Climate Change Impacts on Subsurface Hydrology, Crop Production, Water Use, and Salinity in San Joaquin Valley, CA

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Objectives: 5-year modeling & sensitivity study

▶ Develop and apply hydro-salinity model capable of predicting long-term impact of water and land management decisions at the basin scale - few slides;

▶ Retrospective of a 60-year reconstruction (simulation) of historical changes (since 1940) in groundwater levels, and soil and groundwater salinity - few slides;

▶ Evaluate impacts of 100 years of climate change on crop water requirements, soil and groundwater salinity – focus of today.
Regional flow domain (Belitz et al., 1993) of western San Joaquin Valley

Three-dimensional model domain, bounded by Corcoran clay at the bottom

Groundwater pumping both above (unconfined) and below (confined) clay

- 1,400 km²
- 13 Water Districts

Crop map
Soil map
MOD-HMS: Variably-saturated flow equation

Vadose zone is fully coupled with groundwater

\[
\frac{\partial}{\partial x} \left( K_{xx} k_{rw} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( K_{yy} k_{rw} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left( K_{zz} k_{rw} \frac{\partial h}{\partial z} \right) - W = n \frac{\partial S_w}{\partial t} + S_w S_s \frac{\partial h}{\partial t}
\]

\[
S_e = \frac{S_w - S_{wr}}{1 - S_{wr}} = \frac{1}{\left[ 1 + (\alpha |\psi|)^\beta \right]^\gamma} \quad \text{for} \quad \psi < 0 \quad k_{rw} = S_e^b
\]

Hydraulic parameters, estimated from neural network analysis, using Rosetta
Comparison of measured with simulated groundwater pumping in Westland’s water district

Effect of droughts on groundwater pumping

Groundwater pumping (m/yr)

Year

Simulation results

Effect of droughts on groundwater pumping
Reconstruct Ground Water Table from 1950-2000

Comparison of observed and simulated water table depth maps;
brown: > 30 m, red: 16-30 m, yellow: 7-16 m, green: 3-7 m,
light blue: 2–3 m, blue: < 2 m.
Reconstruct Historical Soil and Groundwater salinity from 1940-2000

Couple MODHMS with UNSATCHEM and simulate simultaneous transport of 7 major ions: Ca, Mg, Na, K, HCO$_3$, SO$_4$, and Cl using 3-D CDE

Pre-development soil salinity

Between Alluvial Fans
Reconstruct Root zone salinity dynamics

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</thead>
<tbody>
<tr>
<td><strong>Average root zone</strong></td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
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<td><strong>Shallow groundwater</strong> (6 m depth)</td>
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<td><strong>Deep groundwater</strong> (20-60 m)</td>
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EC (dS/m)

- > 16
- 12 - 16
- 8 - 12
- 4 - 8
- 2 - 4
- < 2

Schoups et al., PNAS, 2005
Percent Snow remaining for 2050, as compared to current average snow water equivalent.

A1FI – rapid economic growth, peak population in 2050 and rapid introduction of new technologies, however, fossil intensive.

B1 – same population as A1, but rapid changes in economic structures towards service and information economy.

A2 – same population growth, but slow economic development and technological changes.

B1 – highest rainfall and smallest temperature increase
A1FI – lowest rainfall and largest temperature increase
Climate Modeling in SJV – requires downscaling
Statistical Down-scaling

1. Select future atmospheric greenhouse gas scenarios
2. Select GCM’s
3. Bias Correct and Downscale GCM Model Output to model domain
4. Forecast ET and precipitation

PCM sensitivity is 2.1 °C
Hadley sensitivity is 3.3 °C

Figure Adapted from Cayan and Knowles, SCRIPPS/USGS, 2003 by Levi Brekke
Future Temperature, $\text{ET}_{\text{ref}}$, and precipitation (30-year moving averages)
Seasonal crop response to climate change ($ET_{\text{crop}}$)

$k_c$ : Crop Coefficient

$$ET_{\text{crop}} = \text{Sum}[k_c \times ET_{\text{ref}}]$$

- **Effect of increased CO$_2$**: not so clear, crop-dependent, e.g. C$_3$ (cotton, tomato, and vegetables) versus C$_4$ (sorghum, corn)
  - More biomass production, leaf area and photosynthesis
  - However, off set by stomata closure
  - $k_c$ is independent of climate change

- **Effect of increased temperature**
  - Faster plant development, shorter growing season
  - Temperature changes affects $ET_{\text{ref}}$
  - Possible heat stress for some crops
Seasonal ET:
Higher ET_{ref} is offset by shorter growing season
Effect of Climate Change on Surface Water (SW) supply, down-scaled for each water district.....

Correlate precipitation to water supply (sw) from historical data (pink) and from Vicuna et al (2006) model projections (red)

\[ y = 0.6843x - 6.5925 \]

\[ R^2 = 0.7631 \]
Management Responses: $IR = SW + GW$

(\text{IR:} \text{Irrigation Requirement, SW: Surface- and GW: Ground-Water})

\[ IR = (ET - \text{Precip}) / \text{Irr Eff} \]

- Increase groundwater pumping, \( GW \):
  - controlled by existing wells,
  - quality of local groundwater, and
  - pumping costs
  - causes irreversible land subsidence
  - affects soil salinity.

- Reduce irrigation requirement, \( IR \):
  - land fallowing and retirement
  - change cropping pattern,
  - develop heat/water resistant cultivars
  - improve irrigation technology/efficiency
Effect of climate change on groundwater pumping: Compare climate change scenarios with current and 90% irrigation efficiency (IE)
Effect of climate change on shallow groundwater extent: Compare scenarios with current and 90% irrigation efficiency (IE)
Projection of effect of climate change on soil salinity –
Average soil EC > 4 dS/m (top 7 feet)

<table>
<thead>
<tr>
<th>Year</th>
<th>Salt-affected area (in 0.25 mi²)</th>
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<tr>
<td></td>
<td>Observed</td>
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<tr>
<td></td>
<td>hadcm3_sresa1fi</td>
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<tr>
<td></td>
<td>hadcm3_sresa2</td>
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<td>hadcm3_sresb1</td>
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<td>pcm_sresa1fi</td>
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<td>pcm_sresa2</td>
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<td>pcm_sresb1</td>
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<td>hadcm3_sresa1fi_IE</td>
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<tr>
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<td>no_climate_change</td>
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</tbody>
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Nutrient loss from soils can be quantified using:

- B1
- A1Fi - IE=90%

Land Area affected

historical
Effect of climate change on tomato yield
(Colored areas depict yield decrease of 50% or more)
Assessment of Climate Warming:

- Annual crop water demand might be reduced by faster crop development;
- Large uncertainty in precipitation and water supply projections;
- Regardless of climate change, soil and groundwater salinity will continue;
- Land subsidence will be very limited;
- Irrigation community will respond by
  - Increasing acreage of land fallowing and retirement
  - Augment crop water requirement by groundwater pumping
  - Improve irrigation efficiency
  - Shift to high-value and salt-tolerant crops


Additional work is required on quantifying uncertainties in projected climate change predictions and impacts.
Proposed UCD-DWR Lysimeter study
The goal of this IGERT is to train graduate students that are both deeply competent in one or more specific disciplines and broadly conversant in the multiple disciplines that determine the ultimate effects of climate change on society and the natural world.

Key interfaces of this IGERT denoted in red.
Effect of climate change on salt load (dissolved) to groundwater: Cumulative salt load, Million Tons of salt

Blue-green-yellow-red (high to low)

Groundwater pumping

Salt load below root-zone (in million tonnes)

Year

No climate change

A1Fi - IE=90%

historical