DIFFICULTIES IN MODELING SYSTEMS WITH EXTREME CLIMATE RECORDS:
IS A MODEL OF A GROUNDWATER SYSTEM DURING A DROUGHT UNREPRESENTATIVE OR CONSERVATIVE?

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INTRODUCTION

- MODELERS ARE OFTEN ASKED TO PREDICT AN UNCERTAIN FUTURE:
  - POTENTIAL WELL IMPACTS
  - HOW CHANGING PRECIPITATION WILL IMPACT WATER LEVELS AND CHANGE PUMPING CAPABILITIES
  - HOW A CONTAMINANT CAN BE CONTROLLED/REMEDIATED GIVEN FUTURE POTENTIAL PUMPING REGIMES

PREDICTION COMPLICATIONS

- **FUTURE PREDICTIVE SCENARIOS ARE CHALLENGING IN CHANGING ENVIRONMENTS.**
  - **RECHARGE CHANGES**
  - **LAND USE CHANGES**
  - **OPERATIONAL CHANGES**

OUR QUESTION:

WHAT ARE THE FUTURE IMPACTS DUE TO HISTORICAL PUMPING WHEN YOU HAVE A CHANGING SYSTEM?

AVAILABLE TECHNIQUES FOR FUTURE PREDICTIVE MODELING

WHAT WE CAN'T USE:

- REAL DATA (BECAUSE IT DOESN'T EXIST)
- EXISTING INTERPRETATIONS (BECAUSE THE SYSTEM IS IN FLUX)

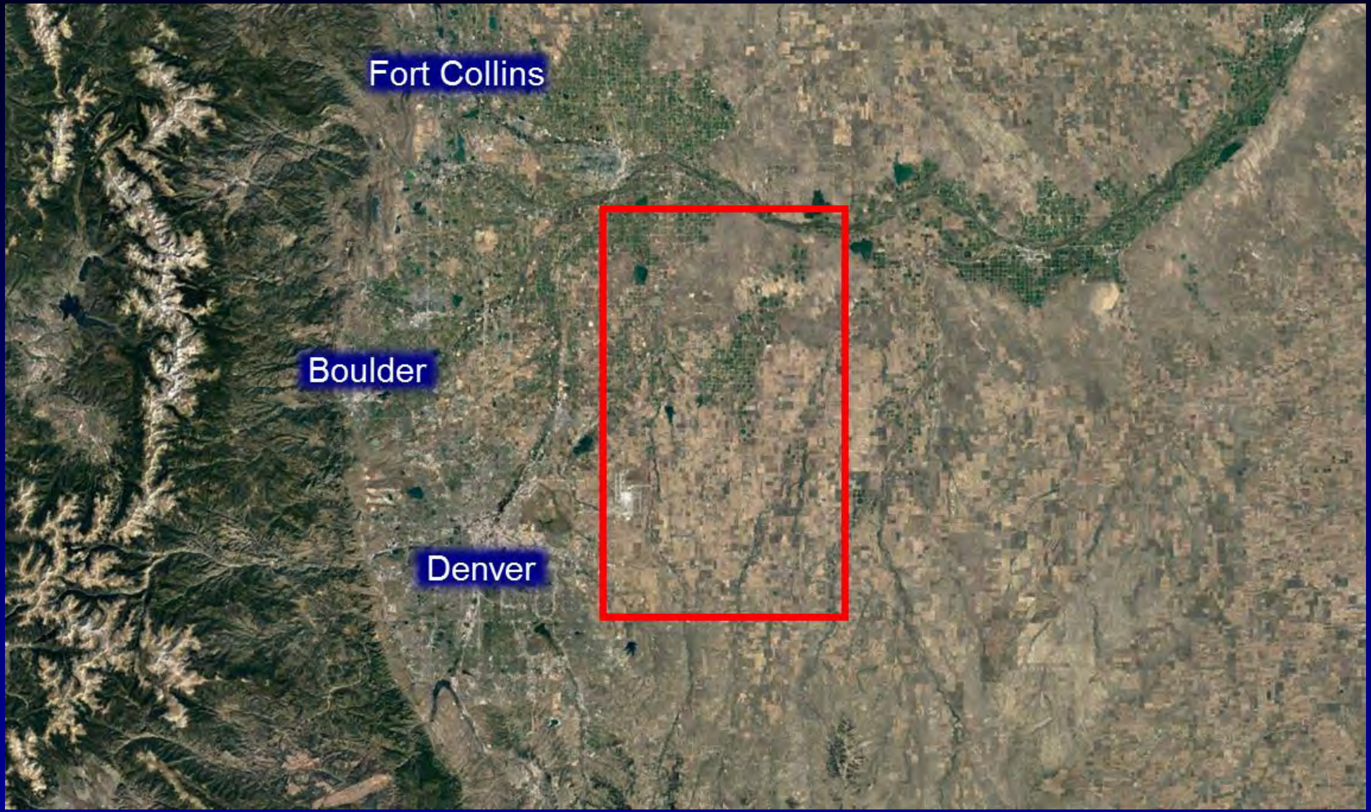
WHAT WE CAN USE:

- EXISTING ACCEPTABLE MODEL
- HISTORICAL DATA TRENDS AND EXTREME SYSTEM EVENTS
- COMPUTER GENERATED PREDICTIONS (PRISM, NLDAS, ETC)
- STOCHASTIC MODELING / MULTIPLE MODELS
- SOME EXISTING INTERPRETATIONS AND EXTRAPOLATION

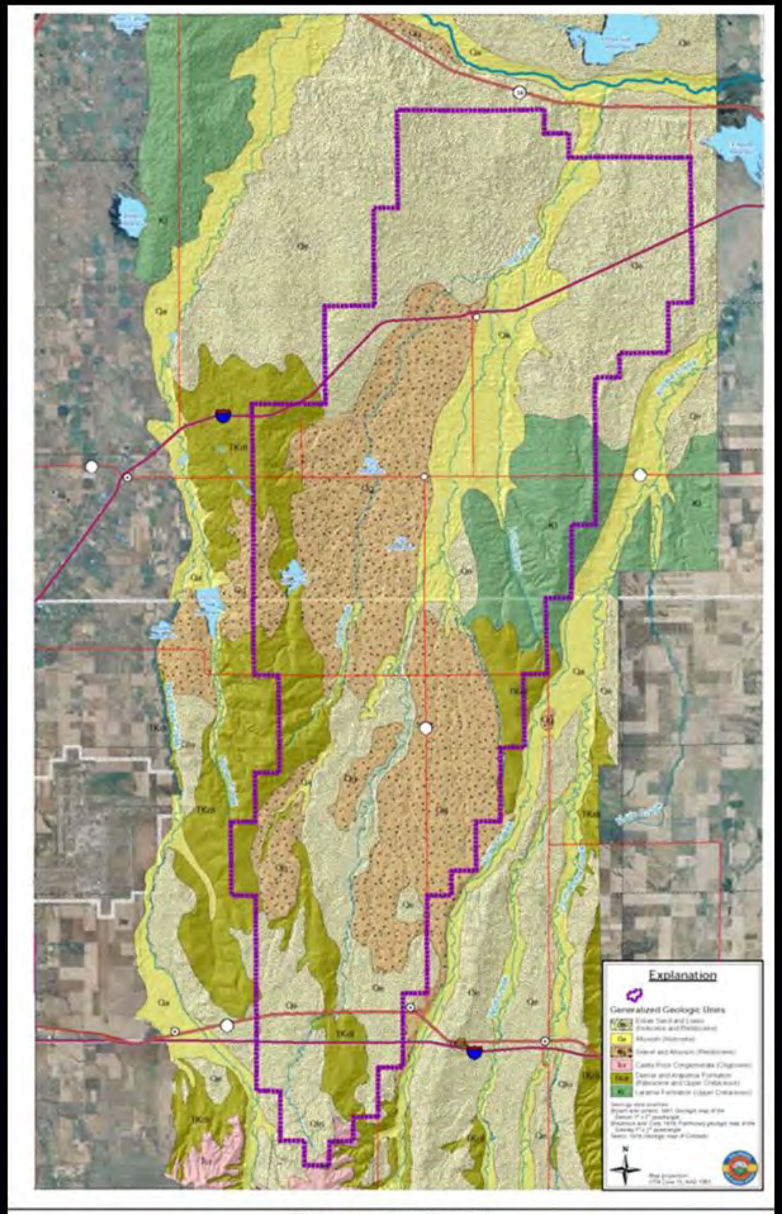
CASE STUDY: CHANGING BASIN IN COLORADO

AN EVALUATION OF CHANGING CLIMATE ON PUMPING REDUCTIONS THAT HAVE BEEN COMPOUNDED BY ANTHROPOGENIC AND ENVIRONMENTAL CHANGE

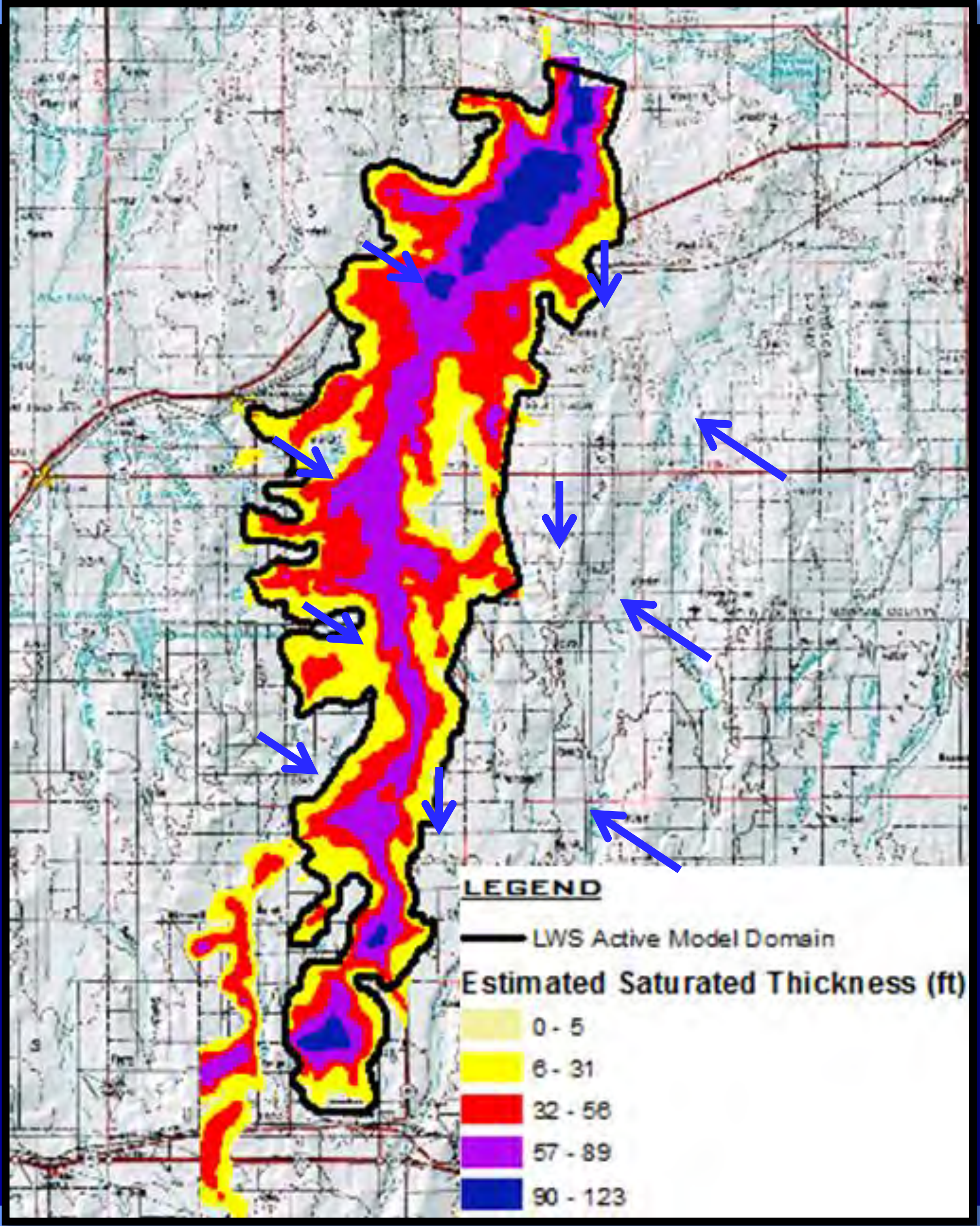
STUDY AREA



- LOCATED APPROXIMATELY 1 HOUR EAST OF DENVER, CO
- APPROXIMATELY 45 MILES LONG AND 18 MILES WIDE
- HISTORICALLY AGRICULTURAL, BUT SHIFTING WATER USAGE IN THE LAST 10-15 YEARS



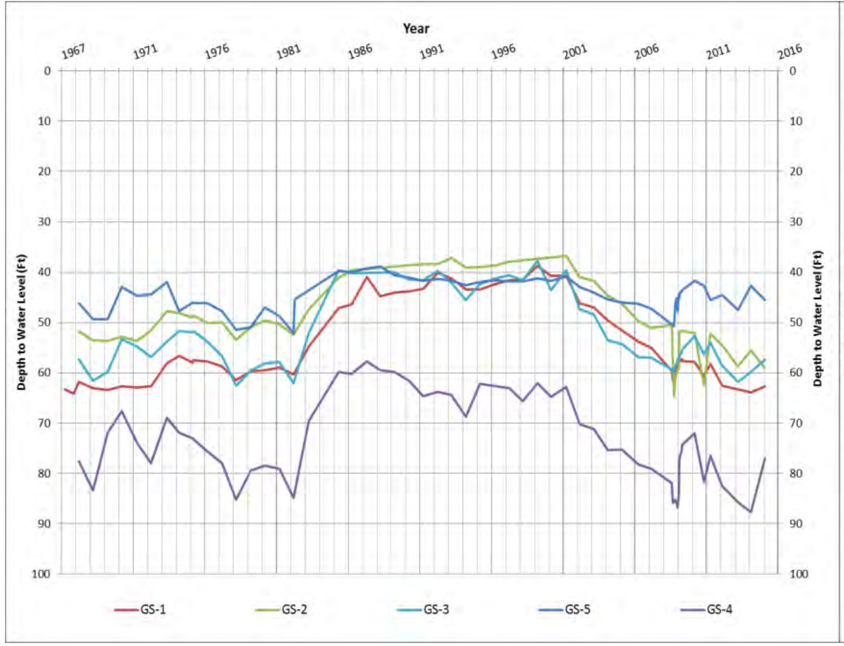
Generalized Geologic Map



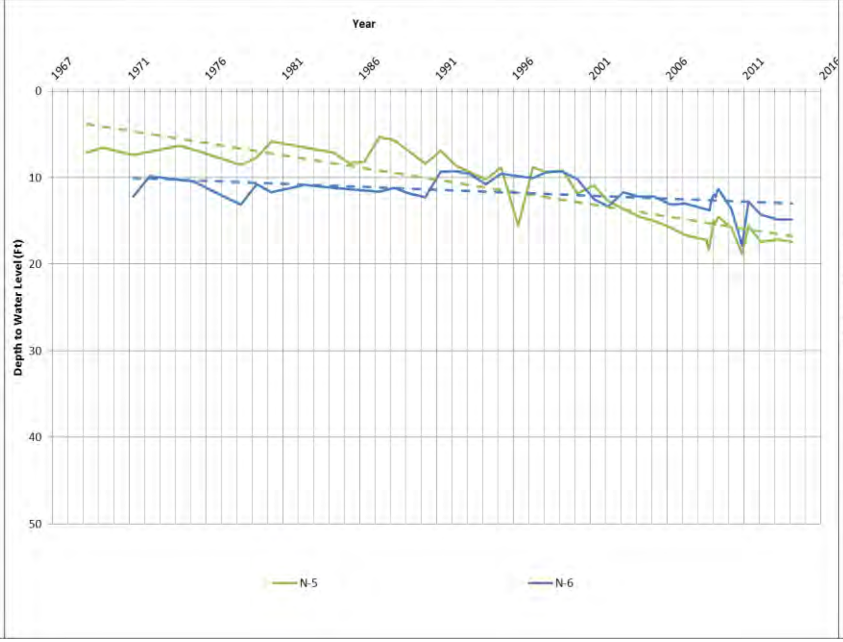
STUDY AREA – HYDROGEOLOGY

Property	Annual Average (ac-ft)
Net Recharge	21,054
Seepage	7,654
Outflows	9,187
Extractions	34,000
Total Storage (Topper, 2010)	~2.3 million

REGIONAL WATER LEVEL TRENDS



Southern Wells

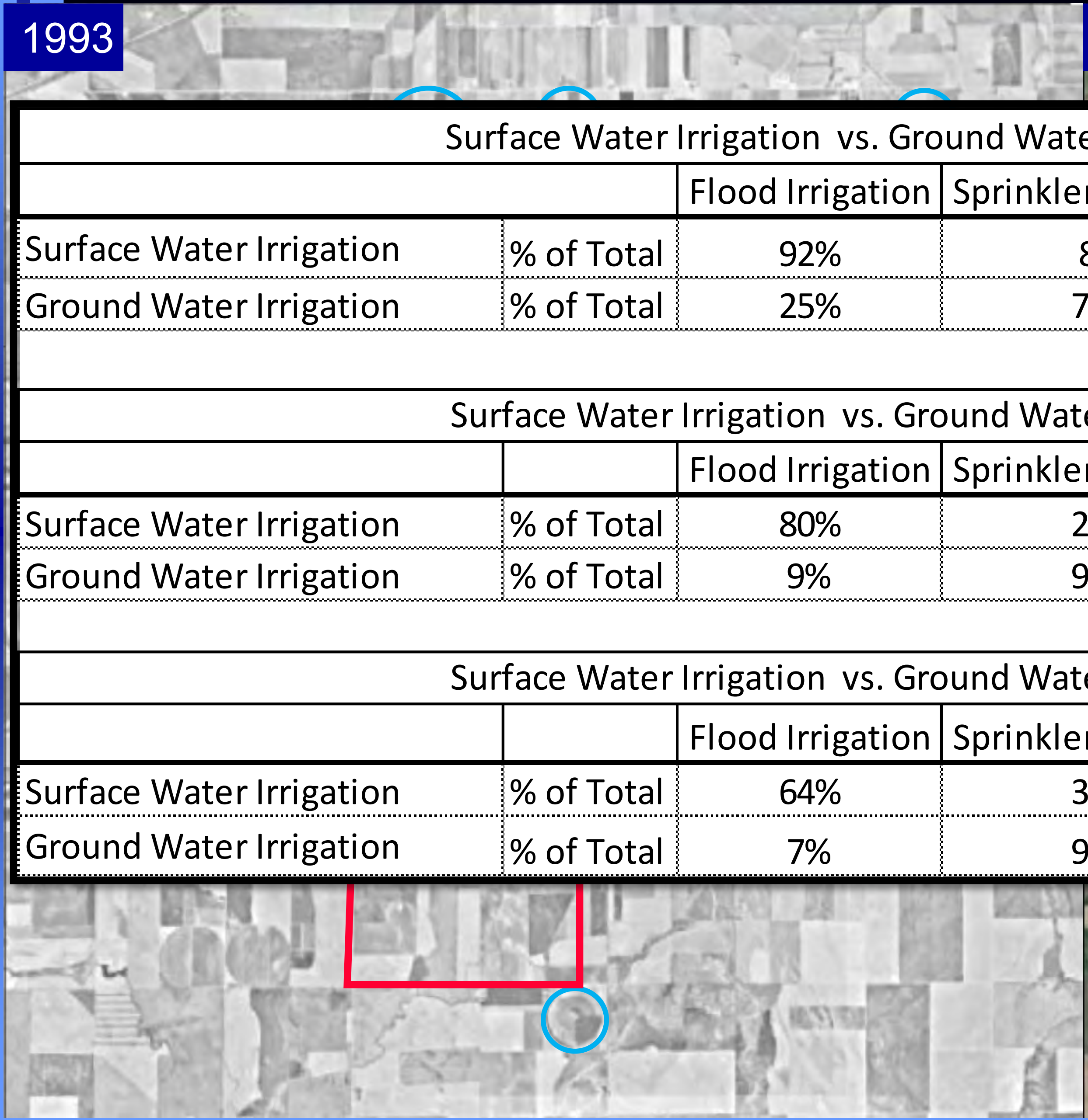


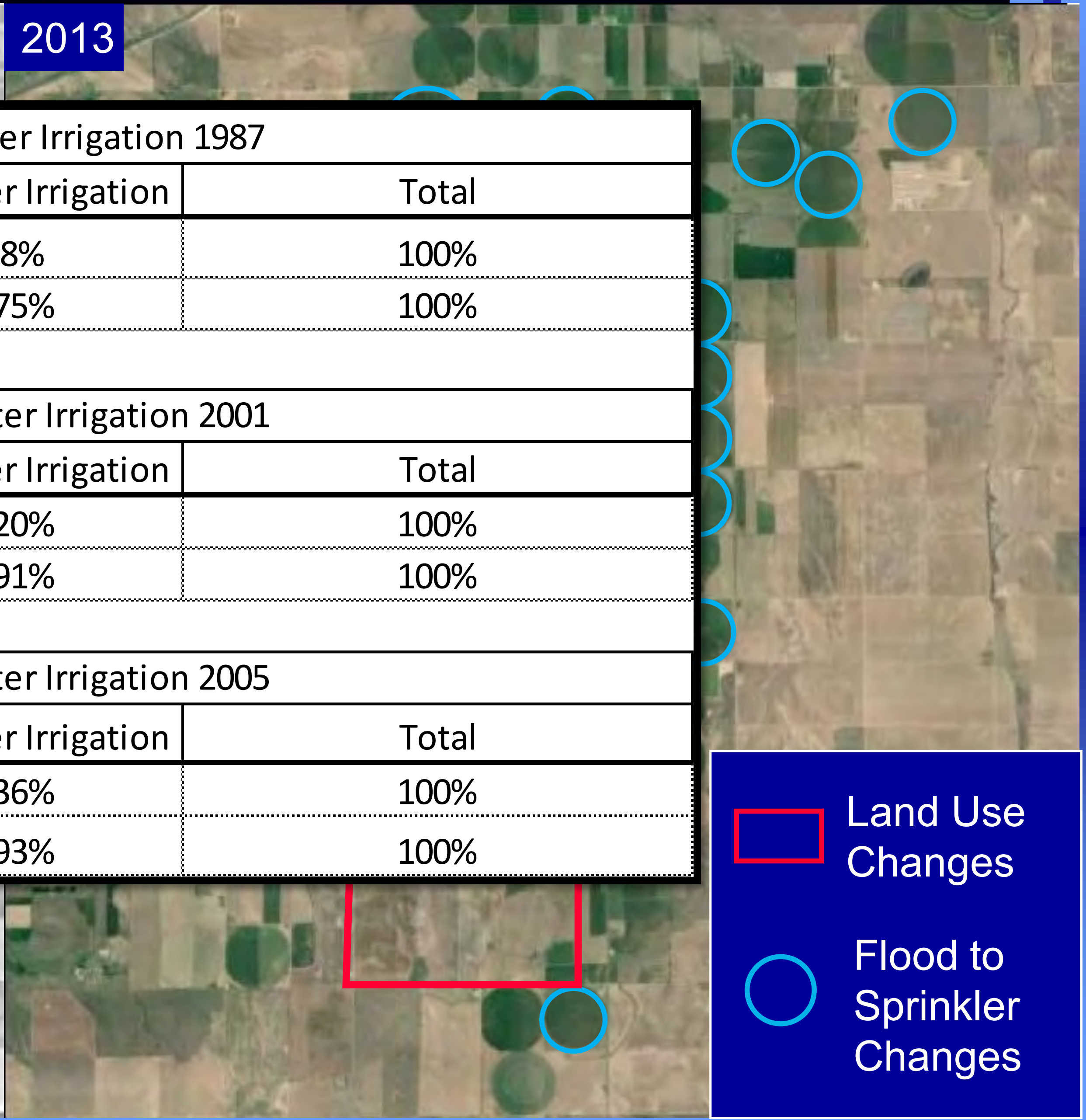
Northern Wells

Mid-Range Wells

State's Opinion: Based on Available data, this basin is “over-appropriated” (or “water short”).

ANTHROPOGENIC CHANGES





Surface Water Irrigation vs. Ground Water Irrigation 1987				
		Flood Irrigation	Sprinkler Irrigation	Total
Surface Water Irrigation	% of Total	92%	8%	100%
Ground Water Irrigation	% of Total	25%	75%	100%

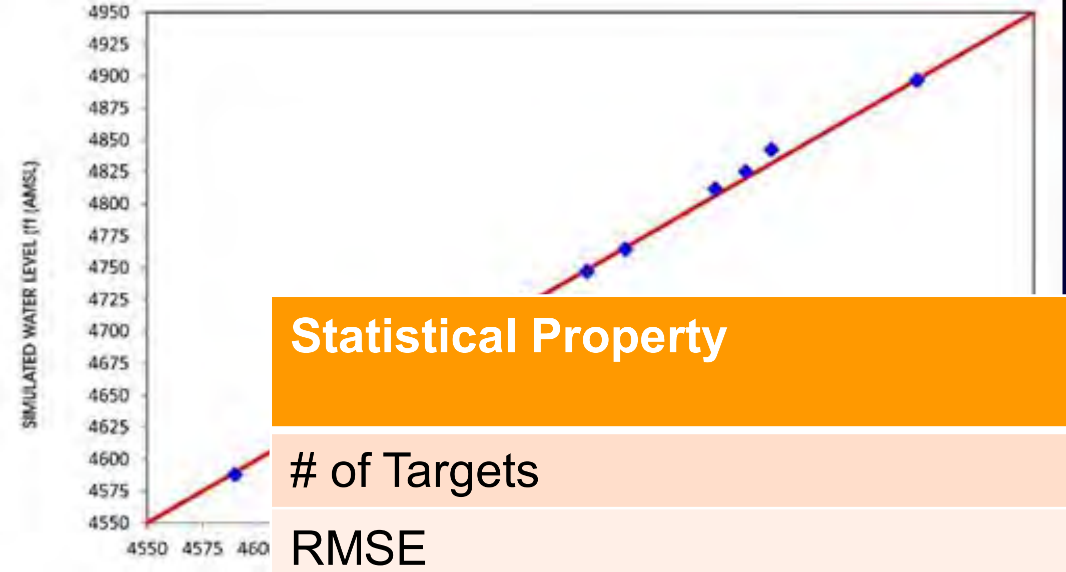
Surface Water Irrigation vs. Ground Water Irrigation 2001				
		Flood Irrigation	Sprinkler Irrigation	Total
Surface Water Irrigation	% of Total	80%	20%	100%
Ground Water Irrigation	% of Total	9%	91%	100%

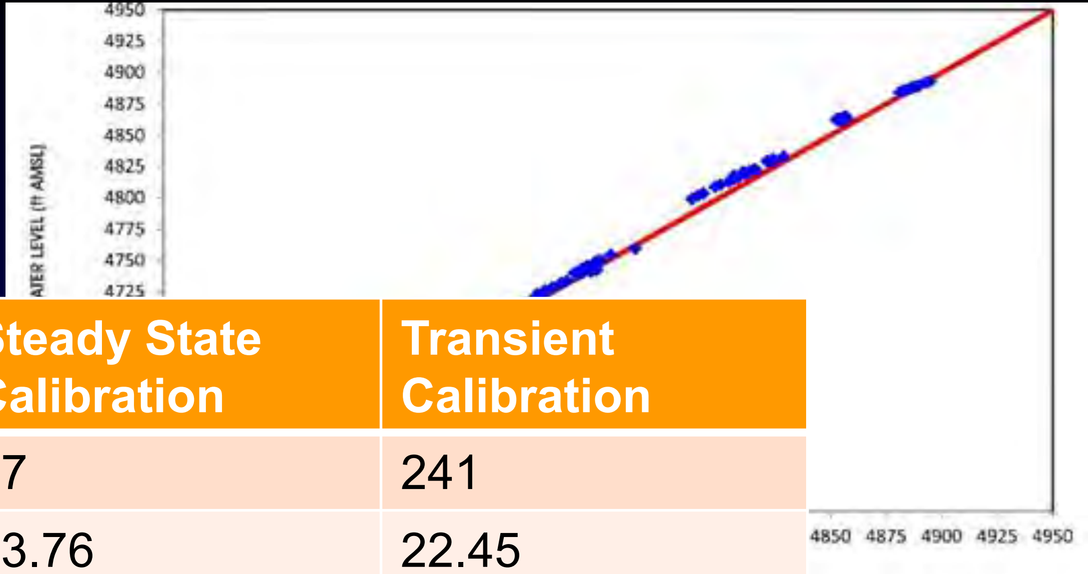
Surface Water Irrigation vs. Ground Water Irrigation 2005				
		Flood Irrigation	Sprinkler Irrigation	Total
Surface Water Irrigation	% of Total	64%	36%	100%
Ground Water Irrigation	% of Total	7%	93%	100%

STUDY AREA– MODELING APPROACH

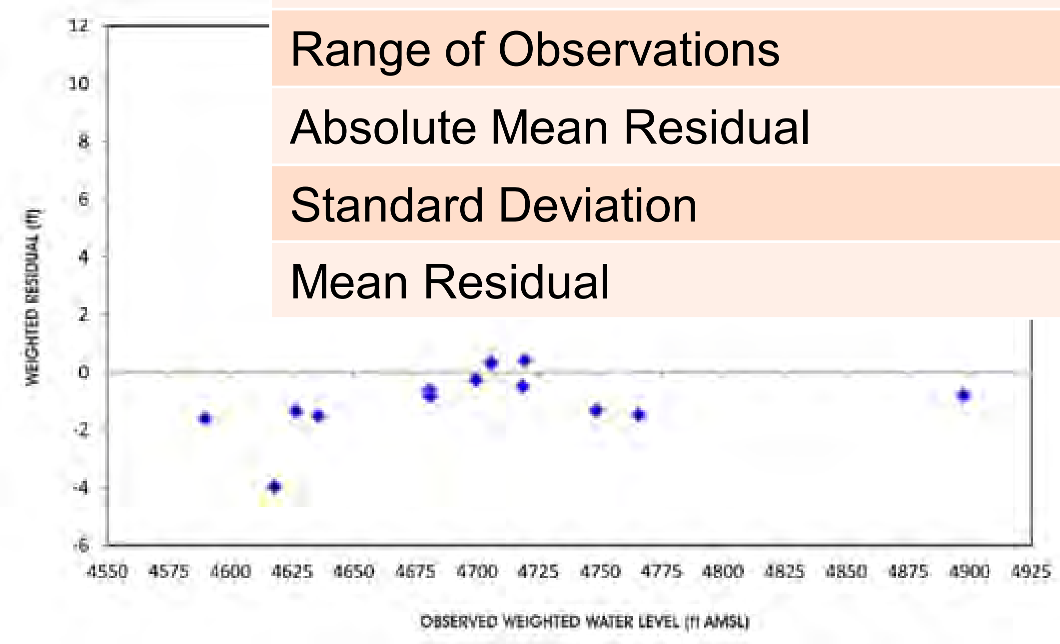
- 636 ROWS, 280 COLUMNS
- INITIAL DESIGN USED: USGS SS MODEL
- MODIFICATIONS FROM CGS AND LWS COLLECTED DATA
- SS: JANUARY 2015
- TR: JANUARY 1998-DECEMBER 2007

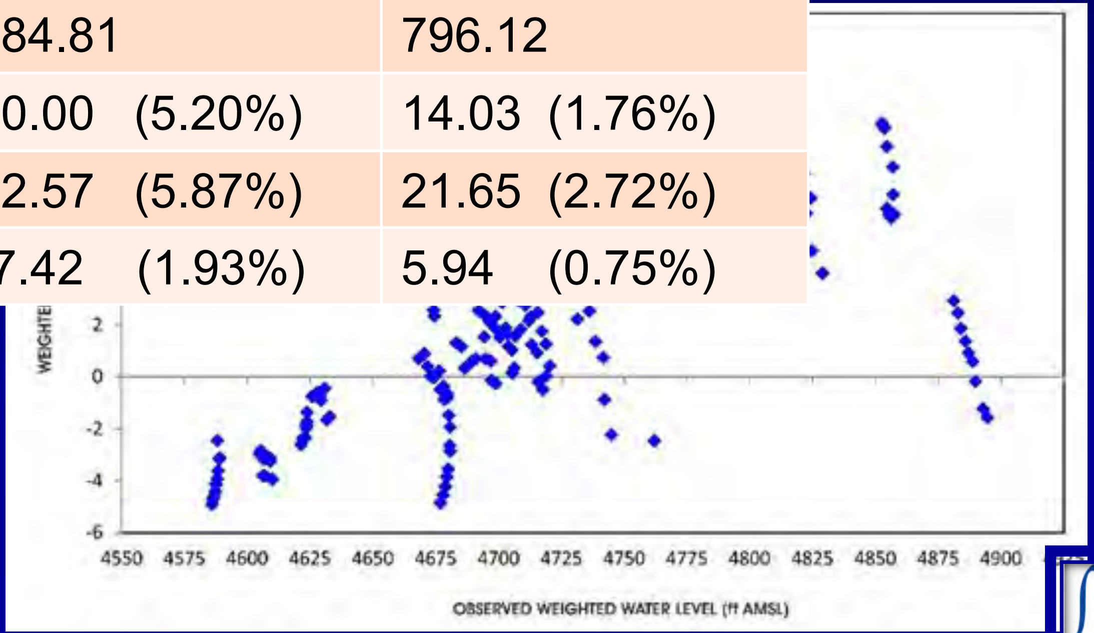
STUDY AREA CALIBRATION RESULTS





Statistical Property	Steady State Calibration	Transient Calibration
# of Targets	17	241
RMSE	23.76	22.45
Range of Observations	384.81	796.12
Absolute Mean Residual	20.00 (5.20%)	14.03 (1.76%)
Standard Deviation	22.57 (5.87%)	21.65 (2.72%)
Mean Residual	-7.42 (1.93%)	5.94 (0.75%)





OUR QUESTION:

WHAT ARE THE FUTURE IMPACTS TO HISTORICAL PUMPING RESULTING FROM FUTURE OPERATIONAL CHANGES?

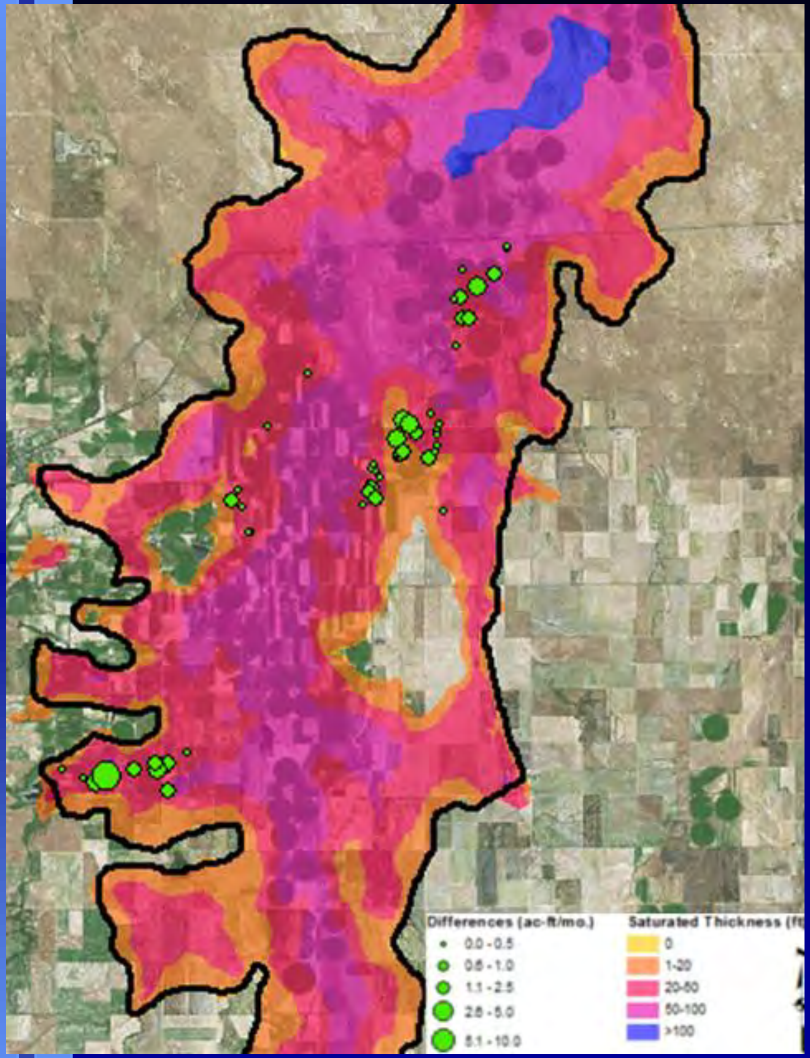
THREE DIFFERENT METHODS TESTED

Steady State Model	Transient Option 1	Transient Option 2
• Average Recharge • Average Extractions • Average Seepage	• Variable Monthly Recharge (120 different rates) • Variable Extractions based on Land Use / Changes • Variable Seepage based on Water Rights Changes	• Variable Monthly Recharge (12 different rates, repeated) • Variable Extractions based on Land Use / Changes • Variable Seepage based on Water Rights Changes

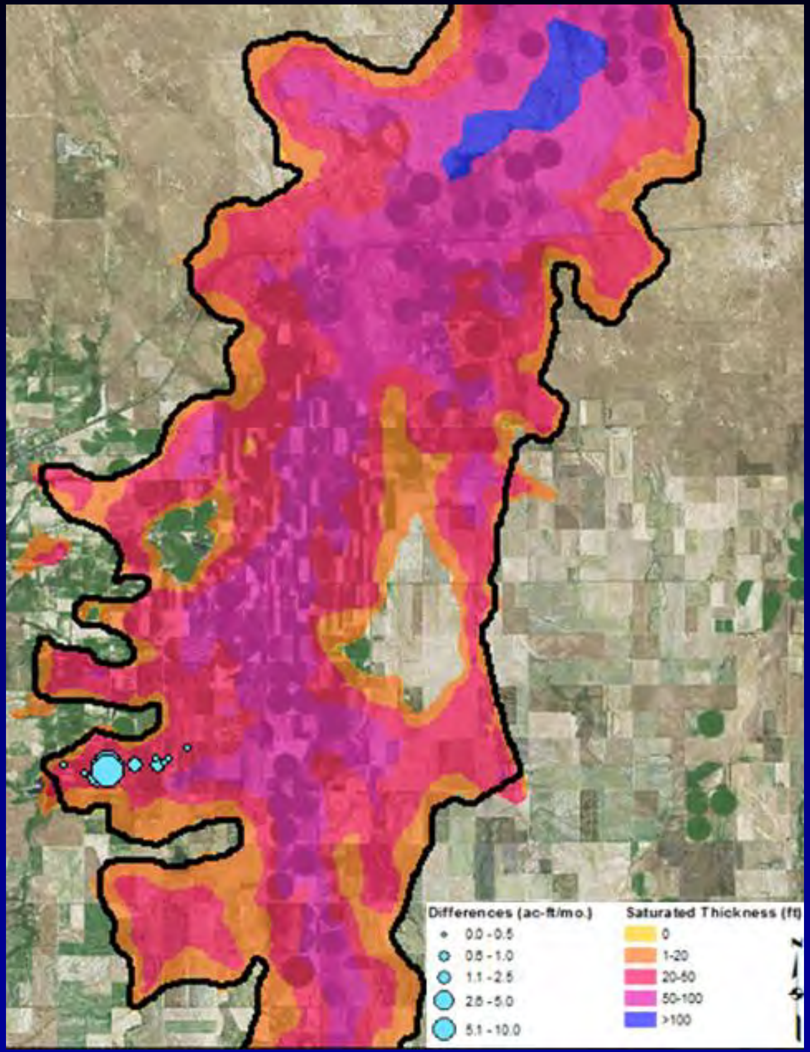
Property	Annual Average (ac-ft/yr)	Property	Annual Average (ac-ft/yr)	Property	Annual Average (ac-ft/yr)
Net Recharge	27,919	Net Recharge	28,159	Net Recharge	31,406
Seepage	1,961	Seepage	1,947	Seepage	1,947
Outflows	4,433	Outflows	10,657	Outflows	10,617
Extractions	28,294	Extractions	31,653	Extractions	31,658
Total Storage (Topper, 2010)	~2.3 million	Total Storage (Topper, 2010)	~2.3 million	Total Storage (Topper, 2010)	~2.3 million

RESULTS

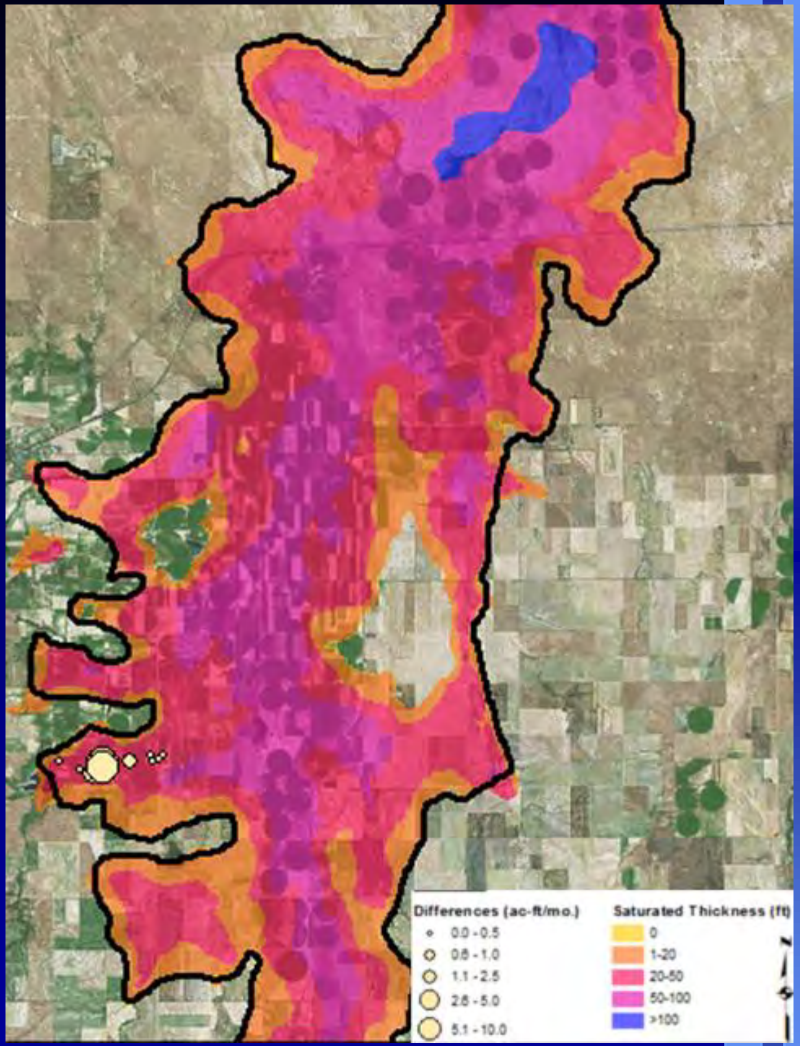
STEADY STATE MODEL



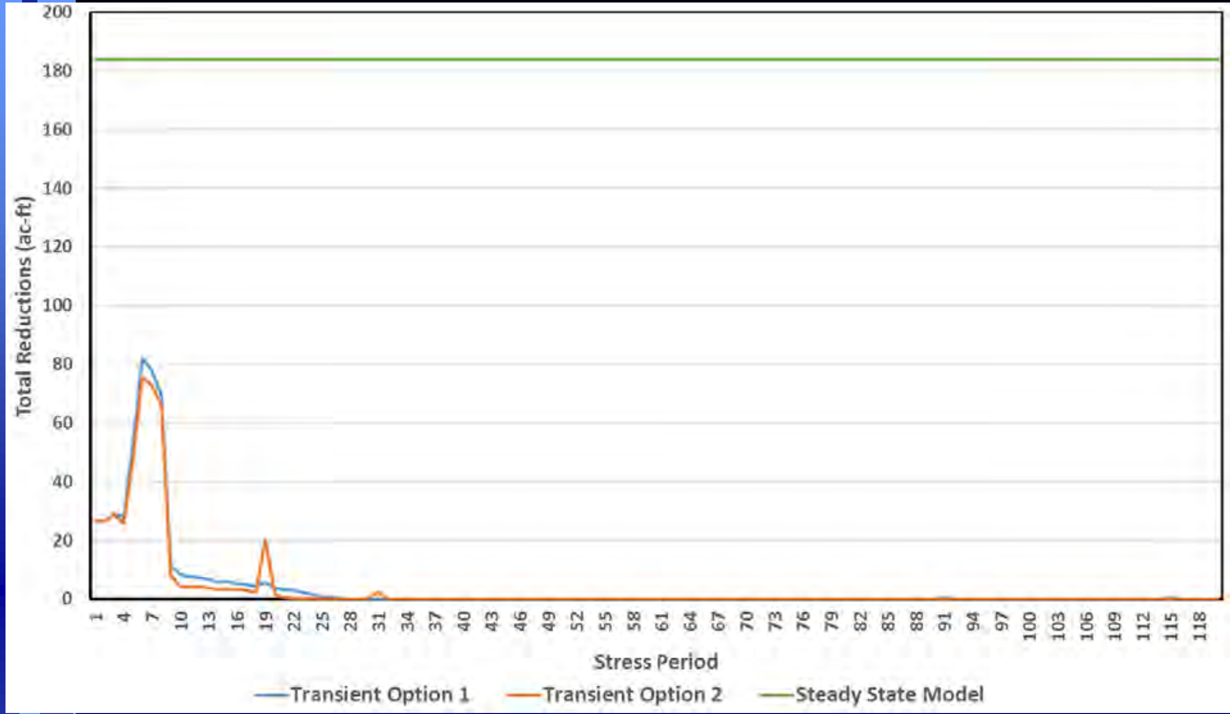
TRANSIENT OPTION 1

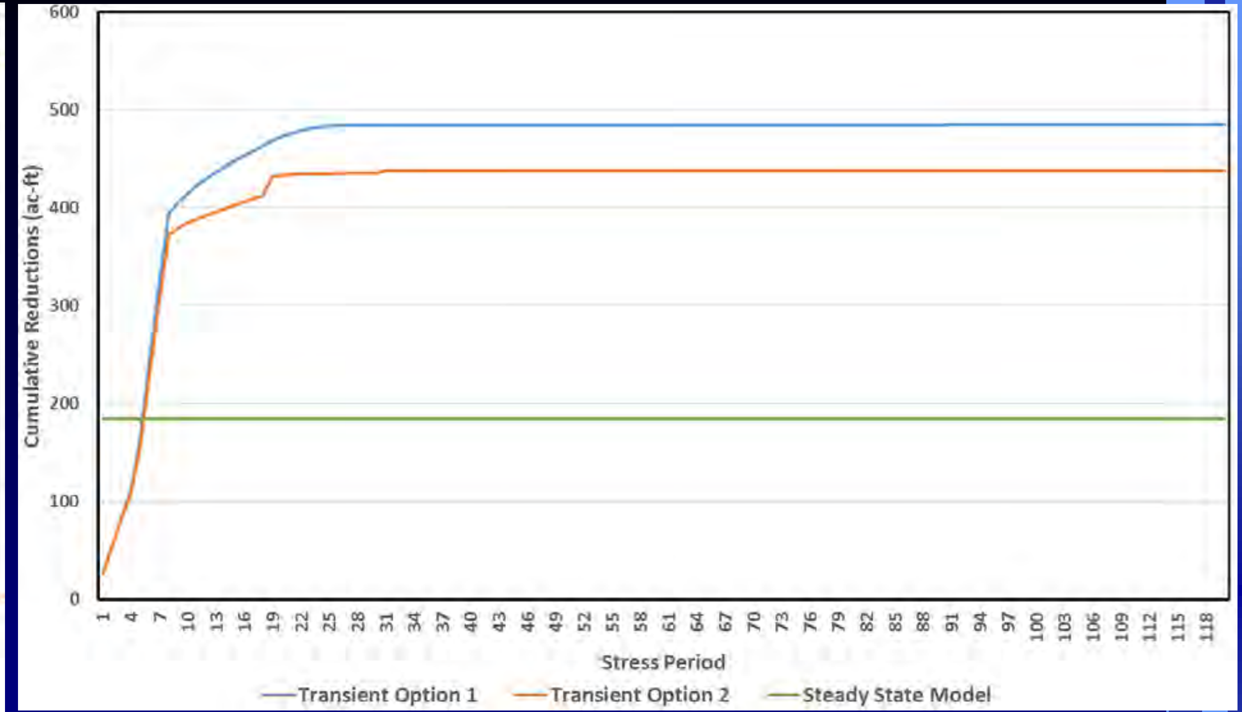


TRANSIENT OPTION 1



RESULTS (cont'd.)





Model	Maximum Reductions (ac-ft/mo.)	Total Reductions (ac-ft)	% of Total Extractions (ac-ft)
Steady State Model	2.88	183.82*	0.65
Transient Option 1	6.21	485.15	1.53
Transient Option 2	5.84	437.58	1.38

NOTE:
The Steady State Model's total reductions are converted from the total steady state reduction volume of 6.03 ac-ft/day for 1 year.

CONCLUSIONS

COMPARISON OF THE THREE MODEL OPTIONS

	STEADY STATE MODEL	TRANSIENT OPTION 1	TRANSIENT OPTION 2
Monthly Impacts			
Early Time	↓	↑	↓
Late Time	↓	↑	↑
Overall Impacts			
Cumulatively	↓	↑	↓
Spatially	↑	↓	↓

CONCLUSIONS (cont'd.)

- ***Each model answers a different question:***

1. **The steady state addresses the average expected impact of pumping operations in the region in an average year (general estimate)**
2. **The variable recharge scenario (Transient Option 1) answers the question of what are the maximum expected impacts contributed over a given month.**
3. **The average recharge scenario (Transient Option 2) answers the question of how variations in pumping will impact the system through operations over an extended period of time.**

No matter the question posed, you need to know what you want to find out before you model it.

THANK YOU!

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