Developing Water Quality Objectives for Salinity Diversions to Agriculture using Steady-state and Transient Models

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Salinity regulation in the San Joaquin Basin

- The Central Valley Regional Board adopted a stakeholder-centric approach to salinity planning and regulation – CVSALTS.
- Tasked with rewriting the Basin Plan for water quality
- Basin Plan includes provision for real-time salinity management
- Requires dischargers (otherwise subject to WDR’s) to adopt a “Board approved” real-time salinity management program
- Program includes continuous monitoring, data access and sharing, modeling and real-time decision support
- Reliance on sensor networks and the development of a stakeholder supported sensor web.
- Need to develop protective water quality (salinity) objectives for irrigation diversions from the San Joaquin River
Monitoring return flow and salinity to the SJR
Management of riparian diversion salinity
Comparison of EC at three SJR monitoring stations

Salt Tolerance of Crops in the Southern Sacramento-San Joaquin Delta, Hoffman, 2010
Criteria affecting water quality for crop production

- **Salinity**
  - Osmotic stress on plants
- **Sodicity**
  - Loss of soil permeability
- **Toxicity**
  - Direct toxic effect on plants

Units of Measure for Electrical Conductivity

1 dS/m = 1,000 µS/cm = 1 mmho/cm

1 dS/m ≈ 640 mg/l or 640 ppm total dissolved solids

Factors affecting salinity objectives for irrigated agriculture

- Season-long crop salt tolerance
- Crop salt tolerance at various growth stages
- Preferential (bypass) flow of applied water
- Effective rainfall
- Irrigation method
- Crop water uptake distribution
- Climate
- Salt precipitation / dissolution
- Shallow groundwater
- Leaching fraction

Comparison of crop salt tolerance 1990’s vs 2000’s

Figure 3.4. Distribution of crops in the LSJR Irrigation Use Area for the 1990s and 2000s based on salt tolerance (from DWR land use surveys; DWR, 2009a).
Seasonal salt tolerance by crop type

\[ Y_r = 100 - b \ (EC_r - a) \]

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Botanical Name</th>
<th>Tolerance Based on</th>
<th>Threshold ECe, dS/m</th>
<th>Slope ( % ) per dS/m</th>
<th>Relative Tolerance **</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>Medicago sativa</td>
<td>Shoot DW</td>
<td>2.0</td>
<td>7.3</td>
<td>MS</td>
</tr>
<tr>
<td>Almond</td>
<td>Prunus dulcis</td>
<td>Shoot growth</td>
<td>1.5</td>
<td>9.0</td>
<td>S</td>
</tr>
<tr>
<td>Asparagus</td>
<td>Asparagus officinalis</td>
<td>Spear yield</td>
<td>4.1</td>
<td>2.0</td>
<td>T</td>
</tr>
<tr>
<td>Bean</td>
<td>Phaseolus vulgaris</td>
<td>Seed yield</td>
<td>1.0</td>
<td>9.0</td>
<td>S</td>
</tr>
<tr>
<td>Corn</td>
<td>Zea mays</td>
<td>Ear FW, Shoot DW</td>
<td>1.7, 1.8</td>
<td>12, 7.4</td>
<td>MS, MS</td>
</tr>
<tr>
<td>Grape</td>
<td>Vitis vinifera</td>
<td>Shoot growth</td>
<td>1.5</td>
<td>9.6</td>
<td>MS</td>
</tr>
<tr>
<td>Oat</td>
<td>Avena sativa</td>
<td>Grain yield, Straw DW</td>
<td>--, --</td>
<td>--, --</td>
<td>T, T</td>
</tr>
<tr>
<td>Safflower</td>
<td>Carthamus tinctorius</td>
<td>Seed yield</td>
<td>--</td>
<td>--</td>
<td>T</td>
</tr>
<tr>
<td>Tomato</td>
<td>Lycopersicon lycopersicum</td>
<td>Fruit yield</td>
<td>2.5</td>
<td>9.0</td>
<td>MS</td>
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<tr>
<td>Walnut</td>
<td>Juglans</td>
<td>Foliage injury</td>
<td>--</td>
<td>--</td>
<td>S</td>
</tr>
<tr>
<td>Wheat</td>
<td>Triticum aestivum</td>
<td>Grain yield, Shoot DW</td>
<td>6.0, 4.5</td>
<td>7.1, 2.6</td>
<td>MT, MT</td>
</tr>
</tbody>
</table>

Values of threshold = \( a \) and slope = \( b \) in above equation
Relative salt tolerance ratings: (S) sensitive, (MS) moderately sensitive, (MT) moderately tolerant, and (T) tolerant.
Steady-state models for soil salinity management

- Bernstein (1964): $L_r = \frac{EC_i}{EC_{e50}}$
  (consistently overestimates $L_r$)

- Bernstein and Francois (1973b) & van Schilfgaarde (1974):
  $L_r = \frac{EC_i}{2*EC_{e0}}$
  (consistently underestimates $L_r$)

- Rhoades (1974):
  $L_r = \frac{EC_i}{5*EC_{et} - EC_i}$
  (reasonable at low $L_r$, overestimates severely at high $L_r$)

- Rhoades and Merrill (1976):
  $L_r = \frac{EC_i}{EC_{e40-30-20-10}}$
  (large swings between over/underestimating $L_r$)

- Hoffman and van Genuchten (1983):
  $C/C_a = \frac{1}{L} + \frac{\delta/Z \times L}{L + (1 - \exp(-Z/\delta)) - 1.73}$
  (correlates best with measured $L_r$ - underestimates at high $L_r$)

$C = \text{salt conc. of soil saturated extract}$

Salt Tolerance of Crops in the Southern Sacramento-San Joaquin Delta, Hoffman, 2010
### Forage grasses

<table>
<thead>
<tr>
<th>Crop</th>
<th>Experimental Results</th>
<th>Lr Prediction Using</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lr</td>
<td>ECi</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>0.20</td>
<td>2.0</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>0.32</td>
<td>4.0</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>0.06</td>
<td>1.0</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>0.15</td>
<td>2.0</td>
</tr>
<tr>
<td>Barley</td>
<td>0.13</td>
<td>2.2</td>
</tr>
<tr>
<td>Cowpea</td>
<td>0.17</td>
<td>2.2</td>
</tr>
<tr>
<td>Fescue</td>
<td>0.10</td>
<td>2.0</td>
</tr>
<tr>
<td>Fescue</td>
<td>0.25</td>
<td>4.0</td>
</tr>
<tr>
<td>Oat</td>
<td>0.17</td>
<td>2.2</td>
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<tr>
<td>Sudan Grass</td>
<td>0.16</td>
<td>2.0</td>
</tr>
<tr>
<td>Sudan Grass</td>
<td>0.31</td>
<td>4.0</td>
</tr>
</tbody>
</table>

### Cereals

<table>
<thead>
<tr>
<th>Crop</th>
<th>Experimental Results</th>
<th>Lr Prediction Using</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lr</td>
<td>ECi</td>
</tr>
<tr>
<td>Barley</td>
<td>0.10</td>
<td>2.2</td>
</tr>
<tr>
<td>Oat</td>
<td>0.10</td>
<td>2.2</td>
</tr>
<tr>
<td>Sorghum</td>
<td>0.08</td>
<td>2.2</td>
</tr>
<tr>
<td>Wheat</td>
<td>0.07</td>
<td>1.4</td>
</tr>
<tr>
<td>Wheat</td>
<td>0.08</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Salt Tolerance of Crops in the Southern Sacramento-San Joaquin Delta, Hoffman, 2010
Graphical solution of model exponential uptake function

Dry bean response at various leaching rates

Salt Tolerance of Crops in the Southern Sacramento-San Joaquin Delta, Hoffman, 2010
Factors affecting performance of existing transient models

- Appropriate water uptake function
- Feedback mechanism for soil-water status, plant growth & transpiration
- Allows additional water uptake from non-stressed region of root zone.
- Accounts for salt precipitation/dissolution
- Can be compared to field experimental data

<table>
<thead>
<tr>
<th>Factor</th>
<th>Grattan</th>
<th>Corwin</th>
<th>Simunek</th>
<th>Letey</th>
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</thead>
<tbody>
<tr>
<td>Water uptake function</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Feedback mechanism</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Water uptake based on stress</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Salt precipitation / dissolution</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Field tested</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Limitations of existing transient hydrosalinity models

- Poor or non-existent documentation
- Developed and more appropriate for use by the research community
- Poorly designed or non-existent graphical user interfaces
- Few are validated with field data
- Very few being used for day-to-day salinity management
- Difficult to make direct comparisons with more widely accepted steady-state models (Hoffman model)
Graphical user interface for CSUID/Hoffman model
Organization of the CSUID/Hoffman model GUI
Data input screens in CSUID/Hoffman GUI

Simulation timespan

- Select Start and End dates

NB: Simulation duration is only slightly influenced by timespan (small timespan → short simulation)

Crop Editor

- Enter crop parameters (growth coefficients, key dates)
- If multiple cuts/harvest (e.g. alfalfa), add ‘Growing seasons’, with different coefficients

Input format

For ET, Irrigation, Rain, Temperature and Radiation:
- Prepare Excel files following the example of the input window
- Check if properly loaded with ‘Plot data’ button
Graphical solution of model exponential uptake function

For valid comparisons between crop yields computed using either the CSUID or Hoffman models, there is a need to reconcile calculations of root zone salinity. Most crop yield models base their calculation on the soil root zone salinity extract (ECe), while the CSUID model computes salinity of the liquid phase to produce ECsw. In order to be able to make direct comparisons between the two model outputs - ECsw was converted to ECe using the standard conversion of ECsw = 0.5 ECe. To account for variations in the conversion ratio – two additional fixed conversions of ECe = 1.5 ECsw and ECe = 2.5 ECsw were created and added to the user interface.
Graphical solution of model exponential uptake function

- CSUID model currently limited to 2 year simulation (730 days)
- Hoffman spreadsheet model requires trial and error solution – model develops response surface automatically
- Can select leaching fractions to input into the Hoffman model or use those calculated by CSUID.
- Can adjust $EC_e / EC_{sw}$ ratio
- Output graphics customized to allow direct comparison of outputs from CSUID and Hoffman models
Output for Hoffman model from CSUID GUI interface

- Leaching Fraction Calculator
- Project Name: C:sers\icmathlot\Desktop\CSUID\Simul\PWD_V1.I.
- One Dimensional Model Setting:
  - Number of Vertical Layers: 50
  - Start Date: 01-Jan-2015 11:00:00
  - End Date: 31-Jan-2015 11:00:00
  - Number of Plantings: 1
  - Leaching Fraction Calculation
    - Models Settings
      - Hoffman's Model Settings
        - Input
      - CSUID Model Settings
        - CSUID Solver
  - Simulation
    - Choose Simulation Type
  - Output
    - Manage and Visualize Model Outputs

Graph showing Hoffman's Model Output with various lines indicating different scenarios.

- Root Zone Salinity Without Precipitation
- Crop Yield Without Precipitation
- SN Salinity With Precipitation
- Crop Yield With Precipitation
Effect of leaching rate and rainfall on yield response

Figure 5.13a. Relative alfalfa yield (percent) as a function of irrigation water salinity (ECI) with L=0.10 assuming median precipitation (solid lines) and minimum precipitation (dashed lines) from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for water years 1952 through 2008.

Figure 5.13b. Relative alfalfa yield (percent) as a function of irrigation water salinity (ECI) with L=0.15 assuming median precipitation (solid lines) and minimum precipitation (dashed lines) from NCDC station no. 8168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for water years 1952 through 2008.
Soil water salinity vs total annual rainfall by root zone uptake function

Figure 5.11a. Average soil water salinity (ECw) vs. total annual rainfall for alfalfa with leaching fractions ranging from 0.07 to 0.20 and irrigation water (Ei) = 1.0 dS/m using the 40-30-20-10 crop water uptake function from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for the water years 1952 through 2008.

Figure 5.11b. Average soil water salinity (ECw) vs. total annual rainfall for alfalfa with leaching fractions ranging from 0.07 to 0.20 and irrigation water (Ei) = 1.0 dS/m using the exponential crop water uptake function* from NCDC station no. 6168, Newman C (for Crows Landing and Patterson) and NCDC station no. 5738, Modesto C (for Maze) for the water years 1952 through 2008.

CWQRCB. LSJR Salt Tolerance Report, 2016
CSUID GUI flow, EC and salt load model outputs

ROOT ZONE WATER BALANCE

ROOT ZONE EC

ROOT ZONE SALT LOADING
CSUID GUI flow, EC and salt load model outputs
CSUID GUI flow, EC and salt load model outputs
Summary and Conclusions

- Real-time water quality (salinity) management will require better understanding of appropriate crop leaching rates for various irrigation application water salinities.
- Steady-state models have been used successfully for planning studies but have limitations as decision support systems at the watershed level.
- Existing transient salinity models have limited utility given their lack of documentation, graphical user interfaces and limited visualization.
- The CSUID-Hoffman model addresses these deficiencies – provides greater decision support capability.
- Model currently being applied to investigate long-term yield declines in alfalfa and Jose tall wheat grass in Panoche Water District.