Modeling Dynamic Network Systems with State-Contingent Penalty Functions

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The Dynamic Network Problem

- Solved by restricted optimizing models
- Two decision aspects
  - The Network problem- allocation over a spatial network within a year
  - The Carryover problem- allocation of states between years with stochastic supplies
- Dimensionality restrictions usually prevent their simultaneous solution
- Optimal spatial dynamic policy requires joint solution

Current Solution Approaches

- Standard Approach to the Network problem
  - Solved by spatial Network Flow Program
  - Stochastic hydrology represented by historical hydrologic sequences
  - Problem.. Spatial monthly allocation is nested within the annual stochastic state allocation problem

- The annual dynamic allocation problem
  - Solved by stochastic dynamic programming
  - Synthetic hydrology
  - Problem.. The curse of dimensionality prevents a realistic spatial specification and dynamic risk and preferences are hard to specify.

A State-Contingent approach

- Managers operate with limited foresight.
  - They know the current stocks and states
  - They know the probability of future water year types.

- State Contingent Calibration.
  - Calibrated to reproduce observed behavior for a set of water year types.
  - Observed behavior reflects the effect of agency risk and intertemporal preferences
  - Having reproduced past water management, we can now optimize under alternative scenarios.

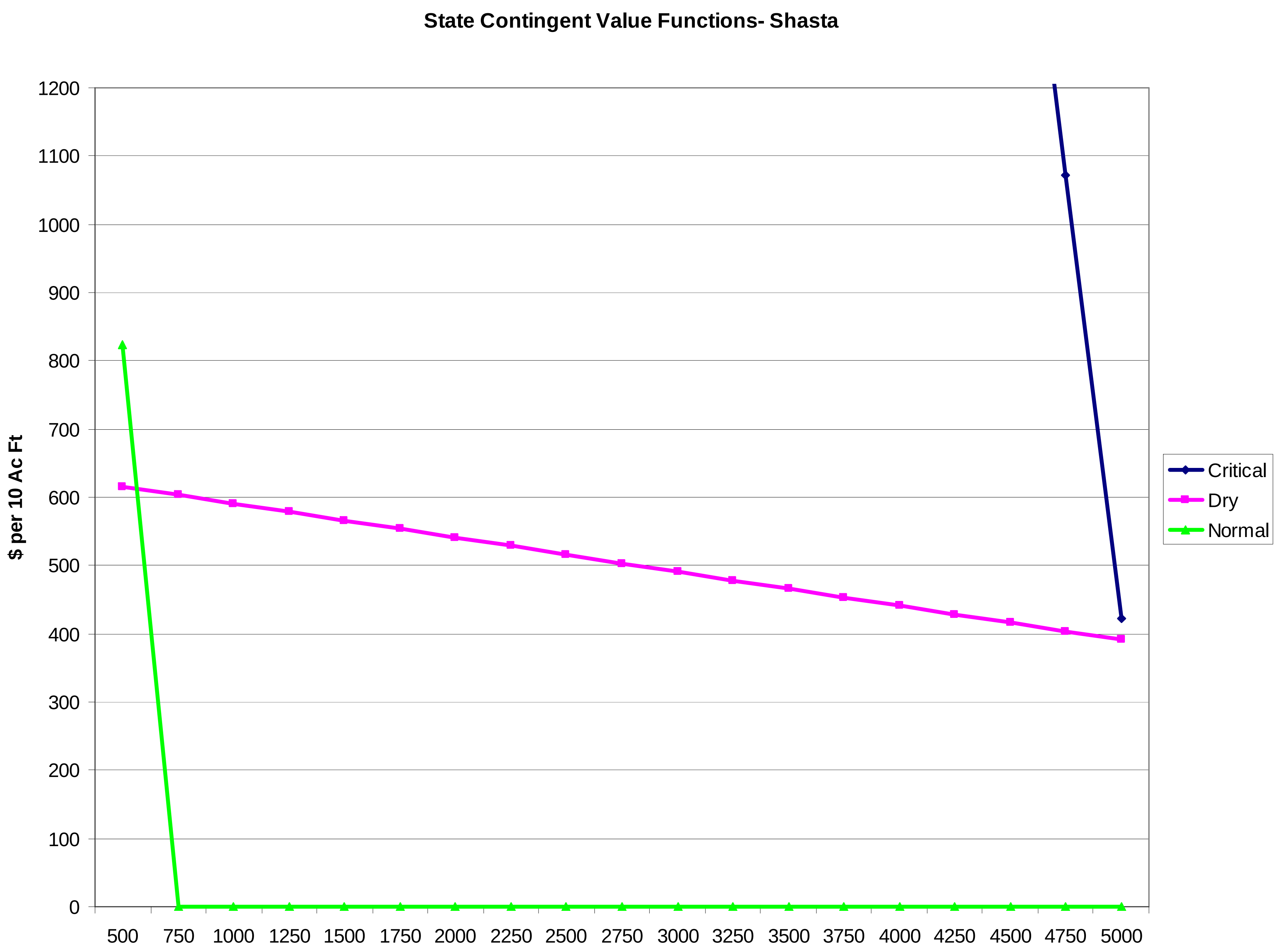
- Two sets of nonlinear (quadratic) calibration functions.
  - Monthly for select spatial calibration nodes
  - Annual for storage carryover values

Modeling Approach

- Characterize a small set of (3-5) years classified as a given water year type.
- Use sets of observed or simulated flows and storage with an objective function and calibration constraints for each year.
- Solve each year and store the lagrangian values for nodal and carryover calibration constraints.
- Obtain the calibration value functions by regressing on the lagrange values for each set of years in each water year type. Impose curvature properties on the estimates.
- Use the calibration values to simulate spatial dynamic decisions by solving recursively linked annual optimization problems- one year Bellman solution.

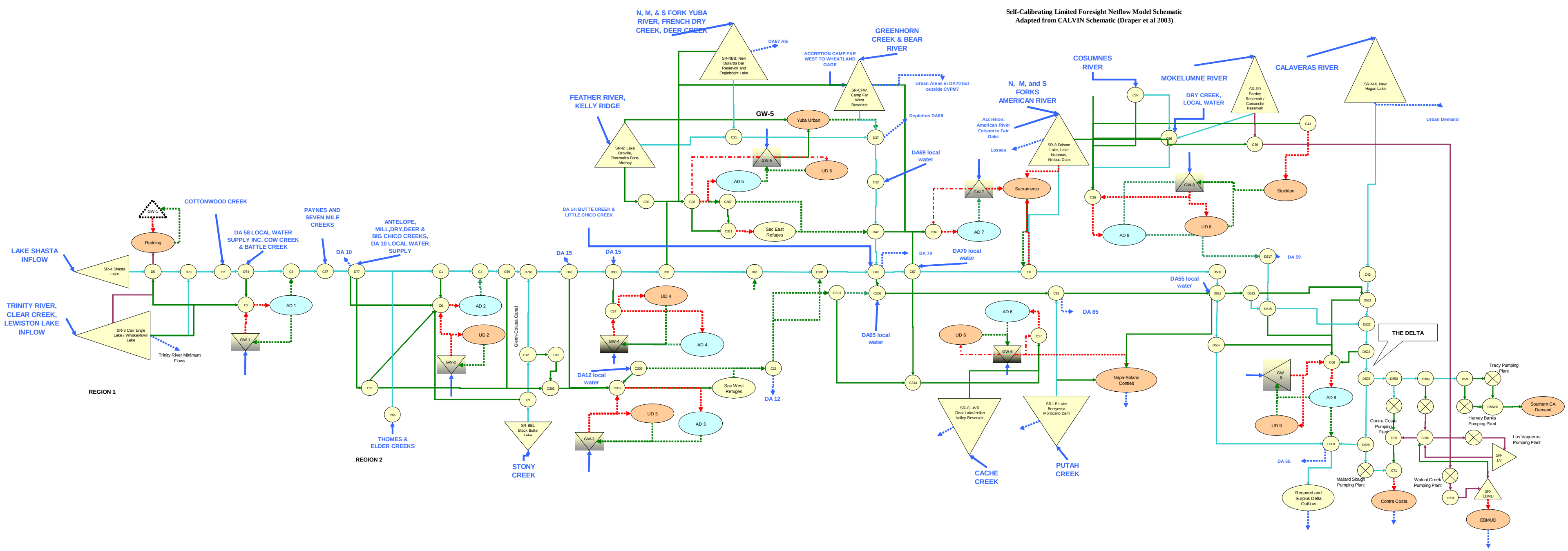
Case Study- The Northern California Water network

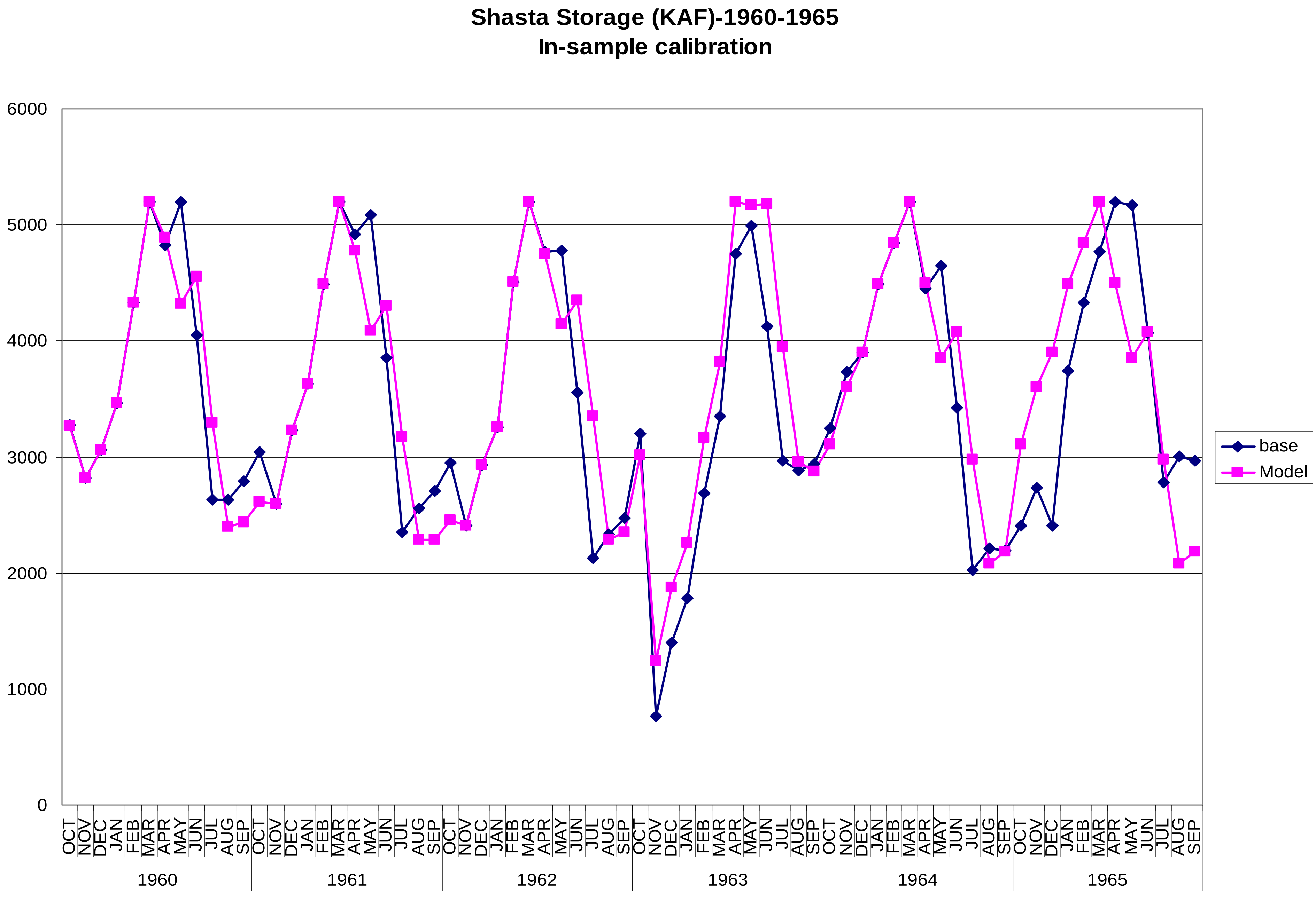
- 124 nodes, 211 arcs
- 13 reservoirs, 9 groundwater basins
- 15 Urban demand points, 9 agricultural demand points.
- 72 years simulated hydrology
- Eight years used for calibration between 1960-1980- normal, dry and drought years.



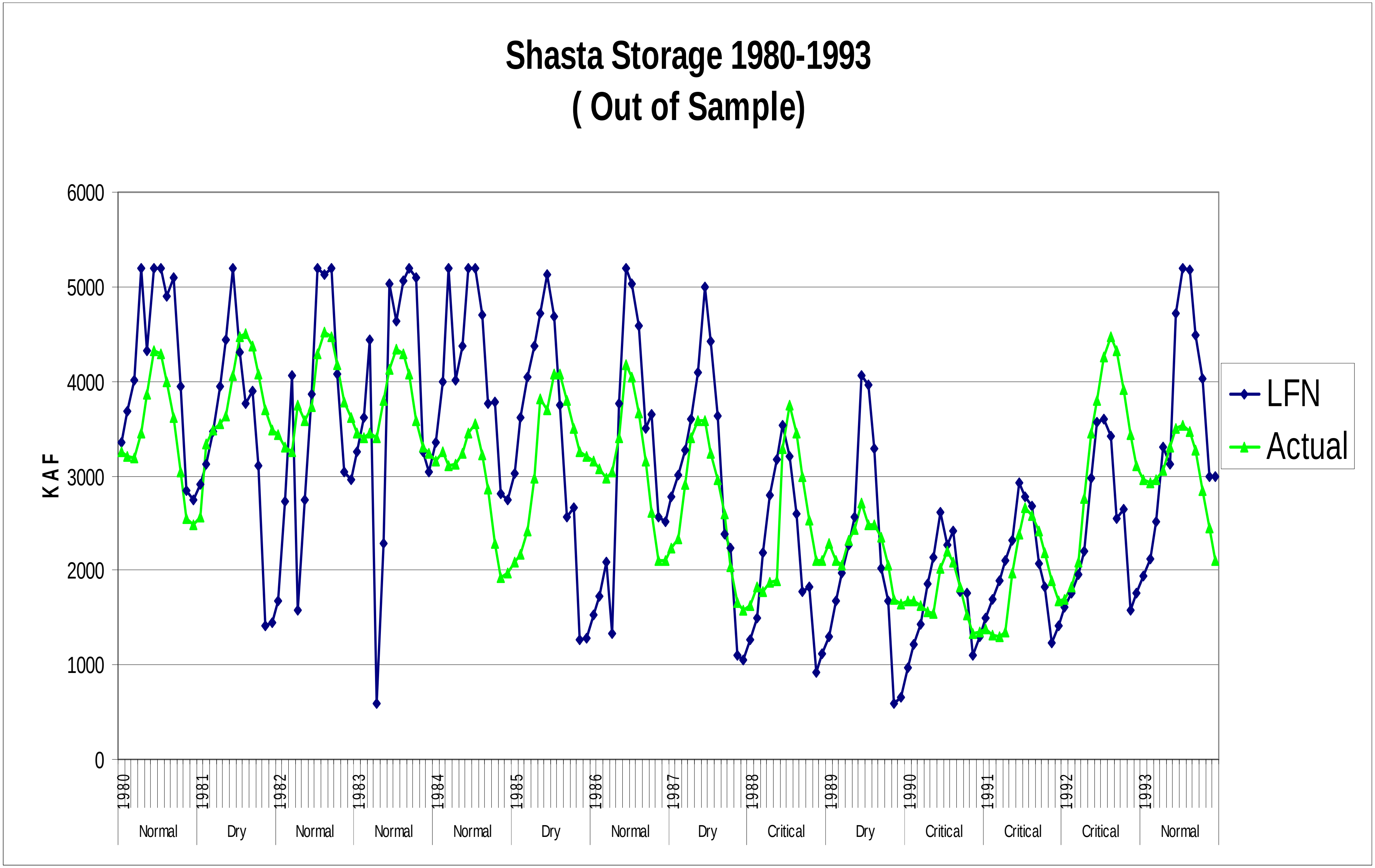
State Contingent Value Functions- Shasta
$ per 10 Ac Ft
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
3250
3500
3750
4000
4250
4500
4750
5000
Critical
Dry
Normal

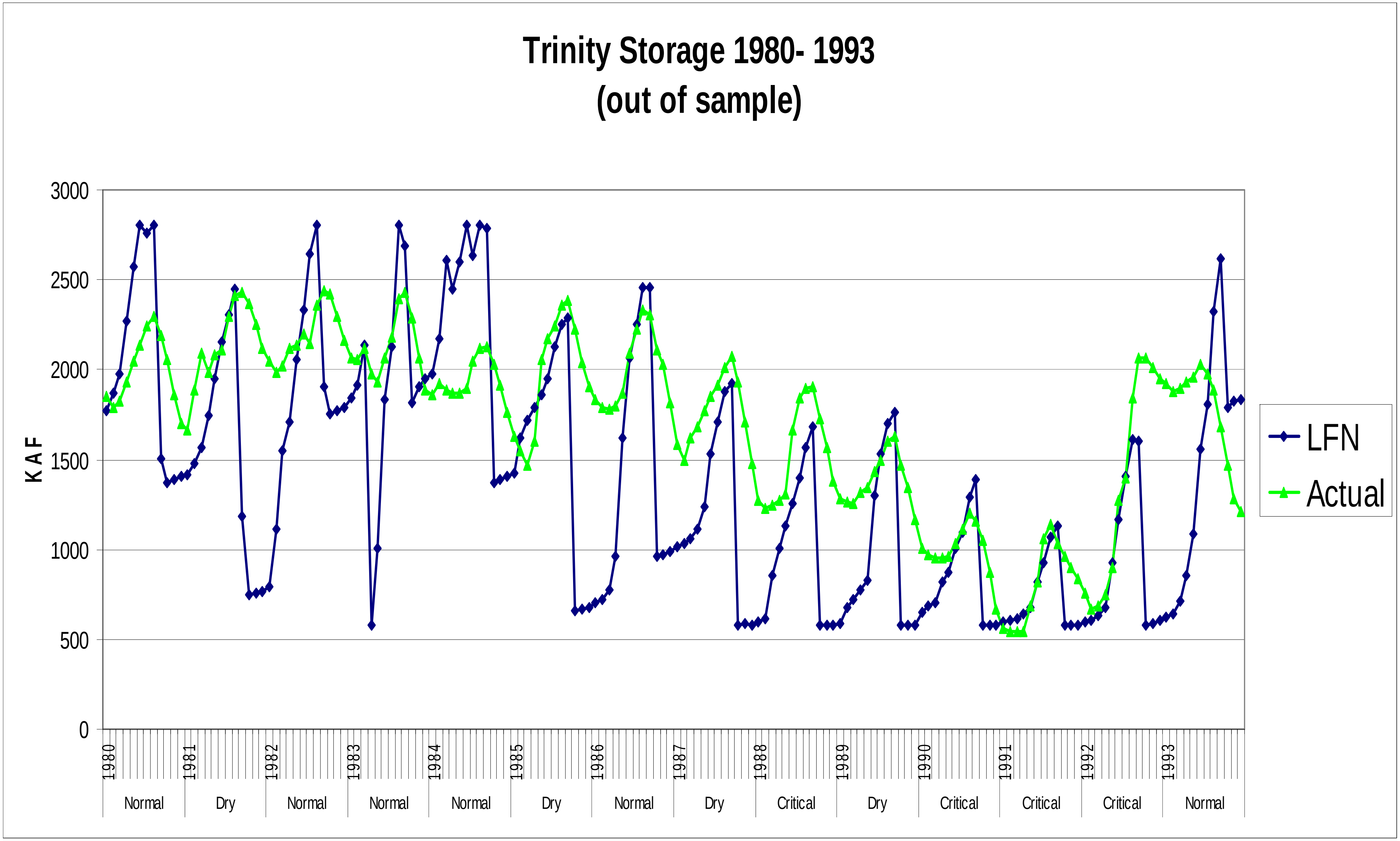
Sacramento Valley Water network

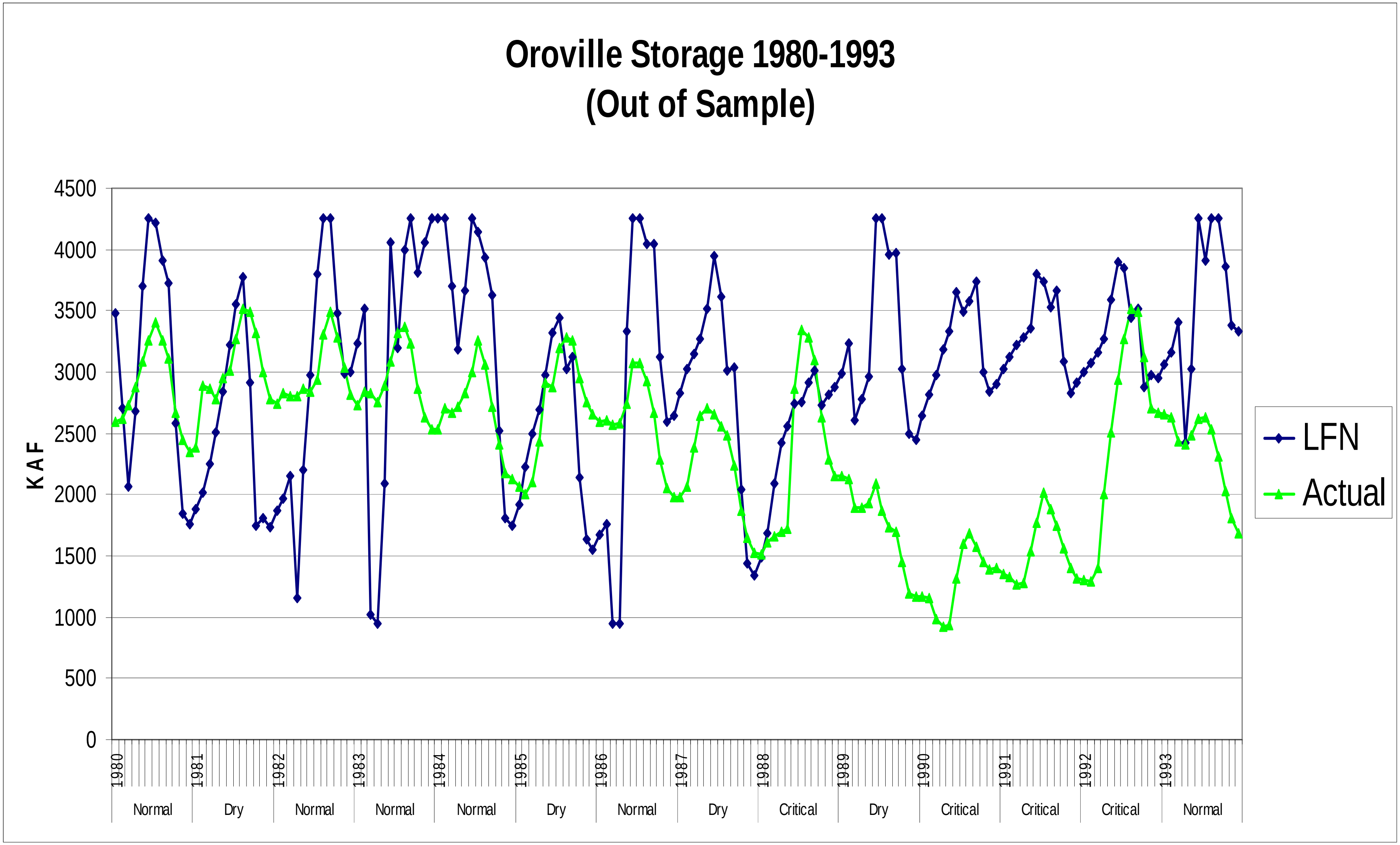




Shasta Storage (KAF)-1960-1965
In-sample calibration
6000
5000
4000
3000
2000
1000
0
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP
1960
1961
1962
1963
1964
1965
base
Model


Shasta Storage 1980-1993
(Out of Sample)
K A F
6000
5000
4000
3000
2000
1000
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
Normal
Dry
Normal
Normal
Normal
Dry
Normal
Dry
Critical
Dry
Critical
Critical
Critical
Normal
LFN
Actual


Trinity Storage 1980- 1993
(out of sample)
K A F
3000
2500
2000
1500
1000
500
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
Normal
Dry
Normal
Normal
Normal
Dry
Normal
Dry
Critical
Dry
Critical
Critical
Critical
Normal
LFN
Actual



Oroville Storage 1980-1993
(Out of Sample)
K A F
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
Normal
Dry
Normal
Normal
Normal
Dry
Normal
Dry
Critical
Dry
Critical
Critical
Critical
Normal
LFN
Actual

Computation times

- Calibration and Estimation time- 3 year types- 8 years in total–

  Desktop Time 14.6 minutes

- Simulation time desktop – 5.4 minutes/year average– 14 (1980-93) years 1.25 hours .

Solution times are comparable or faster than static linear programming network program solutions.

Spatial Dynamic Conclusions

- The contingent calibrated functions are able to model spatial dynamic problems using recursive optimization.
- The model reservoir and groundwater management responds well to different year types, particularly drought years.
- Solution times make recursive optimization models a practical tool for dynamic network problems.

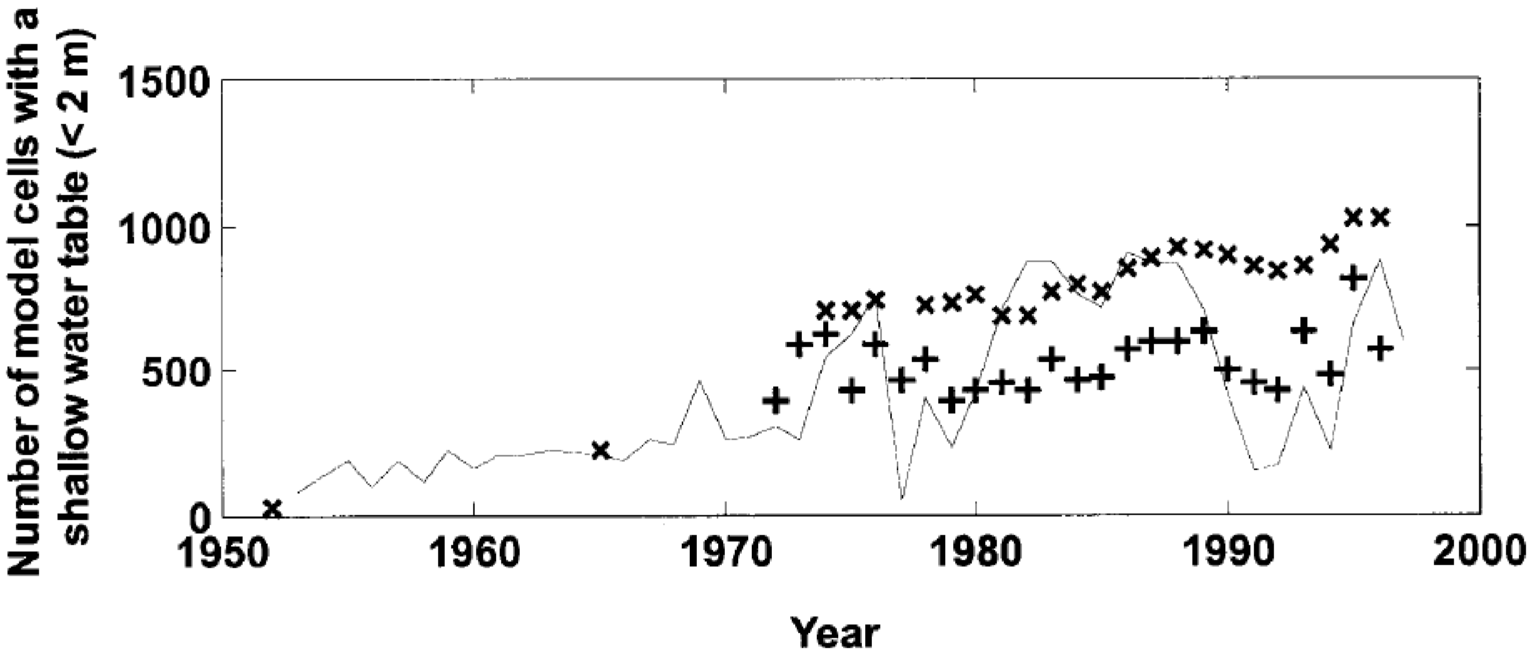
Salinity Projections 2004- 2030

- Sources--- Shoups & Hopmans 2005, Shoups(2004), Orlob(1991), San Joaquin Valley Drainage report(1990) “Rainbow Report”.
- Average annual net salt increase 499,000 tons
- Change in salt affected area- Shoups (2004)

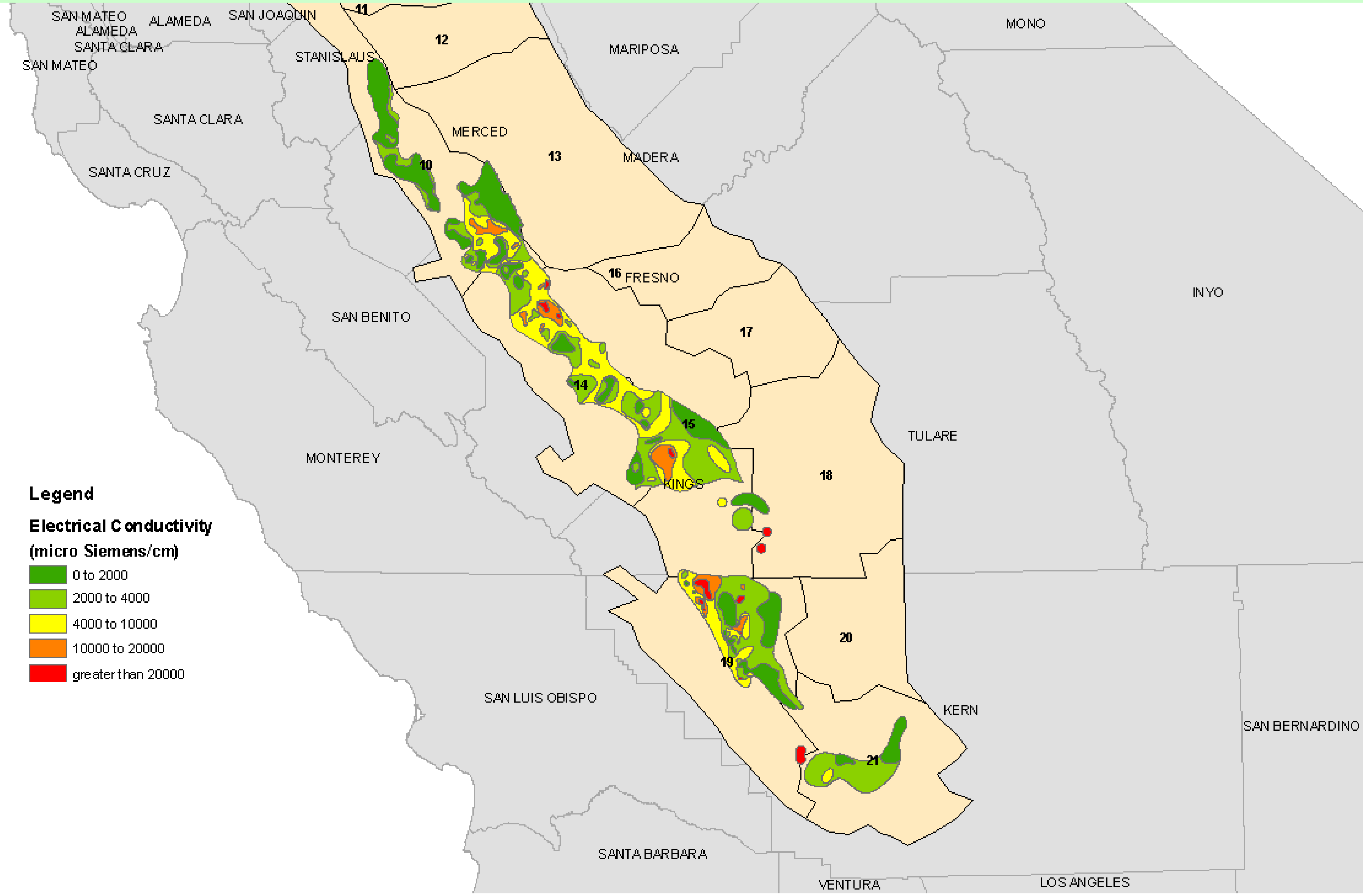
  0.5% / year- Increase of 240,000 acres (13%) by 2030
- Salinity levels and areas- DWR SJ Valley Drainage Monitoring Program 2001- Plate 1.
- 5 salt levels in shallow saline water. Current salt affected area 1.85 million acres
- Deep aquifer salinity accumulation Shoups & Hopmans 2005 50% percolation– net average aquifer salinity change 2004- 2030—264mg/L – 343 mg/L.

Relative change in the shallow groundwater table

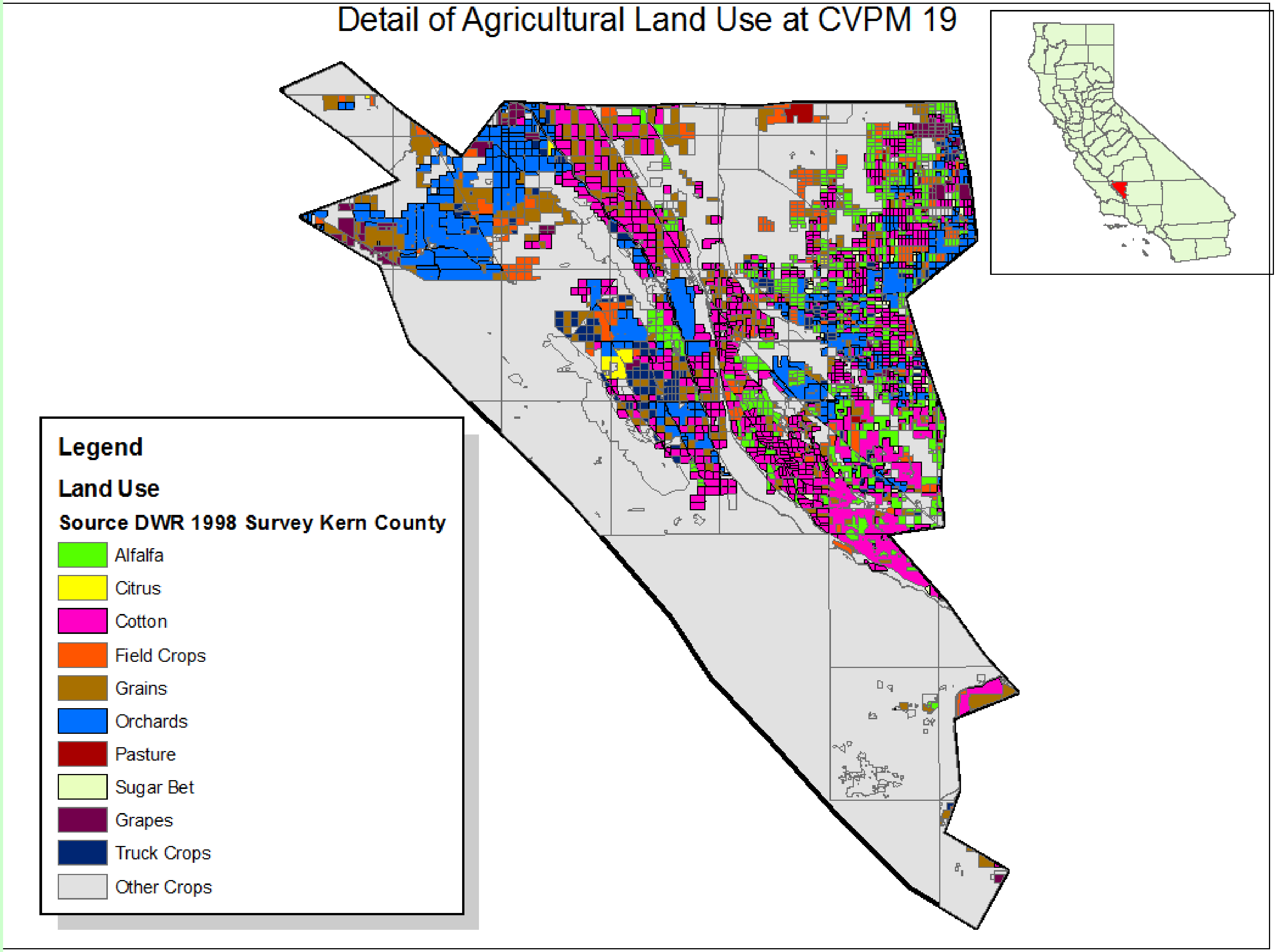
(0.46 - 0.58% /pa-- Shoups 2004).



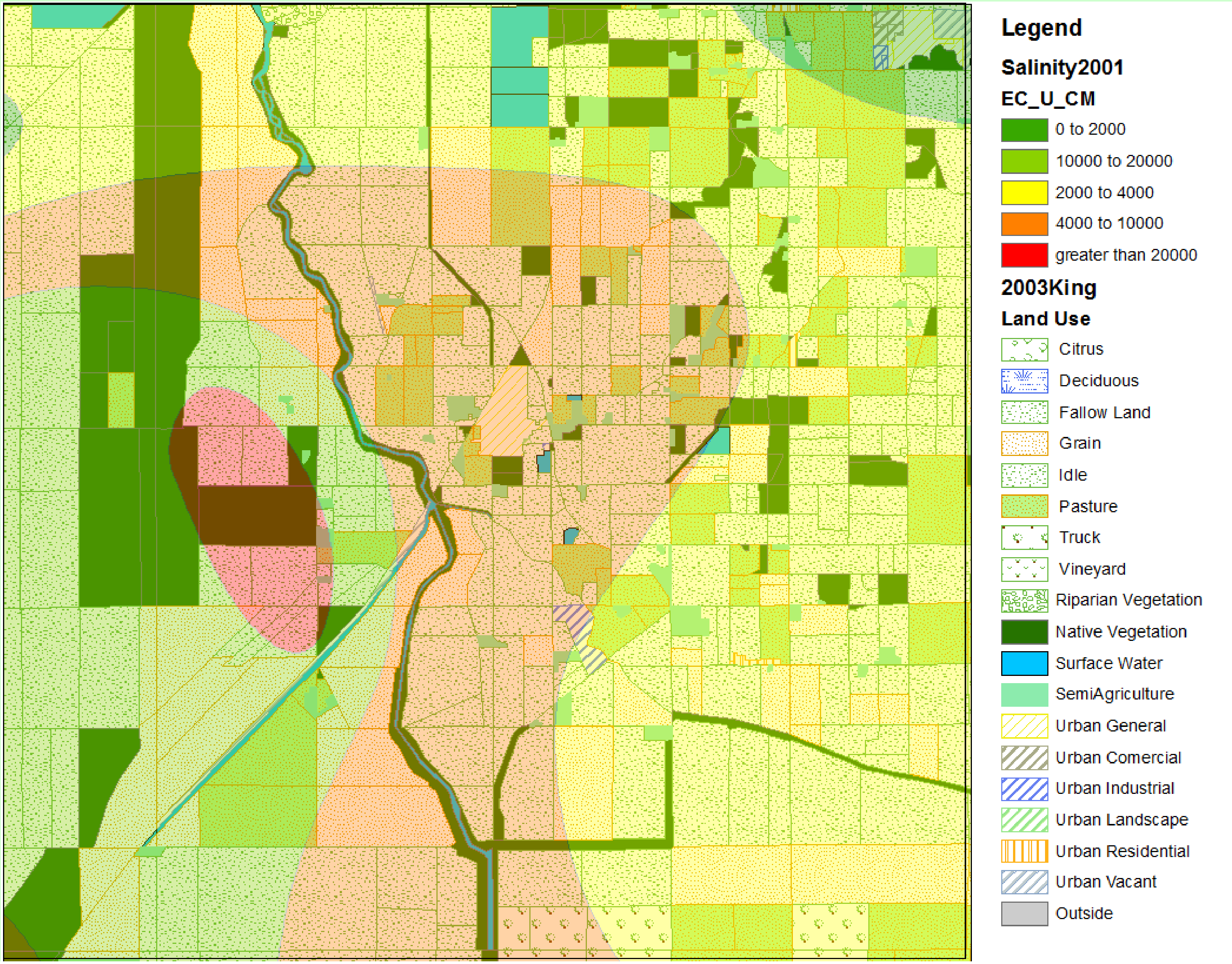
Saline Affected Areas (DWR 2001)



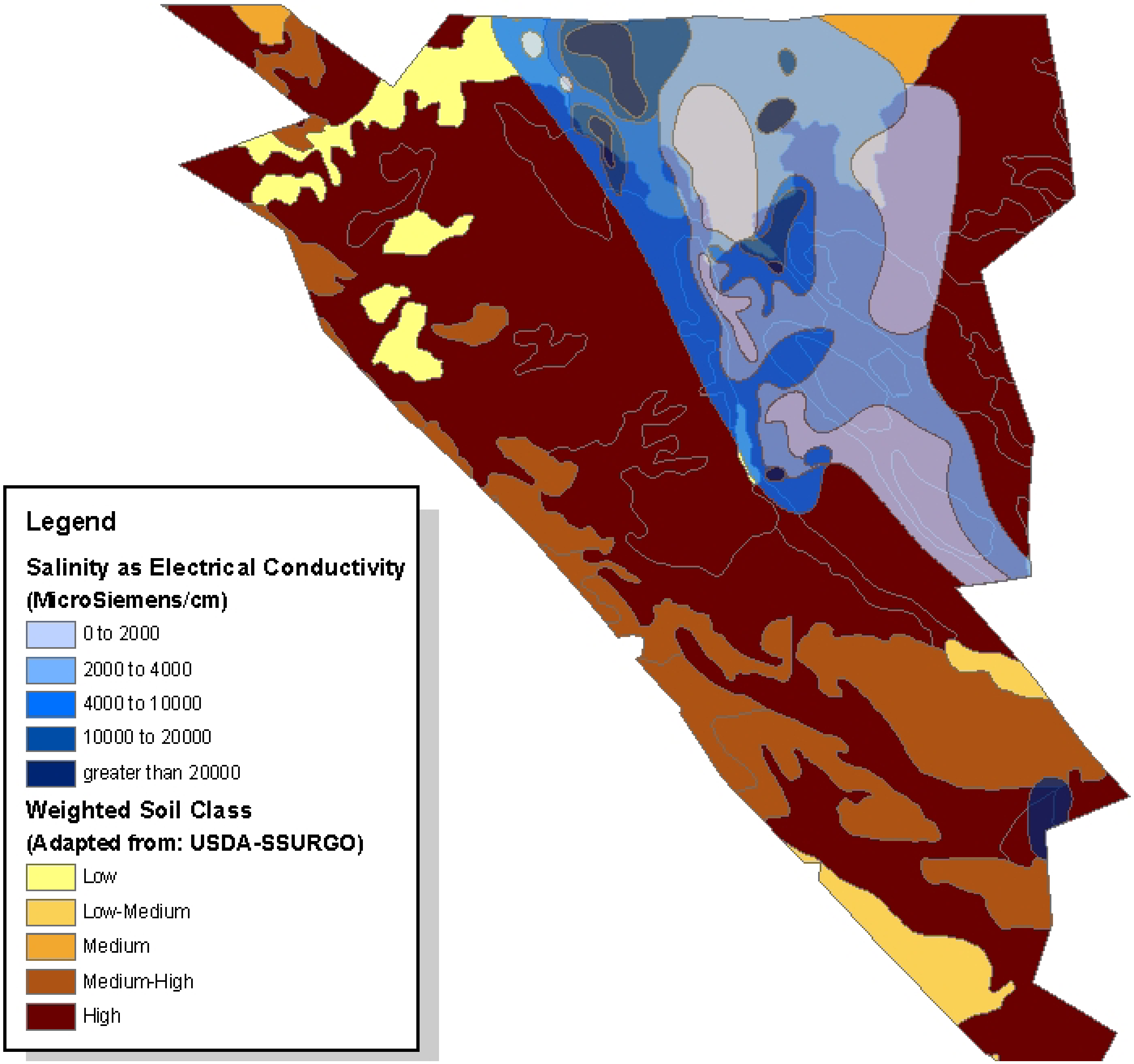
Field Level Crop Data (DWR)



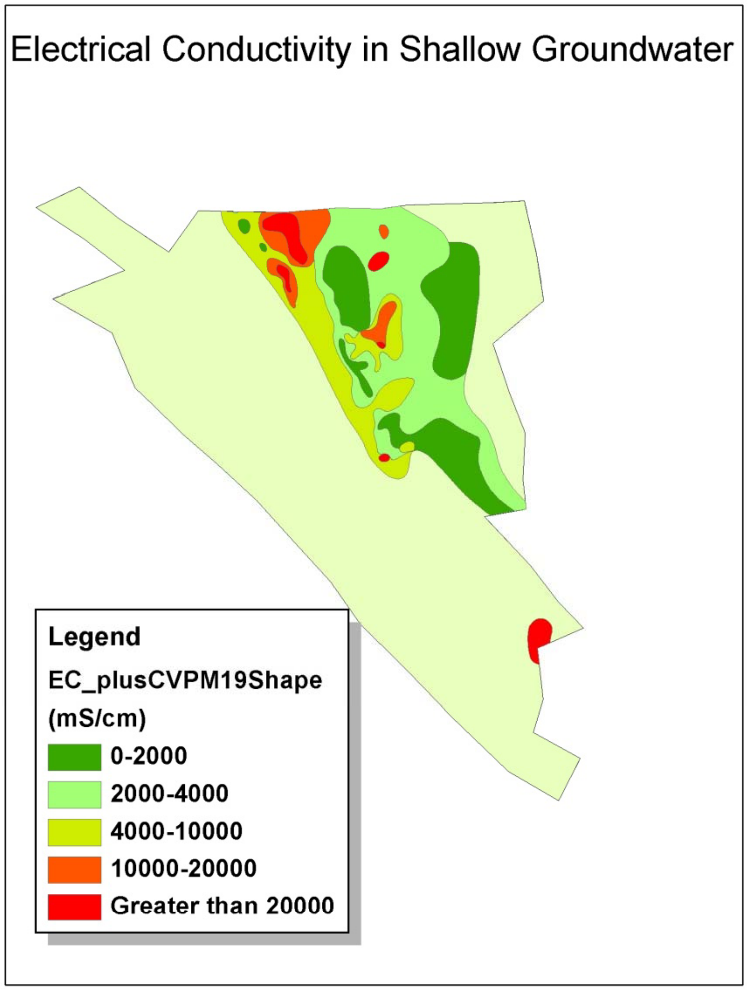
Interaction of Salinity and cropping

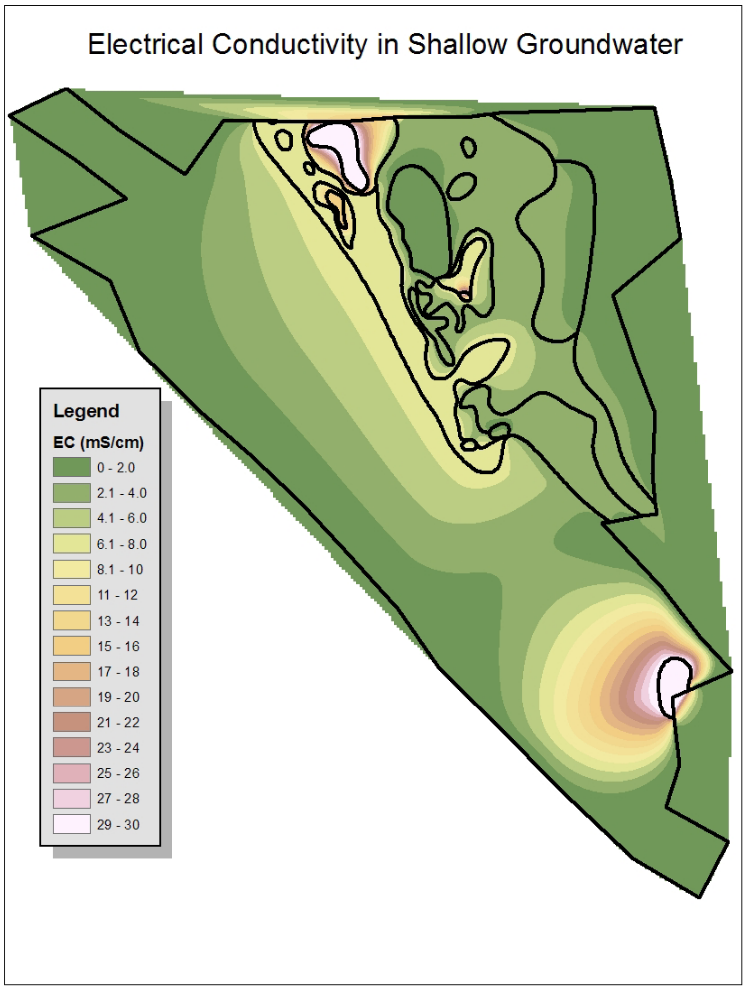


ctrical Conductivity in Shallow Groundwater and Weighted Soil Class at SVP in 19



Natural Neighbor Interpolation





Marginal Effects of Salinity Ordered by Salt Tolerance

Evaluated Separately at Average and by Respective Salinity Zone

Marginal Effects						
Crop	**Salt Tolerance dS/m***	**CVPM 10**	**CVPM 14**	**CVPM 15**	**CVPM 19**	**CVPM 21**
Grapes	1	-0.20%**	-1.06%**	-8.67%**	-0.94%	-13.02%
Orchard	1.4	-12.29%**	-4.69%**	-17.40%**	-5.68%**	-6.22%
Truck (Lettuce)	1.5	-2.95%*	-1.56%*	0.22%*	-0.76%*	-11.78%
Tomato	1.7	n/a	-2.07%*	0.75%*	-0.07%**	n/a
Grain	4.5	0.60%	1.55%*	3.83%*	2.82%**	6.74%
Sugar Beet	4.7	1.10%*	0.75%*	0.39%**	-0.19%**	0.00%
Field	5	2.21%**	-0.45%**	0.69%	-0.96%*	6.40%
Cotton	5.1	6.30%*	4.57%*	9.30%*	5.80%**	7.80%
Alfalfa	8	5.79%*	2.71%*	4.52%*	-0.40%**	6.87%
Fallow	n/a	-0.30%	0.21%	6.04%**	0.46%*	3.21%

•Obtained from http://www.agric.nsw.gov.au/reader/wm-plants-waterquality
•*Denotes significance at 5%
•**Denotes significance at 1%

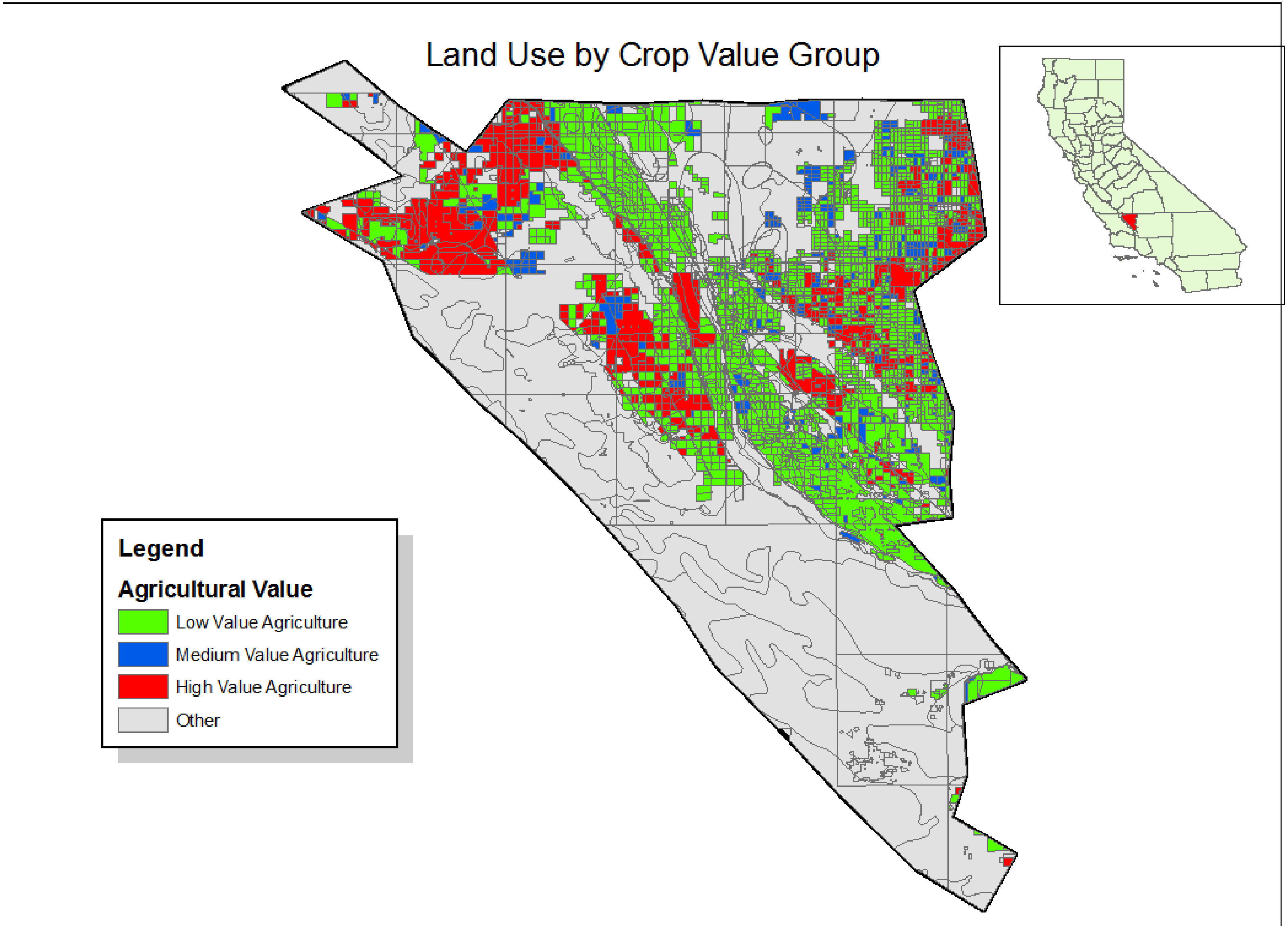
A Multinomial Logit Model of Farmer Salinity Response

$$\Pr(Crop = k) = \frac{e^{\mathbf{x}_i^{'}\beta_k}}{\sum_{l=1}^{12} e^{\mathbf{x}_i^{'}\beta_l}}$$

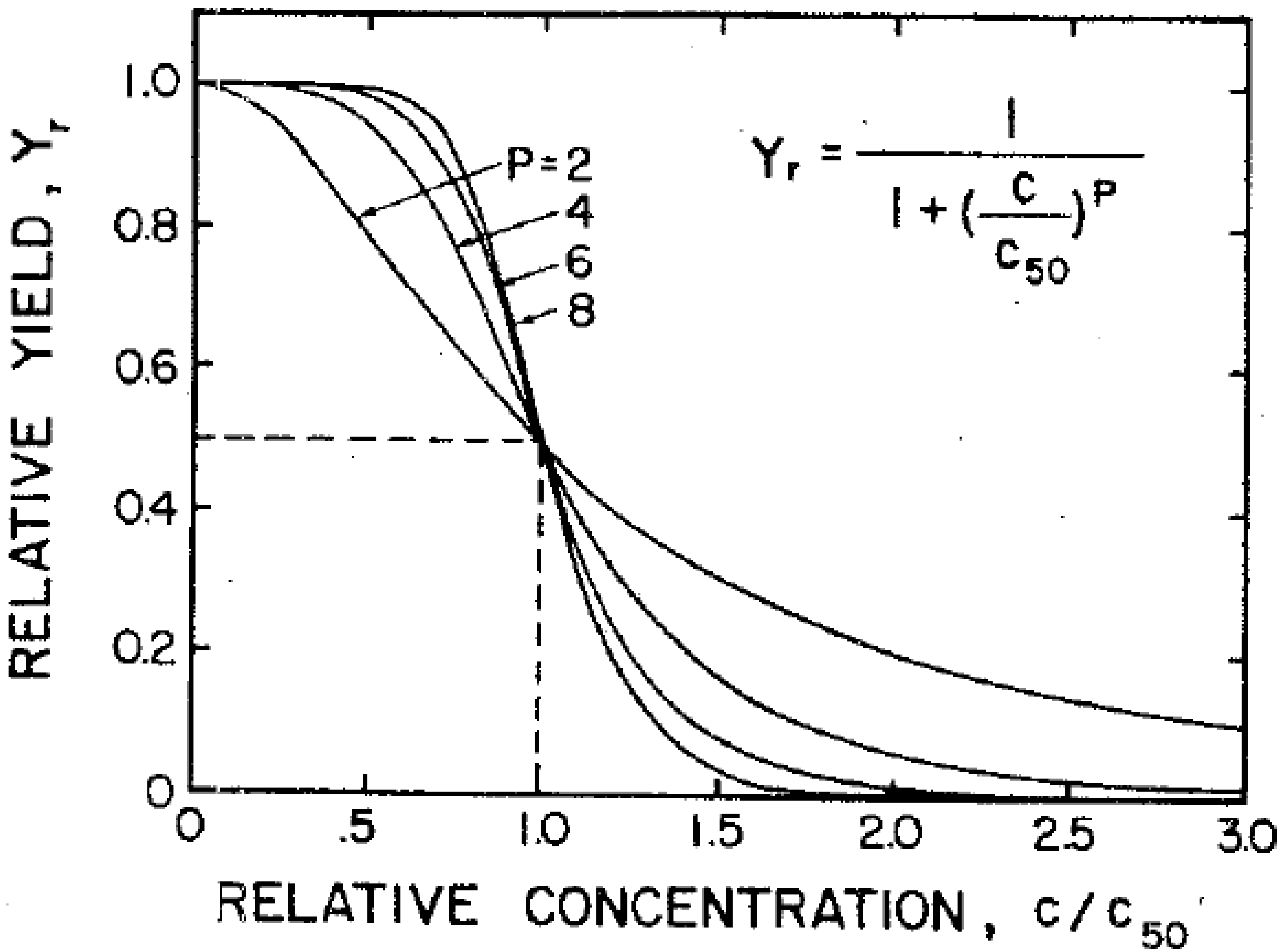
- 13 Crop groups
- Salinity – Continuous measure of shallow groundwater salinity by field
- Soil – Integer 0-7 with decreasing soil quality
- Acres – Continuous measure of parcel area
- Between 4,000 and 10,000 observations per CVPM region, approximately 48,000 observations across all salinity affected CVPM regions

Micro-Modeling Region 19

- Kern County California
- Central Question: Given that farmers adjust crop rotations in response to salinity, what is the effect of salinity on crop yields in practice?
  - Experimental vs. Behavioral
- Focus on a single region
  - 4,700 observations total, 2,400 over saline land


Land Use by Crop Value Group
Legend
Agricultural Value
Low Value Agriculture
Medium Value Agriculture
High Value Agriculture
Other

Experimental Yield Reduction Function



Behavioral Risk Model

- Focus on 5 crop groups in Kern County, CA
- Farmers as profit maximizing crop portfolio managers
- Model must be scaleable
- Estimate farmer risk aversion
  - M-V framework
  - 1980-2005 time series of crop prices and yields
- Given risk aversion, estimate “behavioral rho”
  - CVPM Region 19, 1998 observed crop proportions
  - Given risk aversion, what is the value of rho that leads to observed crop proportions

Estimation of Behavioral Salinity Response Coefficients

Crop Group	Behavioral Rho	Experimental Rho*
Orchard/Citrus	0.51**	unavailable
Grape	0.72**	unavailable
Truck	0.61**	2.86
Grain	1.68**	2.90
Cotton	2.59**	3.00

*From VanGenuchten and Gupta 1993

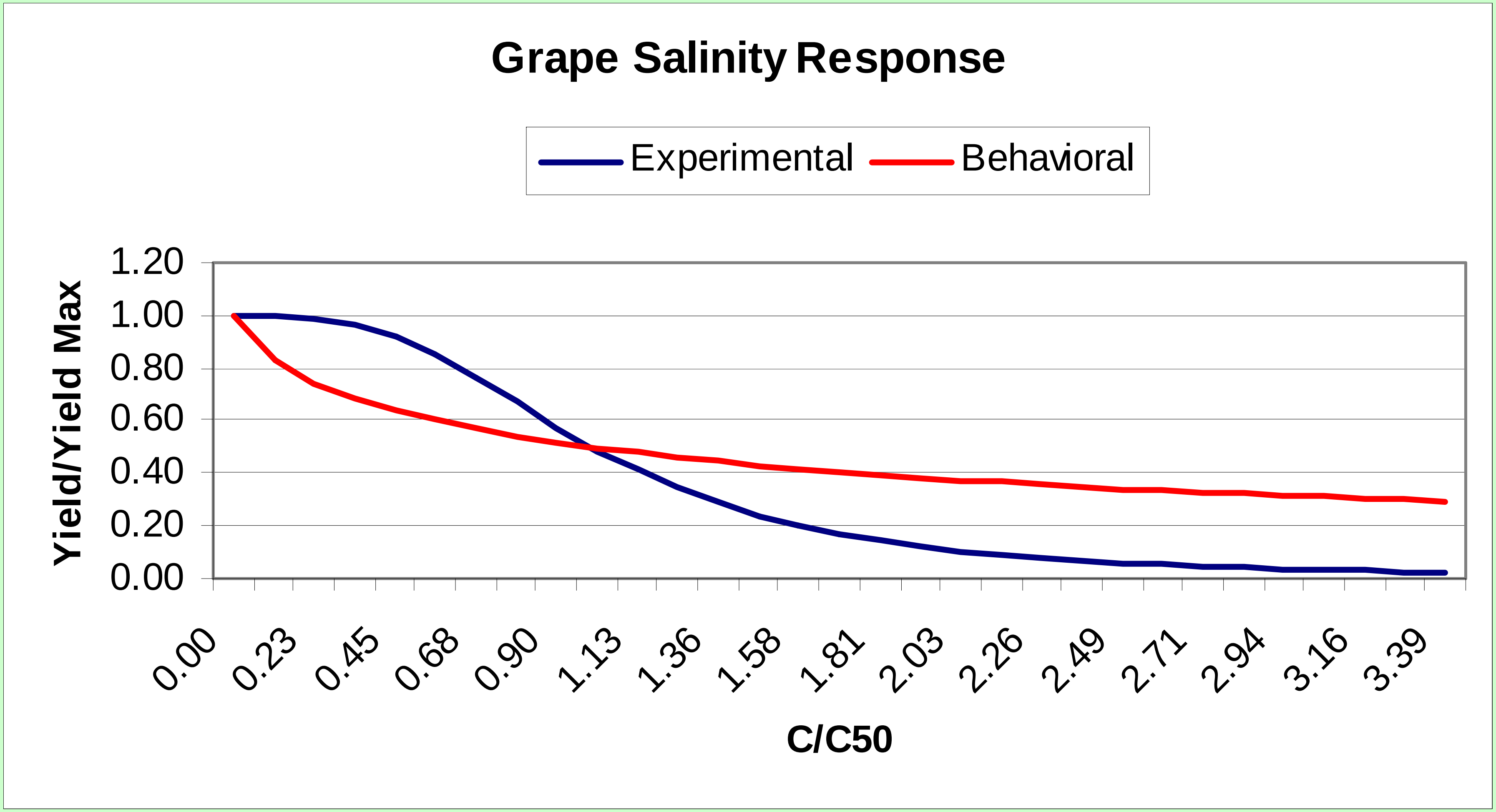
**Robust to salinity bandwidth

- Ordering by salt tolerance

Fundamental Equation:

$$Yield = \frac{Yield_{MAX}}{1 + \left(scale * \frac{c}{c_{50}} \right)^{\rho}}$$

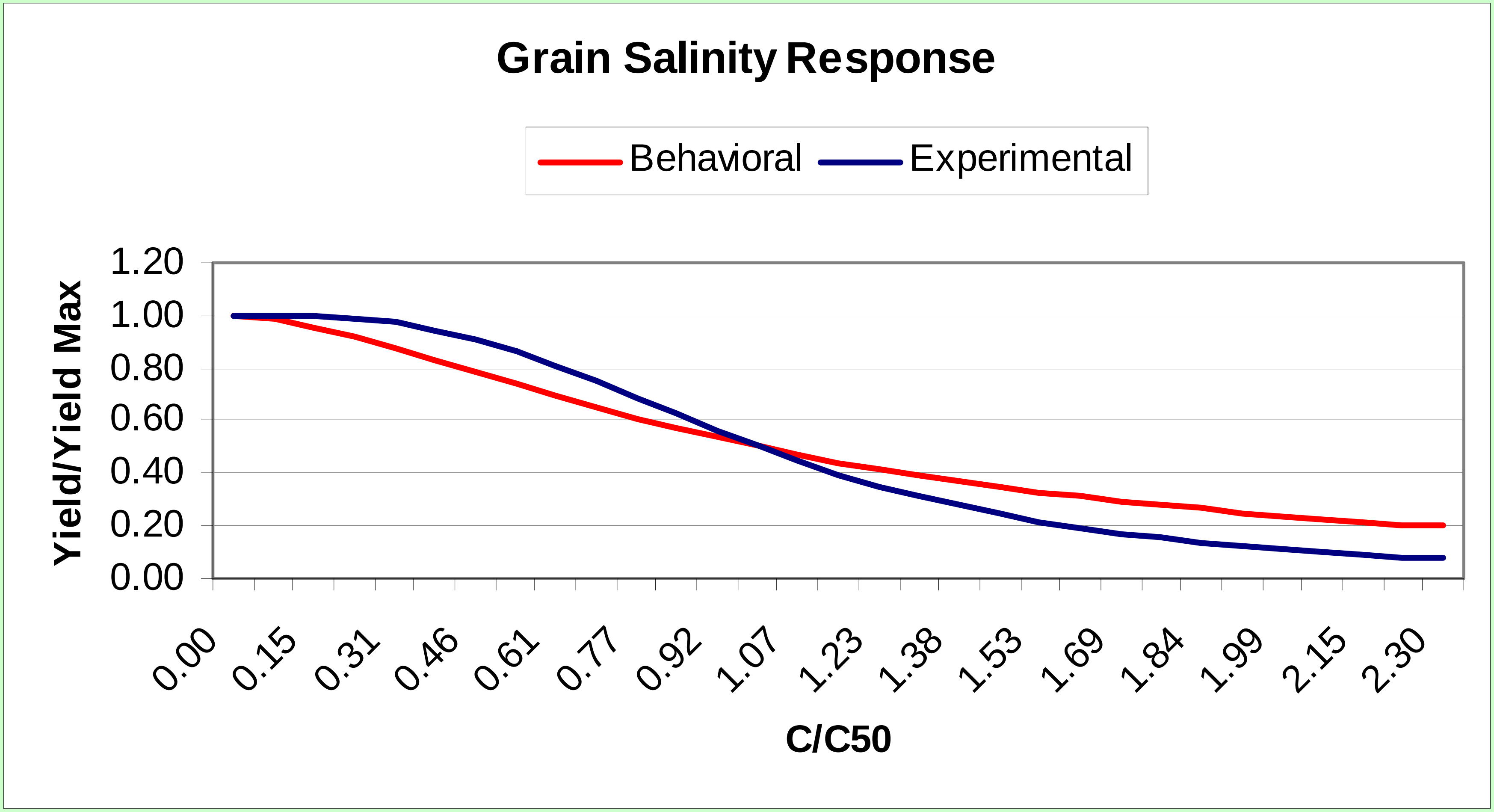
Example of Experimental and Behavioral Salinity Response



$$\rho_{EXEPERIMENTAL} = 2.55$$

$$\rho_{BEHAVIORAL} = 0.72$$

Example of Experimental and Behavioral Salinity Response



$$\rho_{EXPERIMENTAL} = 2.90$$

$$\rho_{BEHAVIORAL} = 1.68$$

Salinity Modeling Conclusions

- Economic response to salinity can be modeled through deductive and inductive methods
- Micro-modeling over salinity regions to determines behavioral salt response
- Increased data availability continues to improve results
- Farmer salinity response functions can be used to reduce economic impacts of salinity, and move toward sustainability.

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