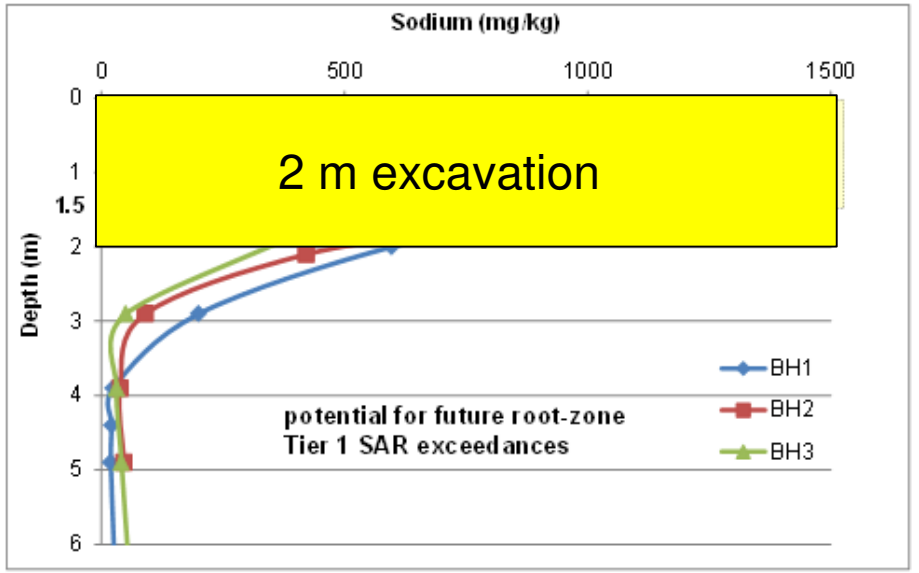
Both chloride and sodium have exceedances, must excavate further

Case Study (cont'd)

- **Now try 2 m excavation depth**
- **<u>Updated subsoil guidelines</u>**

  Chloride: 1,700 mg/kg **Sodium: 676 mg/kg**





- **Chloride still has exceedances, but sodium does not**
  - **Excavation to ~2.5 m required for chloride at some boreholes**
  - **No additional excavation beyond 2 m required for sodium**
- **In this case, subsoil SAR guideline (~16) also met**
  - **not always the case**

Case Study Summary

- **Individual cases vary substantially based on <u>many</u> factors:**
  - **Chloride and sodium impact depth**
  - **Drainage rate**
  - **Soil texture**
  - **Etc, etc**
  - **Impact magnitude**
  - **Root-zone / backfill parameters**
  - **Other receptor proximity**
- **For example, guidelines are reduced if above example had deeper impacts (to 6 m) and discharge scenario instead (1 mm/year upward):**
  - **Chloride guideline drops from 1700 mg/kg→870 mg/kg**
  - **Sodium guideline drops from 676 mg/kg→358 mg/kg**
- **Additional excavation depth then required to meet subsoil chloride / sodium guidelines**

Case Study Summary (cont'd)

- Generating SST guidelines for subsoil chloride, SAR, sodium generally an iterative process
- Frequent opportunities to optimize / refine excavation scenarios and minimize excavation volumes
  - particularly when multiple subareas
  - particularly when both chloride and SAR/sodium impacts

- SST training / certification required to use tool appropriately and effectively

SST Certification Course

SST Certification Course

- **3.5-Day Full Certification Course (Version 3.0)**
  - Covers chloride, SAR, and sodium aspects
  - Course includes theory, case studies, tool practice
  - Comprehensive exam on final day
  - Passing exam mark results in official SST Certificate to allow submittal of assessments
  - Covers both Version 2.5.3 and Version 3.0
  - Full course not required if already SST-certified in previous version
- **1-Day Update Course (Version 3.0)**
  - Optional, open to already-certified participants
  - Discusses chloride updates in Version 3.0
  - Discusses SAR/sodium module including examples
  - No exam, no formal certification

*** NEXT COURSE DATES TBD ***

Thank you! Questions?

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