Parameter Identification of Large-Scale Spatially-Variable Vadose Zone Properties using Global Optimization:

50-year Reconstruction of Salinity Changes in the SJV

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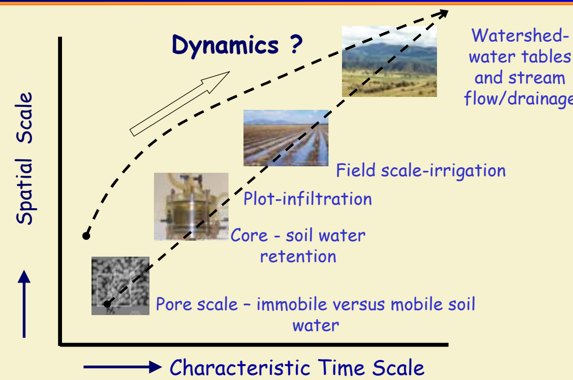
San Joaquin Valley, SJV

Vadose Zone Flow & Transport

Spatial & Time scales



San Joaquin Valley: Irrigated Agriculture

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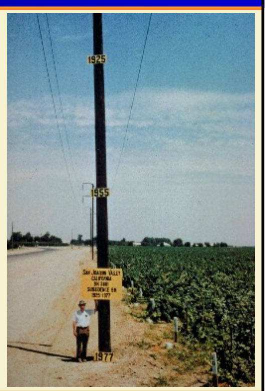
San Joaquin Valley: Issues

- Agricultural sustainability is threatened
  - →shallow water tables
  - →soil and groundwater salinization
  - →limits on drainage discharge from agriculture
    (selenium in Kesterson wetlands)
- Management options
  - →Groundwater pumping
    (subsidence, salinization of production wells)
  - →Drainage re-use
  - →Increase irrigation efficiency

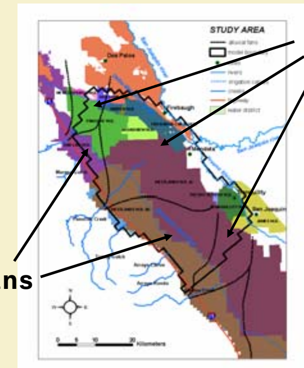
San Joaquin Valley: Issues



Objectives

- Develop a subsurface water flow and salt transport model capable of predicting <u>long-term</u> impact of water and land management decisions on hydrologic system
  - →Groundwater levels, drainage
  - →Soil and groundwater salinization
- 50-year reconstruction (simulation) of observed changes in groundwater levels, and soil and groundwater salinity at the regional scale

Regional flow domain (Belitz et al., 1993) of western San Joaquin Valley



Alluvial fans

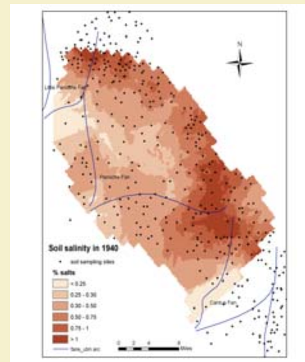
Interfans

- 1,400 km²
- 13 Water Districts (WD)

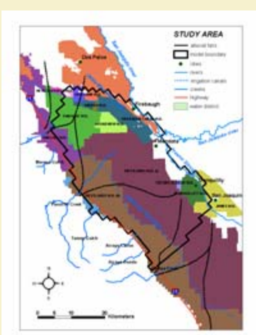
Regional Variably-Saturated Flow and Transport

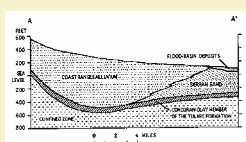
Optimization of regional variably-saturated water flow model – 1,400 km² of western San Joaquin Valley

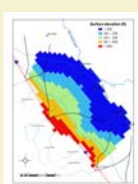
to reconstruct historical soil salinity in the San Joaquin Valley for a 57-year period



Regional flow domain (Belitz et al., 1993) of western San Joaquin Valley

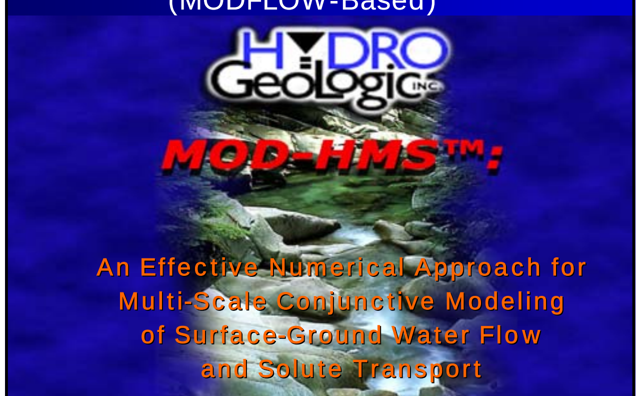






- 1,400 km²
- 13 Water Districts (WD)

3D-Simulation Model – Beta version (MODFLOW-Based)



Model Calibration Procedure

- Identify model calibration parameters;
- Simulate soil hydrology using MOD-HMS,;
- Optimize model parameters using SCEM, by matching observed with measured groundwater tables, groundwater pumping and drainage for 12-year period;
- Use optimized parameters to simulate 50-year soil and shallow groundwater salinity;

Shuffled Complex Evolution Metropolis (SCEM)

SCE → *Vrugt, Gupta, Bouten & Sorooshian WRR 2003* → SCEM

- ✓Global optimizers
- ✓Controlled random search
- ✓Competitive population evolution
- ✓Complex shuffling

- **Result:** Most likely parameter set , including its uncertainty, from posterior probability distribution

Numerical grid for MOD-HMS

- Horizontally
  - Study area discretized into 0.5x0.5 mi grid cells, i.e. typical field size
- Vertically
  - Root-zone (0-2 m): 7 layers, each 0.3 m
  - Semi-confined aquifer: 10 layers, variable thickness up to Corcoran clay

MOD-HMS: Variably-saturated flow equation

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

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

Hydraulic parameters, estimated from neural network analysis, using Rosetta

Hydraulic properties

- Root-zone (0-2 m)
  - Estimated for each soil type using Rosetta
- Semi-confined aquifer (> 2 m)
  - Spatial distribution of grid cell coarse fractions, f_c
  - Determines K_h, K_v and S_f

$$K_{h,v} = \left[K_C^{\omega} f_C + K_F^{\omega}(1-f_C)\right]^{1/\omega} \qquad S_f = S_{f,C} f_C + S_{f,F}(1-f_C)$$

  - S_f determines retention or yield (uniform values for α and β)

Boundary conditions

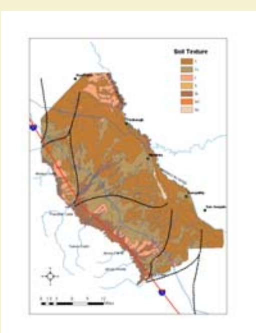
- District-scale data (annual): crop acreages, surface water deliveries
- Downscale to grid cells: (1) random crop assignment, (2) cell-by-cell annual water balance

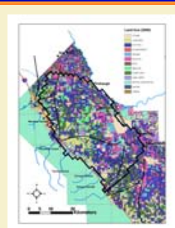
Irrigation requirement $$IR = Max\left\{0, \frac{ET_c - R_{gs}}{IE}\right\}$$

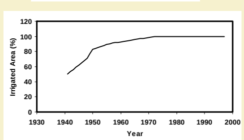
Surface water applied $$SW = IR\frac{SW_d}{\sum_d IR}$$ **Scale to district quantities**

Ground water applied $$GW = Max\{0, IR - SW - DW\}$$

Available data- Soil texture, irrigated area and Crop ET



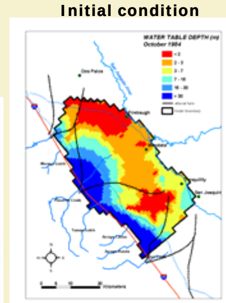




Calibration data

- Annual Drain water for BWD
- Annual Groundwater pumping for WWD
- Annual Groundwater table across region

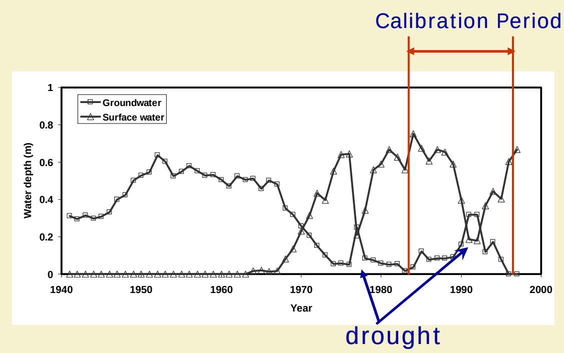
Initial condition



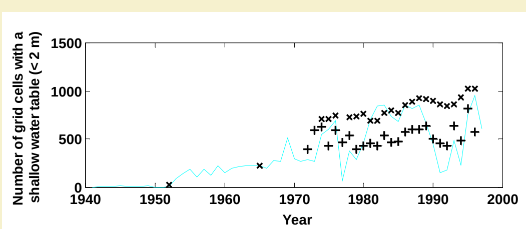
CALIBRATION PARAMETERS-REGIONAL MODEL

Parameter	Description	Units	Min	Max	Prior Distrib
f_{Kc}	Scaling factor K_{coarse}	-	0.5	5	Uniform
K_F	Hydraulic conductivity fine fraction	m/yr	0.3	1.0	Uniform log values
$S_{y,C}$	Specific yield coarse fraction	-	0.05	0.35	Uniform
$S_{y,F}$	Specific yield fine fraction	-	0.05	0.40	Uniform
K_{Corc}	Hydraulic conductivity Corcoran clay	m/yr	0.001	0.10	Uniform log values
f_{ET}	ET correction coefficient	-	0.8	1.2	Uniform
$IE_{shallow}$	Maximum irrigation efficiency	-	0.7	1.2	Uniform
IE_{deep}	Minimum irrigation efficiency	-	0.5	0.8	Uniform
d_e	Drain depth	m	1.5	3.0	Uniform
C_d	Drain conductance	1/yr	0.45	4.5	Uniform

Historical Surface Water and Groundwater Use

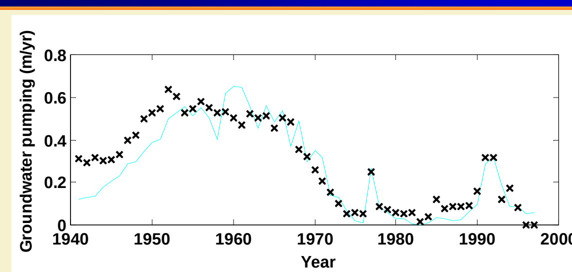


Comparison of simulated with measured shallow water table



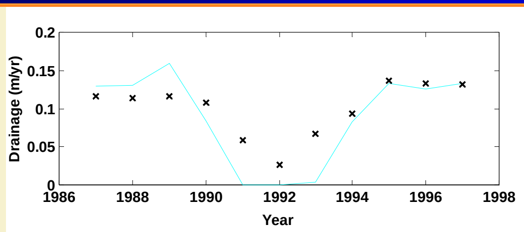
- Long-term trend of gradual increase in shallow water table area due to shift in irrigation water supply from pumped groundwater to imported surface water
- Decline in shallow water table in drought periods of late seventies and early nineties.

Comparison of measured with simulated groundwater pumping in Westland's water district



- Shows effect of droughts on groundwater pumping

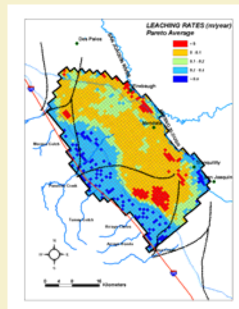
Comparison of measured with simulated drainage in Broadview Water District, since drains were installed



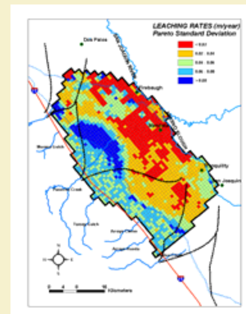
- Shows effect of early nineties drought

Spatially-distributed leaching rates: 1985-1997

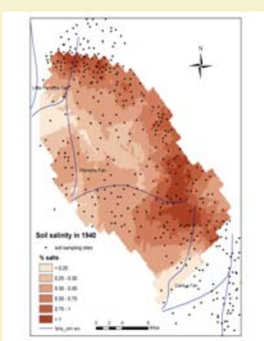
Time-averaged mean



Standard deviation



Next Step: 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

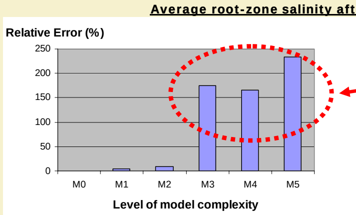
Role of salt chemistry

- Significant amounts of gypsum present;
- Gypsum acts as a source/sink of salts through mineral dissolution/precipitation;
- Nonsaline Na/Cl canal water turns into Na/SO4 saline drainwater;
  - → Dissolution of gypsum into Ca and SO4;
  - → Ca replaces Na on exchange complex (clay).

Role of salt chemistry

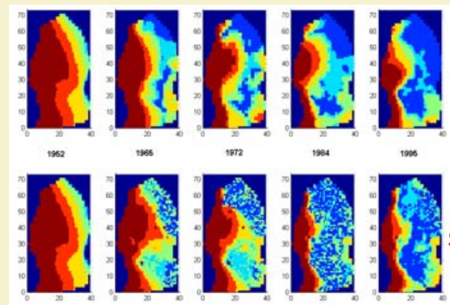
Level of model simplification	Boundary conditions	Nodal spacing (cm)	Cation exchange	Calcite dissolution-precipitation	Ion complexation	Gypsum dissolution-precipitation
M0 - Unsatchem	Daily	1	Yes	Yes	Yes	Yes
M1	Annual	1	Yes	Yes	Yes	Yes
M2	Annual	15	Yes	Yes	Yes	Yes
M3	Annual	15	No	Yes	Yes	Yes
M4	Annual	15	No	No	No	Yes
M5	Annual	15	No	No	No	No

Average root-zone salinity after 10 years



chemistry important

Reconstruct Ground Water Table from 1950-2000

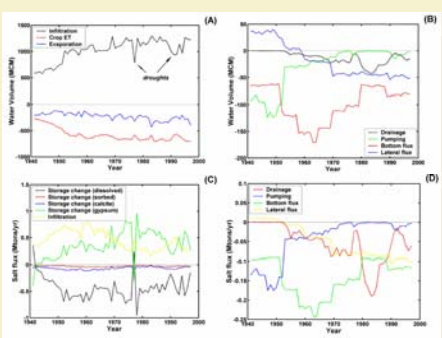


Observed

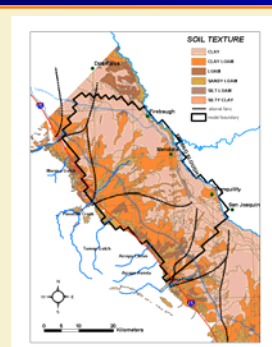
Simulated

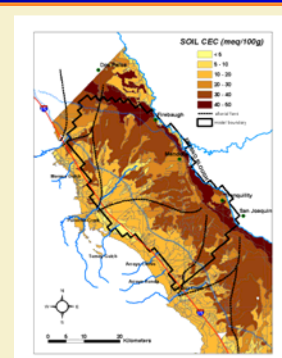
Comparison of observed and simulated water table depth maps; brown: > 30 m, red: 16-30 m, yellow: 7-16 m, green: 3-7 m, light blue: 2–3 m, blue: < 2 m.

Hydrology and salinity dynamics from 1940-1995

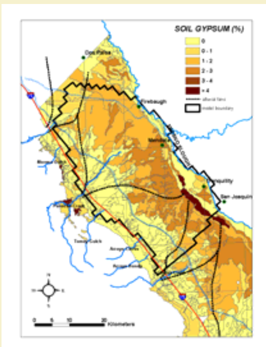


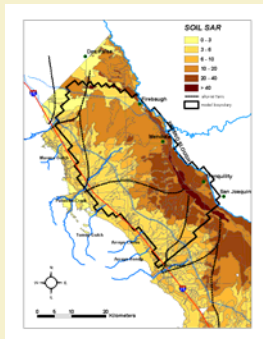
Soil Chemistry





Soil Chemistry





Irrigation Water salinities

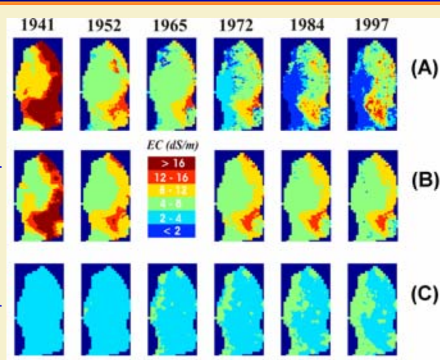
	Type	TDS	SAR *	Ca	Mg	Na
Units		mg/l	$(meq/l)^{0.5}$	meq/l	meq/l	meq/l
Delta-Mendota Canal (DMC)	Na/Cl	319	2.31	1.10	1.25	2.5
California Aqueduct	Na/Cl	308	2.4	0.998	1.234	2.54
Groundwater (sub-Corcoran)	Na/SO_4	1,085	16.82	1.25	0.12	13.92
Rainfall	Na/Cl	1.6	0.36	0.002	0.0032	0.0183
San Joaquin River flood-plain deposits north of Mendota	Na/HCO_3	326	4.09	0.80	0.48	3.27
Kings River flood-plain deposits south of Mendota	Na/HCO_3	414.3	5.71	0.90	0.14	4.12
Panoche Creek	Na/SO_4	4092	7.95	14.92	15.18	30.84

Reconstruct Root zone salinity dynamics

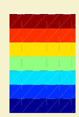
Average root zone

Shallow groundwater (6 m depth)

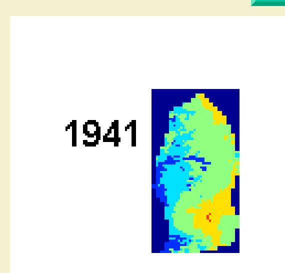
Deep groundwater (20-60 m)



Root zone salinity reconstruction 1941-1998

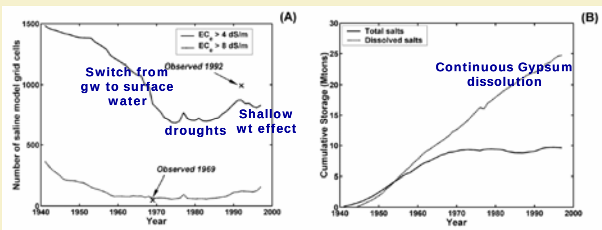


TDS (mg/l)	EC_e (dS/m)
> 10,240	> 16
7,680 – 10,240	12 – 16
5,120 – 7,680	8 – 12
2,560 – 5,120	4 – 8
1,280 – 2,560	2 – 4
< 1,280	< 2
inactive cell	inactive cell

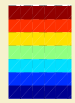


Regional trends in soil salinity

Initial high soil salinity



Root zone salinity: 1992



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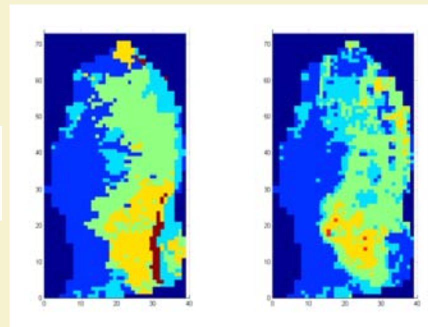
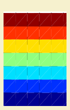
Observed **Simulated**



Shallow water table TDS: 1985



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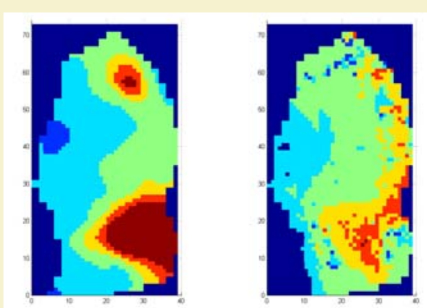
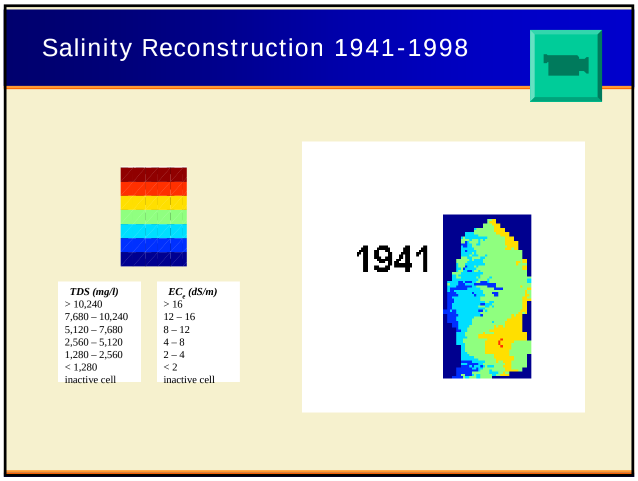


Predicted long-term trends

- Regional water table rises, as irrigation water is switched from local groundwater to imported canal water;
- Initial salt leaching, followed by increase in soil salinity because of development of shallow water table;
- Shallow groundwater salinity dynamics follows soil salinity trends, e.g. droughts;
- No changes in deep groundwater salinity;
- Salt chemistry (gypsum) was highly relevant.



Salinity Reconstruction 1941-1998
TDS (mg/l)
> 10,240
7,680 – 10,240
5,120 – 7,680
2,560 – 5,120
1,280 – 2,560
< 1,280
inactive cell
ECe (dS/m)
> 16
12 – 16
8 – 12
4 – 8
2 – 4
< 2
inactive cell
1941