



Equilibrium Environmental Inc

Subsoil Salinity Tool (SST) Version 3.0

Insights into Producing More Robust Guidelines with Lower Remediation Volumes

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- **City of Calgary**

Presentation Overview

- **Introduction to SST Version 3.0**
 - General information and conceptual model
- **Key changes to chloride guidelines from Ver 2.5.3**
 - Drainage rate updates
 - Root-zone pathway
 - Dugout pathways (livestock/irrigation)
 - Aquatic life pathway
 - DUA pathway
 - Subareas
 - Other features
- **SAR / sodium guidelines**
 - General information and conceptual model
 - Case study
- **SST certification course**

Introduction to SST Version 3.0

Subsoil Salinity Tool

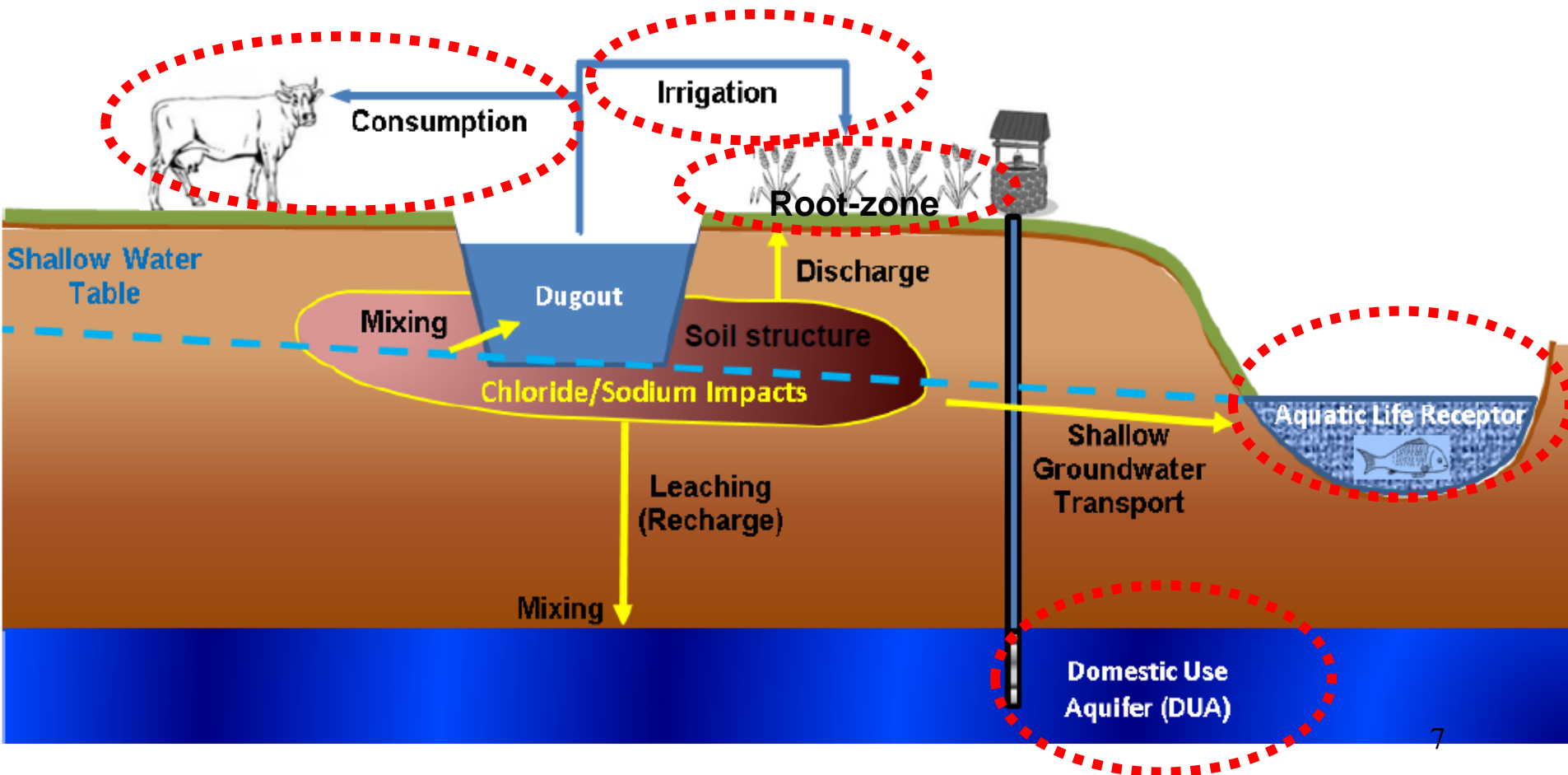
- **Subsoil Salinity Tool (SST) allows generation of Tier 2 subsoil chloride guidelines for below the root-zone (>1.5m)**
 - Tier 1 guidelines for EC and SAR applicable in root-zone
- **Introduced in 2008, several versions since then**
 - Most recent is Version 2.5.3 from 2014
 - Version 3.0 to be released soon in 2020
- **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

- Limited to information for only 1 subarea at a time

SST - Soil information - Jul 9 2015 - 2.5.3 run.DAT

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Example input page

5. Soil Information

Buffer Allocation Factor (BAF) for SubArea

Total number of SubAreas at the site :

3

****Minimum of 1 or Maximum of 5 Areas.**

SubAreas	DUA pathway	Aquatic life pathway
Area 1	0.2	0.2
Area 2	0.5	0.5
Area 3	0.3	0.3
Total	1.000	1.000



****NOTE: Sum of the BAF for all the SubAreas should be equal to 1.0.**

Select SubArea for Analysis:

Area 1

Impact and Source Information (for entire site or SubArea)

Top of Impact (m)

4 m



Source Length (m)

15



Bottom of Impact (m)

8 m



Type of Root Zone Analysis (for entire site or SubArea)

Select Type of Analysis:

Excavation and Backfill of Root Zone

Original EC buffer

2.6

Backfill Salinity - enter EC only

No	Depth (m)	EC (dS/m)	New Buffer (dS/m)
1	1.0 to 1.5 m	0.42	2.58

Calculate

A new salinity buffer is calculated as the difference between the salinity of the backfill and the Tier 1 guideline.

Guideline Calculation

Click to Calculate Guideline

Calculate Guideline



Save

Help

Previous

Close

SST Version 3.0

Example input page

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

SST V3.0 PRE-RELEASE (test (5 areas chloride and SAR).dat)

4. Groundwater Information

Shallow Groundwater Information

Background Chloride in Shallow Groundwater (mg/L): ? Default

at the point of GW discharge into the nearest surface water receptor

☐ FAL sentinel well? Distance to FAL sentinel well (m): ?

☐ Adjacent agricultural land sentinel well? Distance to agricultural land sentinel well (m): ?

Required for chloride assessments

Shallow Groundwater Salinity Transport Information

Shallow Groundwater Transport Lithology: ? ☐ Default

Lateral Hydraulic Conductivity for Shallow Groundwater (m/s): ?

Lateral Hydraulic Gradient for Shallow Groundwater (m/m): ?

Calculated Shallow Groundwater Velocity (m/yr): 0.403

Required for chloride assessments or SAR assessments

Deep Groundwater Salinity Transport Information

Deep Groundwater Transport Lithology: ? ☒ Default

Lateral Hydraulic Conductivity for Deep Groundwater (m/s): ?

Lateral Hydraulic Gradient for Deep Groundwater (m/m): ?

Calculated Deep Groundwater Velocity (m/yr): 0.009

Required for chloride assessments

DUA Information

DUA or Maximum Depth of Drilling (m): ? ☒ Default


Background Chloride in DUA (mg/L): ?

Lateral Hydraulic Conductivity for DUA (m/s): ?

Lateral Hydraulic Gradient for DUA (m/m): ?

Calculated DUA Darcy Velocity (m/yr): 0.883

Required for chloride assessments

Alberta Environment and Parks  ☒ Chloride ☐ SAR

SST Version 3.0 General Info and Parameter 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 1×10^{-6} and 1×10^{-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 Simultaneous Subarea Handling

- Example of five subareas for chloride

SST V3.0 PRE-RELEASE (test (5 areas chloride and SAR).dat)

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5A. Chloride Soil

Total number of SubAreas at the site: 5

****Minimum of 1 or Maximum of 5 Areas.**

Original EC Buffer (dS/m): 2.4

Water Table Depth (m): 4

	SubArea	DUA BAF	Aquatic Life BAF	Source Dimension (m)	Distance to Aquatic Life Receptor (m)	Top of Impact (m)	Bottom of Impact (m)	Type of Root Zone Analysis	95th Percentile Chloride Impacted Root Zone (mg/kg)	Calculated EC Impacted Root Zone (dS/m)	New EC Buffer Impacted Root Zone (dS/m)	Average EC of Backfill (dS/m)	Average Saturation Percent of Backfill (%)	New EC Buffer of Backfill (dS/m)
▶	1	.2	.2	25	250	1.5	9	Excavation and Backfill				0.6	85	2.4
	2	.2	.2	30	250	3	10	Unimpacted Root Zone						
	3	.2	.2	25	250	1.5	2	Impacted Root Zone	150	1.0	2.0			
	4	.2	.2	50	250	1.5	4	Excavation and Backfill				1	40	2.0
	5	.2	.2	50	250	4	7	Unimpacted Root Zone						
	Total	1.0	1.0											

****NOTE:** Sum of the BAF for all the SubAreas should be equal to 1

Guideline Calculation

Calculate Guidelines



Save

Previous

Help

Save as

Main

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

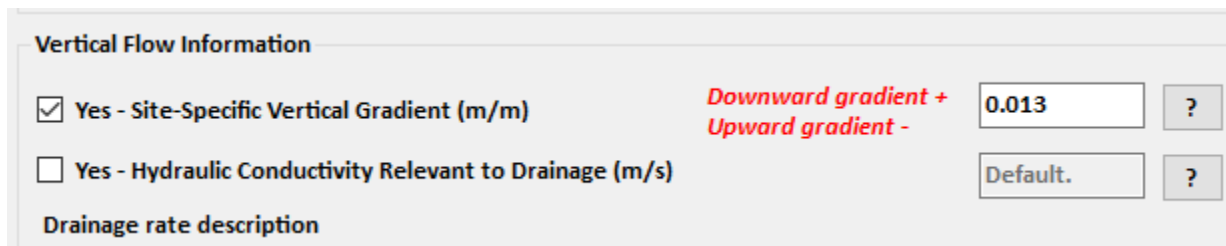
Chloride Guideline Updates

SST 3.0 Chloride Guideline Updates

- **Guideline calculation protocols for chloride enhanced and expanded for all pathways**
 - Guideline protocols made more robust and refined in multiple areas
- **In many cases, the extra refinement has allowed removal of various conservative assumptions**
 - Frequently results in increased guidelines and reduced remediation volumes while maintaining equivalent levels of protection for all receptors
- **Some updates highly significant and affect all pathways**
 - Bulk density
 - Drainage rates
- **Other new features target specific pathways**
 - Sentinel wells relevant to aquatic life or adjacent agricultural land

Drainage Rate Updates

- Drainage rates previously determined by texture and climate (CMI), and potentially over-ridden by vertical gradient information
- More refined updated protocols retain the climate influence while also allowing modification from vertical gradient
 - More robust approach, generally less conservative
- Additional option use of hydraulic conductivities relevant to drainage removes some uncertainties from using vertical gradient in its own



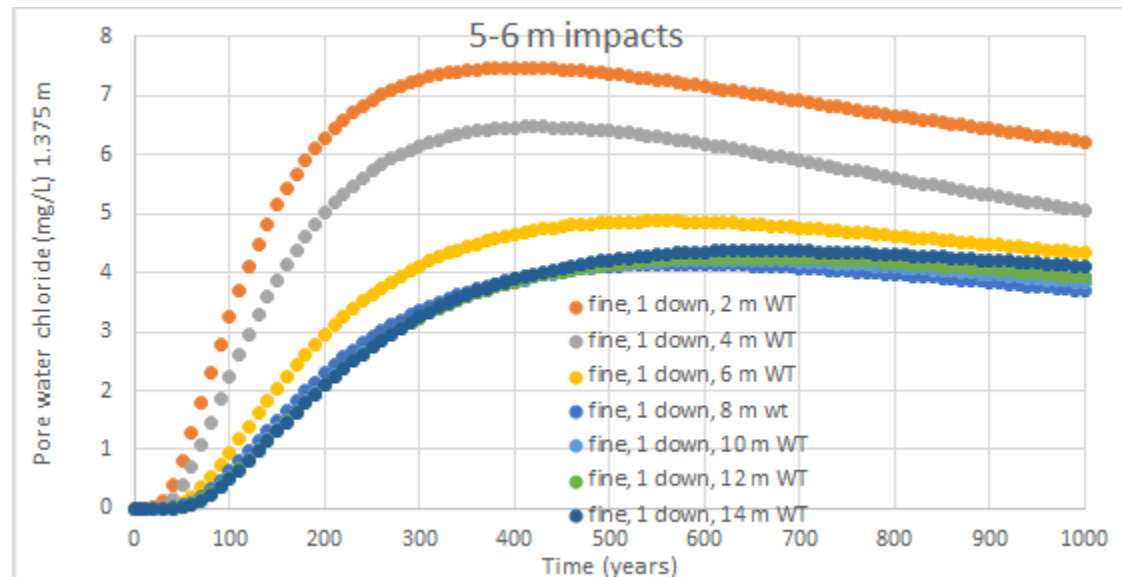
The screenshot shows a software window titled "Vertical Flow Information". It contains two checkboxes and two input fields. The first checkbox is checked and labeled "Yes - Site-Specific Vertical Gradient (m/m)". To its right, there is a red label "Downward gradient +" and a red label "Upward gradient -". The input field next to it contains the value "0.013". The second checkbox is unchecked and labeled "Yes - Hydraulic Conductivity Relevant to Drainage (m/s)". The input field next to it contains the text "Default.". Below these fields is a label "Drainage rate description".

Option	Value
<input checked="" type="checkbox"/> Yes - Site-Specific Vertical Gradient (m/m)	0.013
<input type="checkbox"/> Yes - Hydraulic Conductivity Relevant to Drainage (m/s)	Default.

- Additional intermediate drainage rate categories allow smoother transitions and more refinement than Ver 2.5.3
 - Less conservative in many cases, frequently higher guidelines¹⁴

Root Zone Pathway Updates

- **Drainage rate updates**
 - refined drainage rates result in reduced upward transport to the root-zone in some cases
- **Root-zone scenario updates**
 - Improved modeling reduces conservatism in ‘impacted root-zone’
 - Improved ability to specify backfill properties such as sat%
- **Water table updates**
 - Substantially more refined influence of water table depth and moisture content on upward migration
 - Deeper water tables reduce root-zone risk and generally increase RZ guidelines

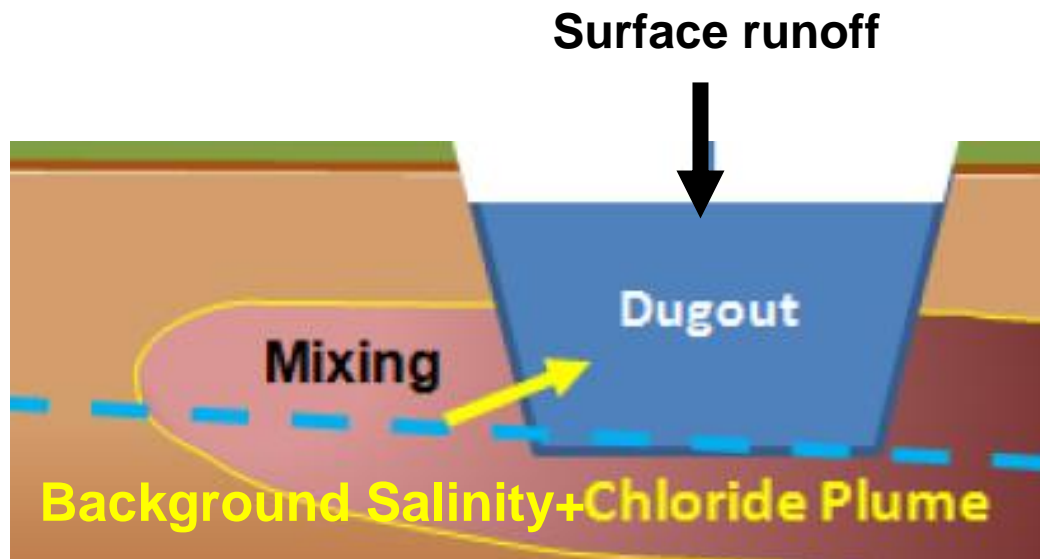


Dugout Pathway Updates

- **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

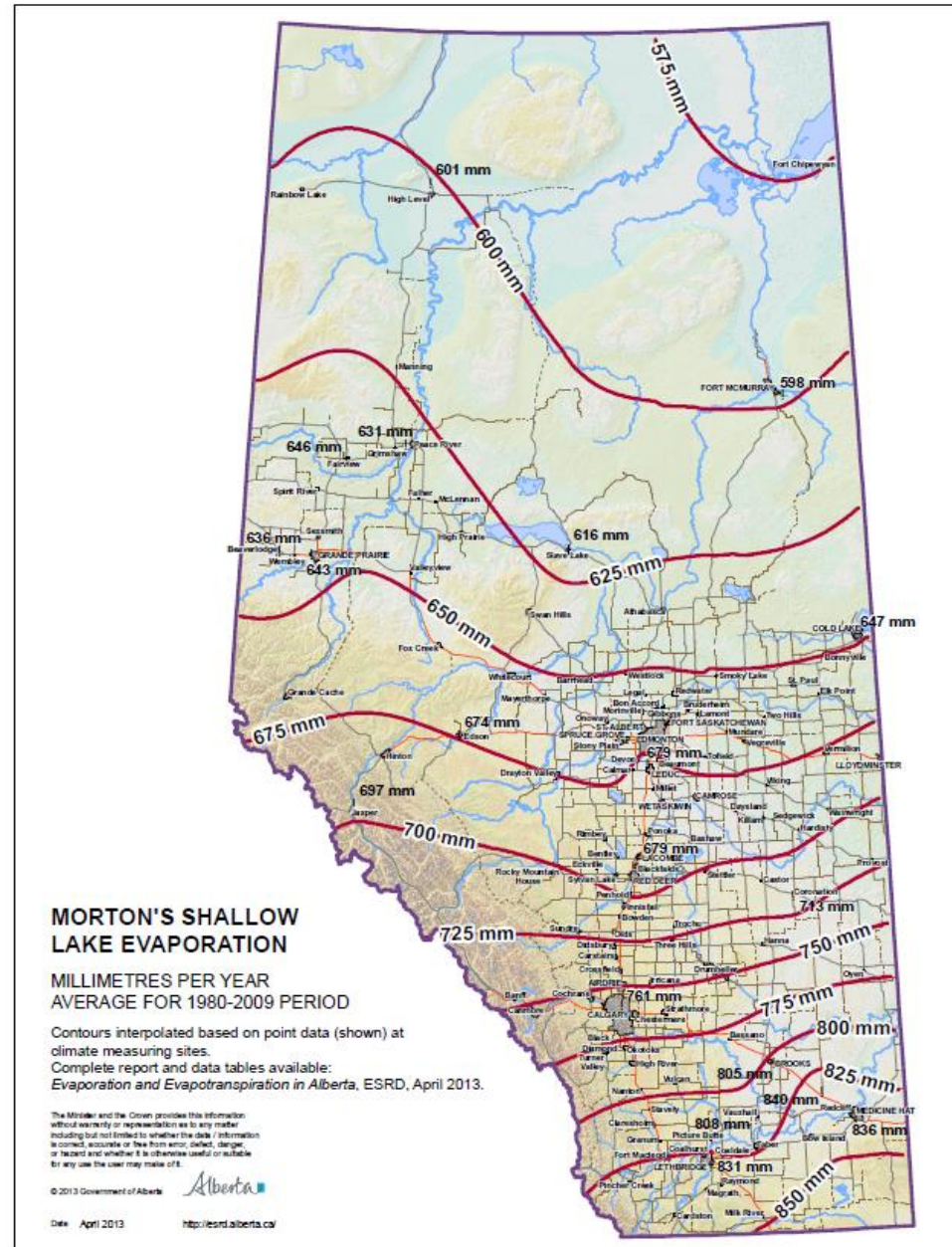
Dugout mixing model

- Dugout depth now assumed to be 6 m rather than 4 m based on Alberta Agriculture sizing guidelines
- 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
 - generally higher guidelines, sometimes substantially higher



Dugout guideline updates

- Dugout sizing and mixing calculations taken from Alberta Agriculture information combined with updated Alberta evaporation information
- Net effect of the dugout protocol updates is generally higher guidelines for both livestock watering and irrigation water
- Dugout pathways excluded less often, but generally less constraining and less likely to drive remediation



Aquatic Life Pathway Updates

- **Additional modeling performed to handle the faster potential groundwater velocities in coarse soils**
 - Up to approximately 25 m/year (coarse default)
- **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

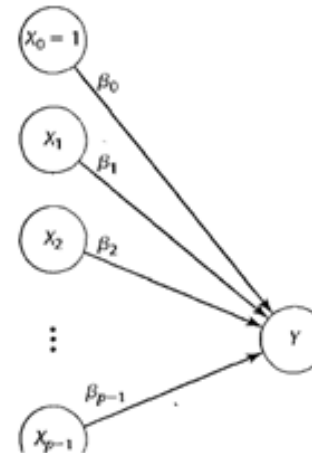
Aquatic Life Neural Network

- Allows more complex corrections for subarea interactions than would be possible with more traditional (linear) approaches
- Particularly valuable for reducing extra conservatism for FAL receptors very near to Site
 - Results in guideline increases for FAL

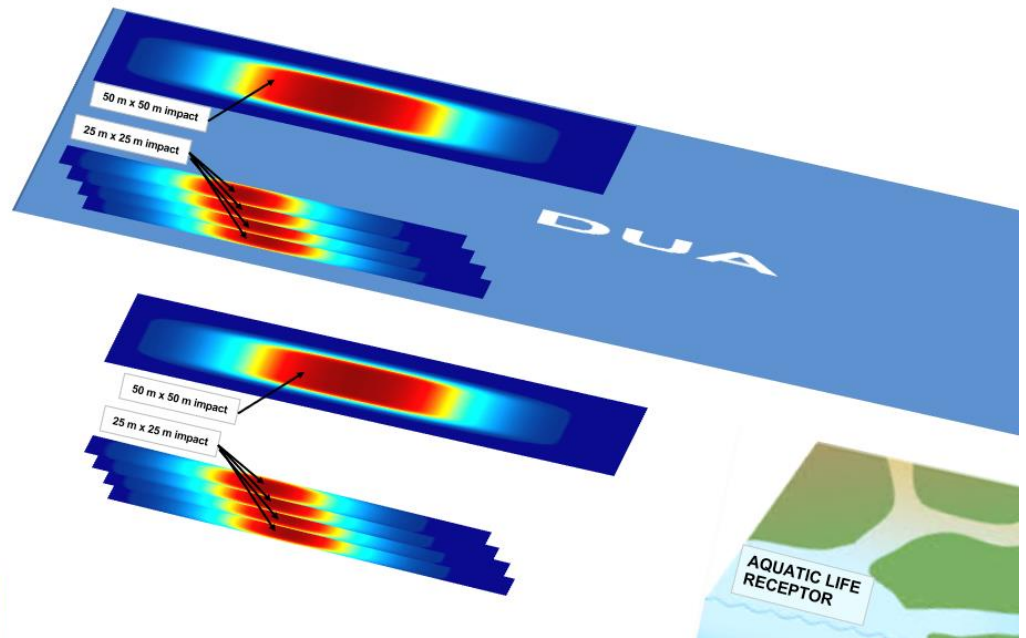
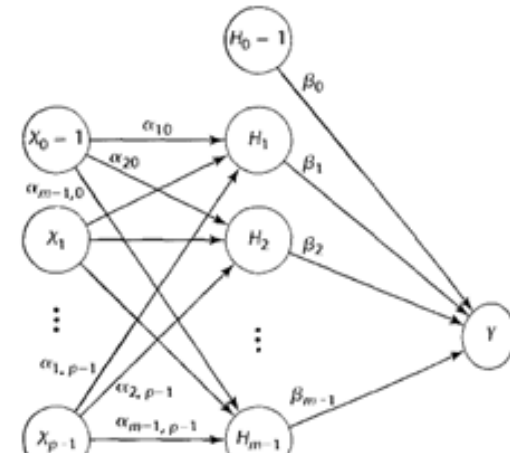
FIGURE 13.8
Network Rep-
resentations of
Linear
Regression
and Neural
Network
Models.

$$E\{Y\} = \beta_0 + \beta_1 X_1 + \cdots + \beta_{p-1} X_{p-1}$$

(a) Linear Regression Model



(b) Neural Network Model

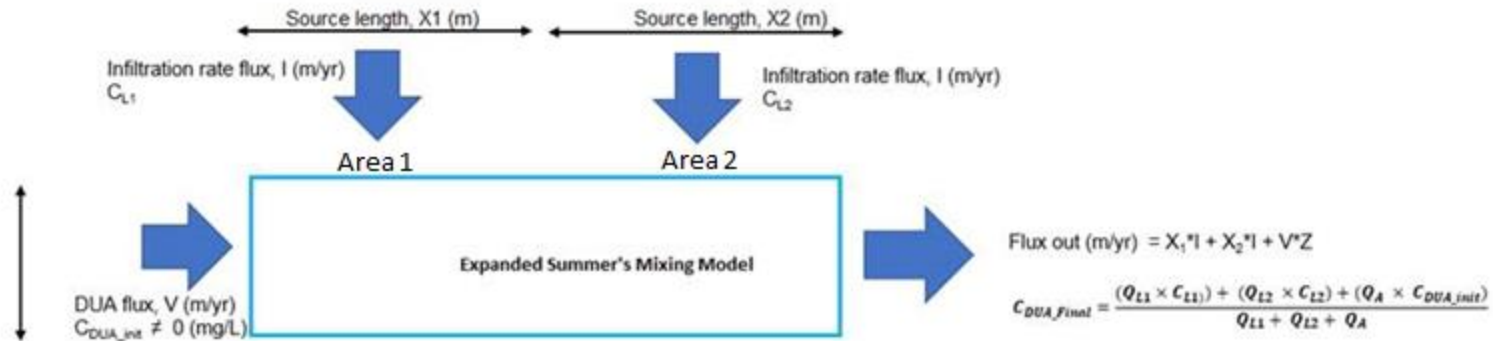


DUA Pathway Updates

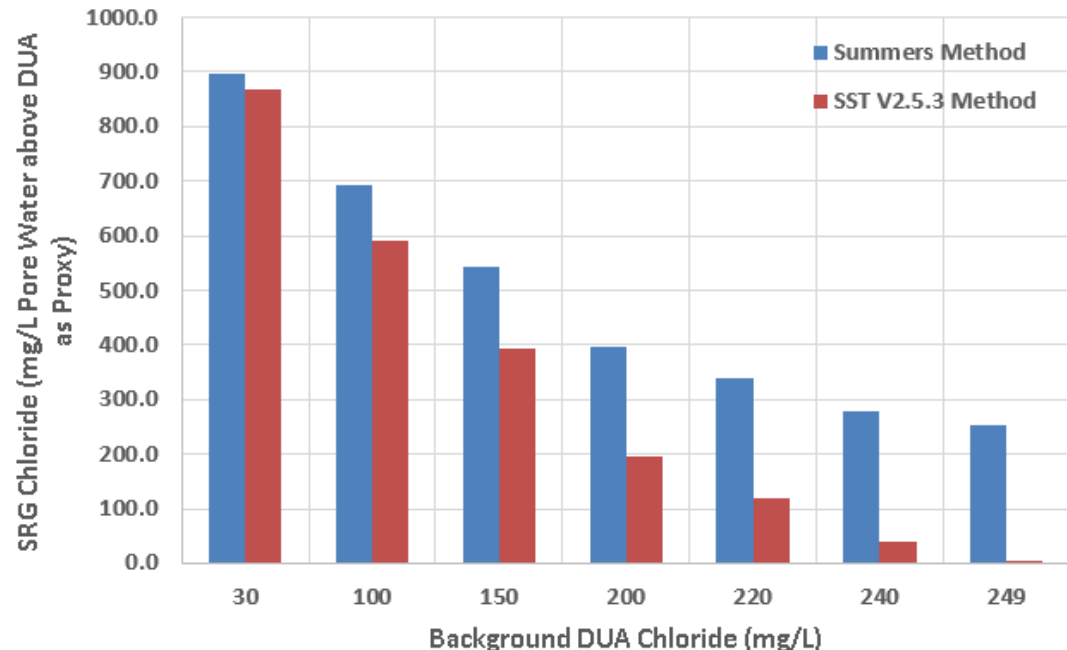
- **Additional smoothing of guidelines introduced via intermediate drainage rates**
- **Pore water conversions for fine soils now give lower concentrations due to lower bulk density / higher porosity**
 - Results in higher soil guidelines, all else equal
- **Dilution into DUA ('Dilution Factor 3') now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

DUA Summers Mixing Model

- Allows more accurate step-wise loading onto DUA
 - Mass balance calculations for water and chloride



- Improved handling of background DUA chloride
 - Improved accuracy compared to previous 'buffer' method, particularly when background DUA chloride concentrations are high



Sentinel Well Feature

- New feature allowing analysis of hypothetical sentinel wells relevant to either:
 - aquatic life receptor (FAL)
 - nearest agricultural land (dugout pathways if site is non-agric)

4. Groundwater Information

Shallow Groundwater Information

Background Chloride in Shallow Groundwater (mg/L): ? Default

at the point of GW discharge into the nearest surface water receptor

☒ FAL sentinel well? Distance to FAL sentinel well (m): ?

☒ Adjacent agricultural land sentinel well? Distance to agricultural land sentinel well (m): ?

A red dashed oval highlights the two sentinel well options and their distance inputs.

- Provides upper bounds for future groundwater chloride concentrations at those sentinel well locations
- Useful for risk management and monitoring activities, especially for sites which cannot be remediated completely in the short-term

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, the 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)**
- **Three key pathways for SAR/sodium**
 - Soil structure pathway
 - Root-zone (upward migration) pathway
 - Irrigation (dugout) pathway

SAR / Sodium Module Inputs

- Example with five subareas, three root-zone scenarios

SST V3.0 PRE-RELEASE (test (5 areas chloride and SAR).dat)

5B. SAR Soil Information

Clay Content Information

Root Zone clay content: Medium clay (18-36%) ?

Subsoil clay content (%): Medium clay (18-36%) ?

Background Subsoil Information

Average Subsoil EC (dS/m): 1 ?

Average Subsoil SAR: 1 ?

Average Subsoil Sat. Percent (%): 40

Total number of SubAreas at the site: 5 **Minimum of 1 or Maximum of 5 Areas.

Tier 1 SAR guideline 1 to 1.5 m: 4.0

	SubArea	Top of Impact (m)	Bottom of Impact (m)	Type of Root Zone Analysis	Impacted Root Zone Average EC (dS/m)	Impacted Root Zone 95th Percentile SAR	Backfill Average EC (dS/m)	Backfill Average SAR	Backfill Average Saturation Percentage (%)	Backfill Average Clay Content (%)
	1	1.5	4	Unimpacted Root Zone						
	2	2	5	Impacted Root Zone	1	1				
	3	3	> 6	Excavation and Backfill			1	2	50	Medium clay (18-36%)
	4	1.5	2	Unimpacted Root Zone						
	5	3	4	Impacted Root Zone	2	2				

Guideline Calculation

Calculate Guidelines


Alberta Environment and Parks

Save Previous Help

Save as Main

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 - PRE-RELEASE VERSION

	Pathway	Guideline - SubArea 1	Guideline - SubArea 2	Guideline - SubArea 3	Guideline - SubArea 4	Guideline - SubArea 5
▶	Rooting Zone (mg/kg Sodium)	690	910	580	1200	2400
	Irrigation Watering (mg/kg Sodium)	ML (15000)	ML (9700)	4900	ML (35000)	ML (27000)
	Constraining Pathway for Sodium	Root Zone	Root Zone	Root Zone	Root Zone	Root Zone
	Constraining Guideline for Sodium (mg/kg Sodium)	690	910	580	1200	2400
	SAR Guideline for Soil Structure	25	27	29	25	29

Root Zone: 1 mm/yr recharge

DUA: 6 mm/yr recharge

****Note: ML = Management Limits for Sodium**
(6,500 mg/kg for fine soils and 4,500 mg/kg for coarse soils)



Save

Close

Save as

Report

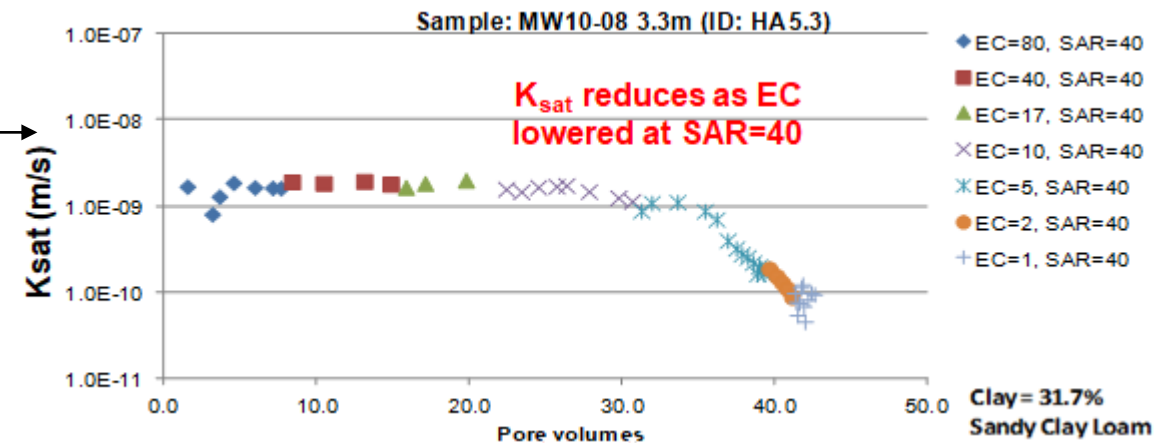
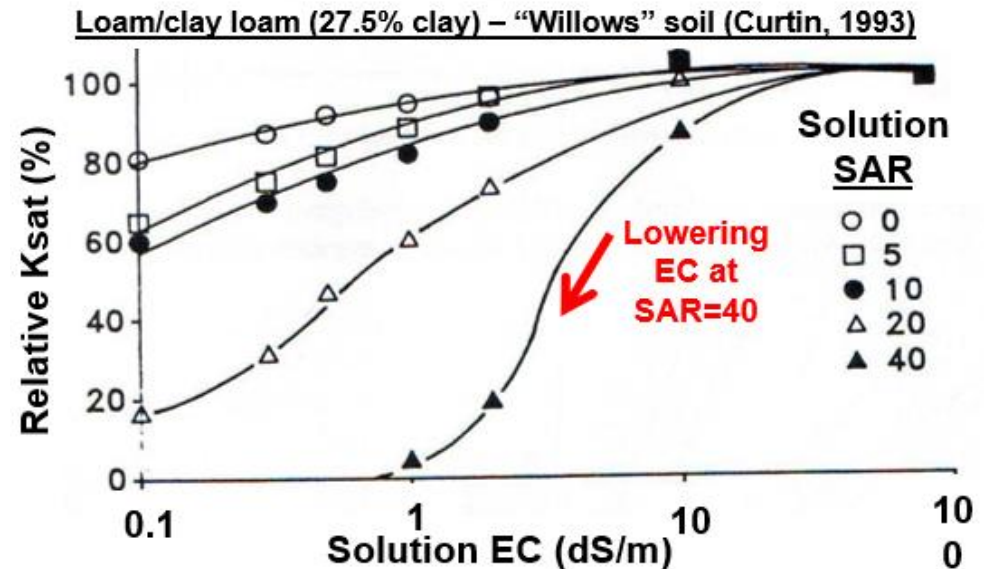
Help

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
 - Relevant to potential water table water-logging
 - K_{sat} losses influenced by combination of EC, SAR, and texture
- 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



Soil Structure Guideline Example

- Example site:
 - Fine-grained, Agricultural land, Central Parkland
 - Tier 2B, moderate background TDS (~2,000 mg/L)
 - 4 m water table, relatively slow shallow GW velocity (0.4 m/year)
 - Medium clay content in root-zone and subsoil (18-36%)
 - ‘Good’ background EC and SAR in root-zone (0.5-1 each)
 - ‘Good’ background EC and SAR in subsoil (~1 each)
 - Top of impacts ranging from 1.5 to 3 m depending on subarea
 - Bottom of impacts ranging from 2 to >6 m depending on subarea
 - Some areas require shallow excavation for Tier 1 EC/SAR exceedances or subsoil chloride
 - Some areas have unimpacted or slightly impacted root-zone
- Results in subsoil SAR guidelines from 25-29 depending on subarea, root-zone scenario, and depth of impacts
 - No remediation for subsoil SAR needed in this case

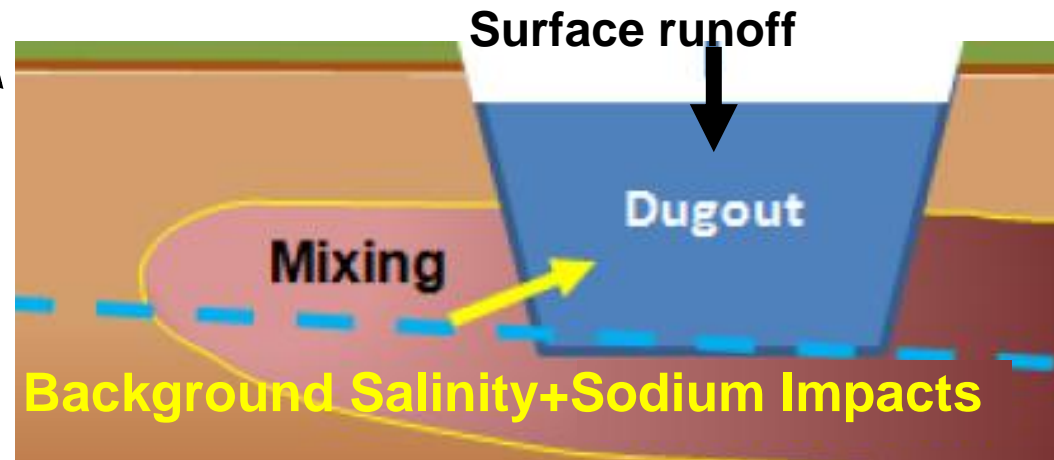
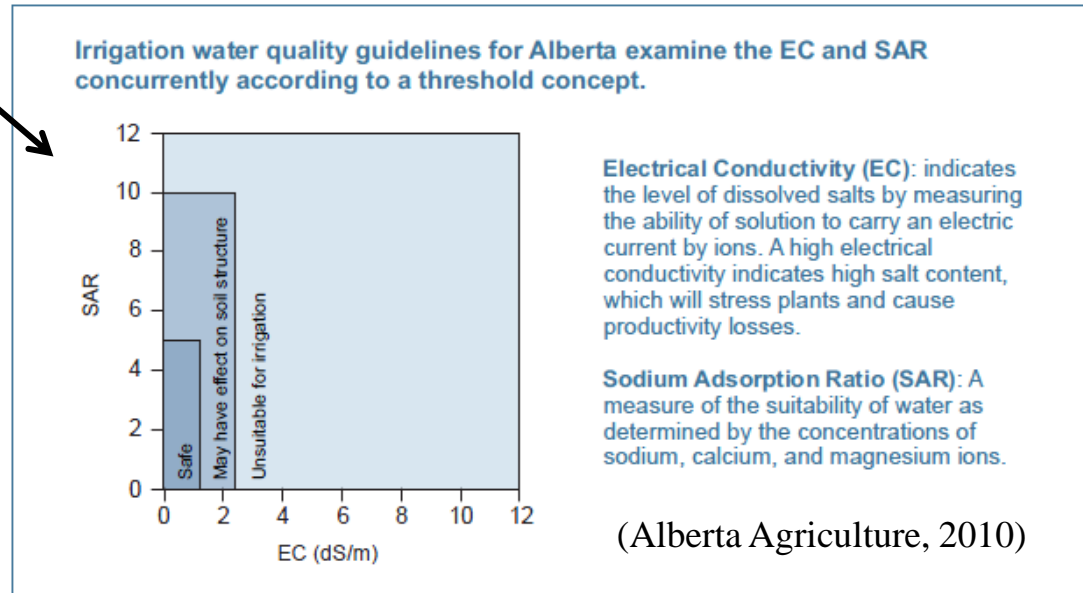
Root-Zone Pathway

- **Elevated subsoil sodium has potential to migrate upward into root-zone and cause future Tier 1 SAR exceedance**
 - Root-zone SAR poses higher risk than subsoil SAR due to hardpan potential, poor infiltration, etc
- **Sodium similar to chloride, but generally slower and more attenuated due to cation exchange reactions**
 - Modelled with 'LeachC'
- **Migration of sodium into low SAR soils results in sodium cation exchange on clay and releasing calcium or magnesium**
- **Results in slower sodium transport than chloride and more gradual SAR increase than would otherwise be predicted**



Irrigation Water Pathway

- Subsoil sodium may migrate into dugout water and cause irrigation water SAR exceedance
- Irrigation water SAR calculated via updated mixing model
 - consistent with updated mixing calculations 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

Summary of SAR/sodium guidelines

- Based on case studies performed on dozens of actual sites, it appears relatively rare that additional remediation will be required for subsoil SAR or sodium beyond what is required for chloride
- Soil structure issues from subsoil SAR are generally not a primary risk driver, particularly after remediation for chloride
- Risk to irrigation water from subsoil sodium may potentially be a factor on some sites, but generally rare after remediation for chloride
 - Particularly with updated dugout mixing calculations
- Root-zone risk from elevated subsoil sodium may require minor additional excavation on some sensitive sites, but in most cases is not required based on required chloride remediation
- In example, most constraining sodium guidelines (580-2,400 mg/kg for root-zone pathway) did not require additional remediation beyond what is needed for chloride

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 COURSES TO BE DELIVERED ON-LINE (DATES TBD) *****

Thank you! Questions?

SSThelp@eqm.ca