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The impact of Irrigation Capital Subsidies on Common-pool Groundwater Use and Depletion

Results for Western Kansas

Nicolas E. Quintana Ashwell

Graduate Research Assistant, Ph.D. Candidate

Jeffrey M. Peterson

Professor

Department of Agricultural Economics, Kansas State University

Background

- More efficient technologies may result in higher water use and faster aquifer depletion in certain river basins
  - Sheierling et al., 2006; Ward and Pulido Velazquez, 2008
- "….optimal control would not enhance the welfare of farmers compared with a strategy of free markets."
  - Gisser and Sanchez, 1980
- Without intervention, efficient irrigation technology adoption may be slower than socially optimal.
  - Shah et al., 1995

Research Goal

Assess the effects of irrigation capital subsidies in a dynamic common pool context.

- Water extraction
- Discounted welfare

and answer the questions

Can an irrigation capital subsidy policy capture potential surplus?

How much?

Assumptions

Framework from Burness and Brill (2001) – extension of Gisser and Sanchez (1980).

- Single-cell, unconfined aquifer
- Water is weakly essential input
- Water requirements set to meet FWY

Model

- Hydrology
  - Evolution of the water table height (elevation, ft) over time

$$\dot{H} = \frac{1}{As}\left[N - \left(1 - \alpha(k)\right) w \right]$$

$$\alpha'(k) \le 0$$

  - Declining yields from groundwater storage (AF/hr)

$$Y = 2Q_0 d\left[H(t) - Hc - \frac{d}{2} \right]$$

  - Water accounting identity/application efficiency

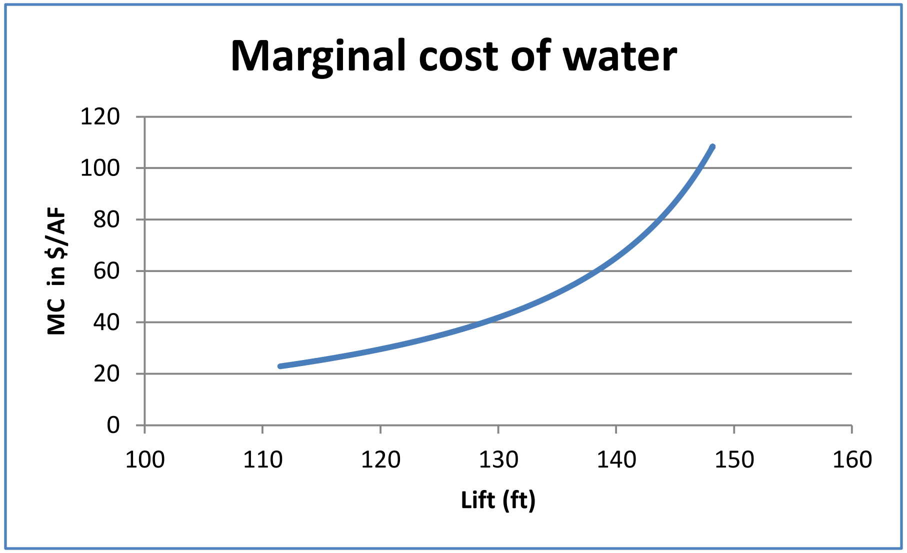
$$e(k)w = C_R A \qquad e(k) \in (0,1) \quad \frac{de}{dk}(k) \ge 0 \quad \frac{d^2e}{dk^2}(k) \le 0$$

Model

- Costs: $$\hat{C}(w,k;H) = C(H)w + (r+\delta)kA + \Theta L(k)$$

- Marginal pumping costs ($/AF)

$$C\left(H\left(t\right)\right) = \phi \frac{\left(S_L - H\left(t\right)\right)}{\left(H\left(t\right) - Hc\right)}$$



- Capital costs ($): $(r+\delta)kA$

- Labor cost associated to irrigation capital ($)

$$\Theta L(k)$$

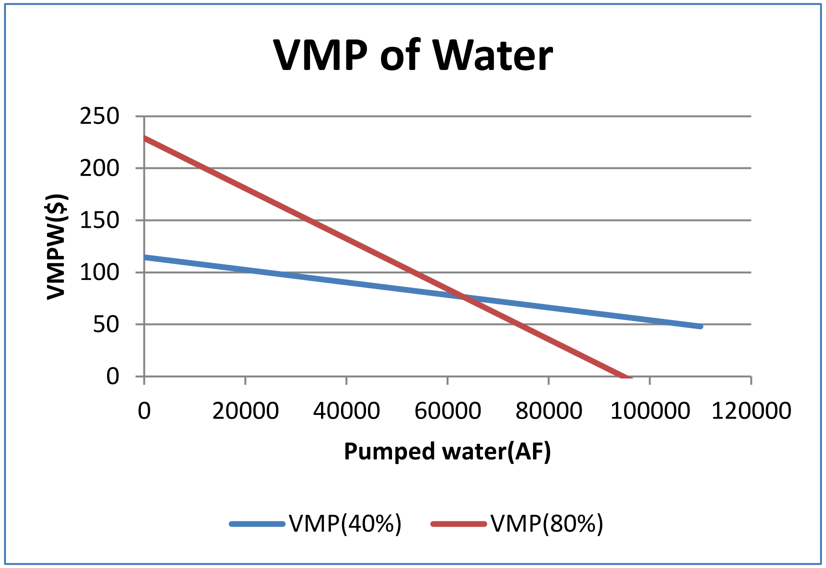
$\Theta = \theta \cdot wage$

θ: labor required for flood irrigation operation (hrs)

$$\frac{dL}{dk}(k) \le 0$$

Model

- Revenues($): revenue is area under the Value Marginal Product of Water (VMP).



- Net Present Value of Net Farm Benefits

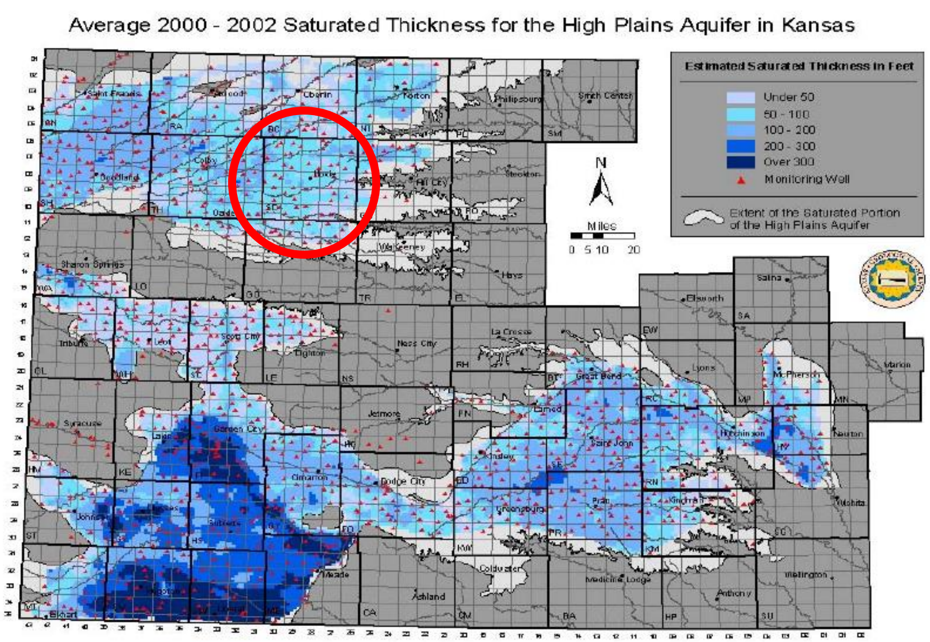
$$V = \int_0^{t^*} e^{-rt} \left[R(e(k)w) - \hat{C}(w,k;H) \right] dt$$

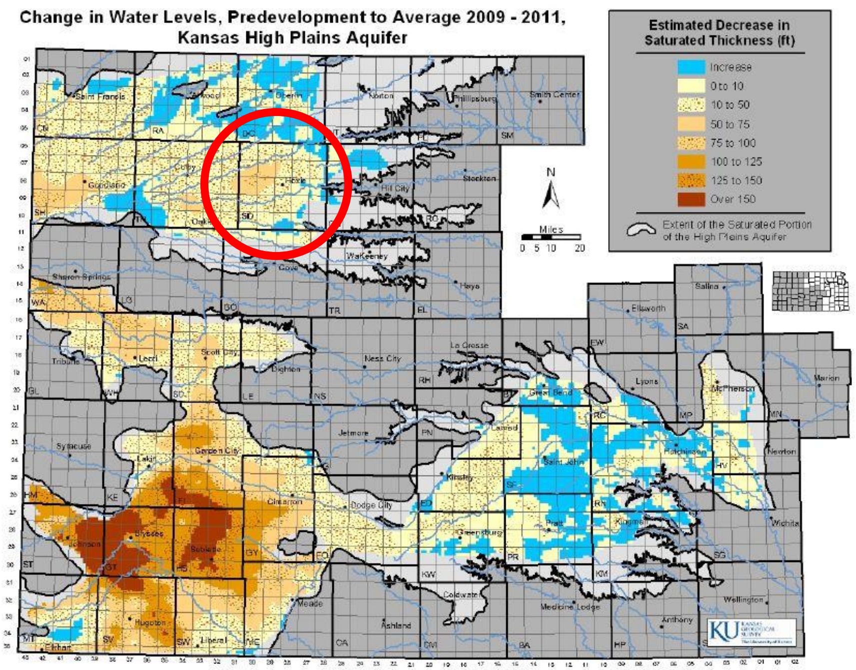
- Myopic solution:

$$\underset{\{w,k\}}{Max} \quad R(e(k)w) - \hat{C}(w,k;H)$$

- Planning solution: optimal control problem where w and k are the control variables and H is the state variable.

Case Study: Sheridan Co, KS





Case Study: Sheridan Co, KS

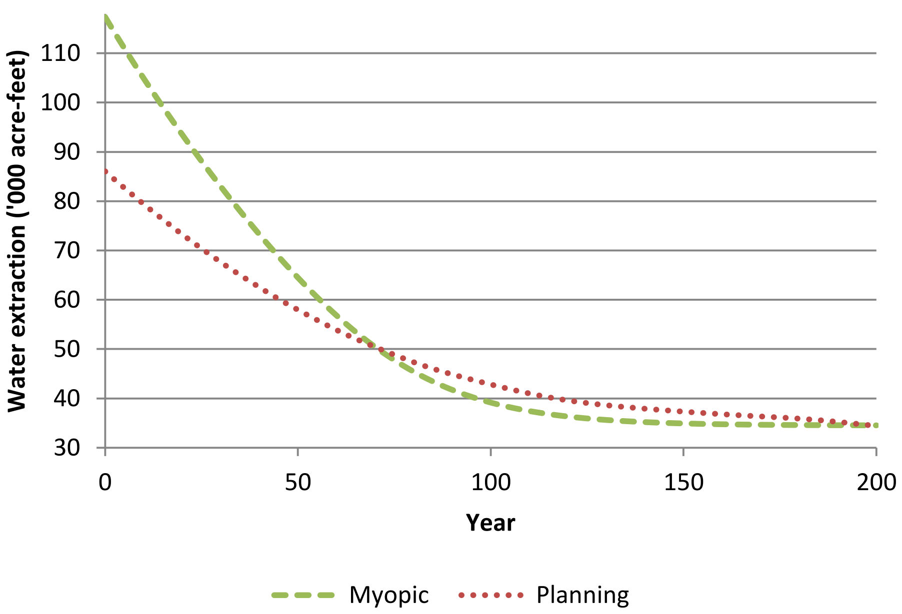
Table 1: Parameter and aquifer initial values for Sheridan, KS.

Parameter	Value
Area overlying the aquifer	415,620.50 acres
Irrigated area	77745 acres
Specific yield	0.1725
Depth to water	111.5 ft.
Saturated thickness	61.03 ft.
Drawdown	20 ft.
Natural recharge	28747.08 AF per year
Efficiency	
Flood irrigation	50 %
Center pivot	90 %
Subsurface drip	98 %
Capital costs	
Flood irrigation	$ 33 per acre
Center pivot	$ 575 per acre
Subsurface drip	$ 1188 per acre
Discount rate	3.89 %
Depreciation rate	10%
Baseline labor requirement	0.8 hrs per acre
Wage rate	$ 9.12 per hr.

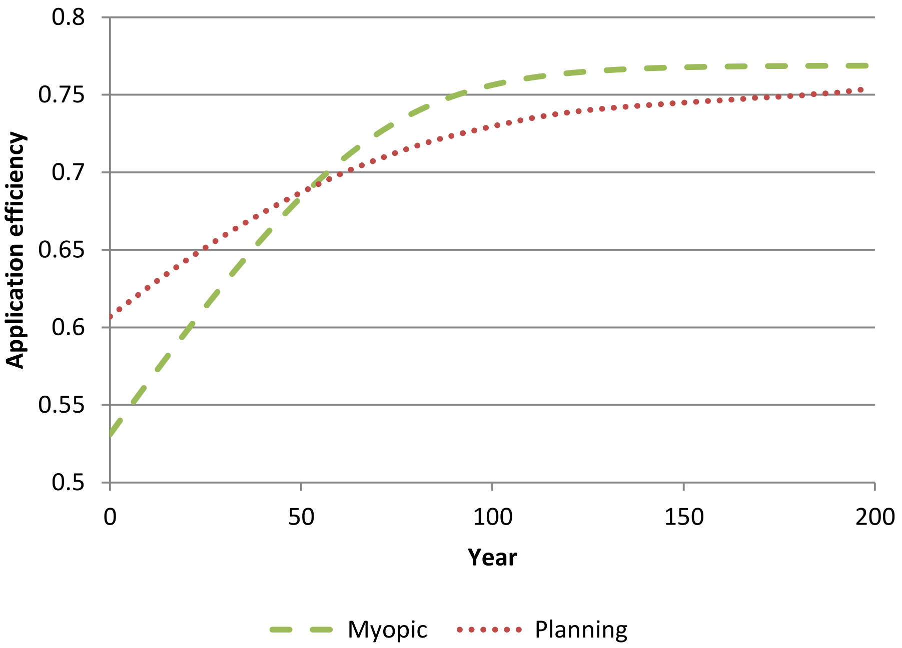
Case Study: Sheridan Co, KS

Baseline Simulated Results

Simulation Results: Water Extraction(AF)



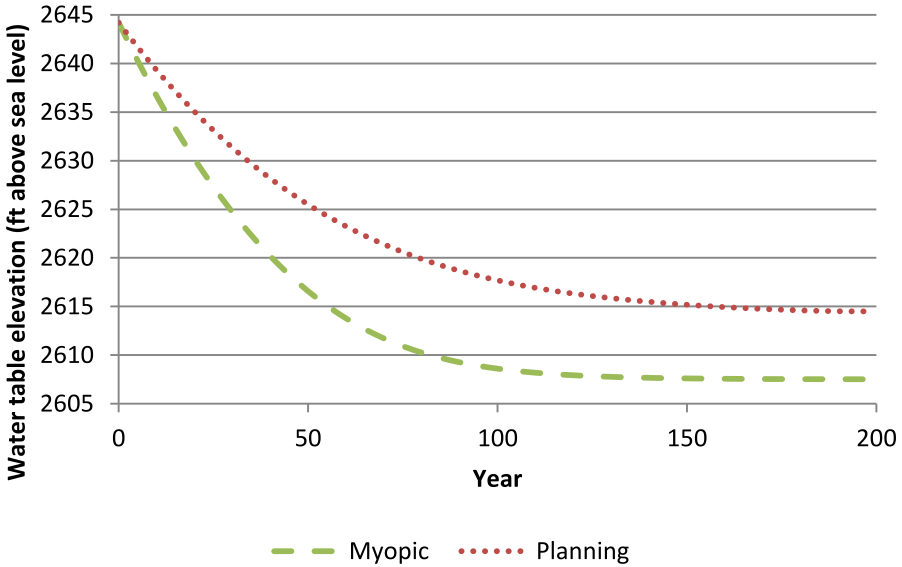
Simulation Results: Efficiency



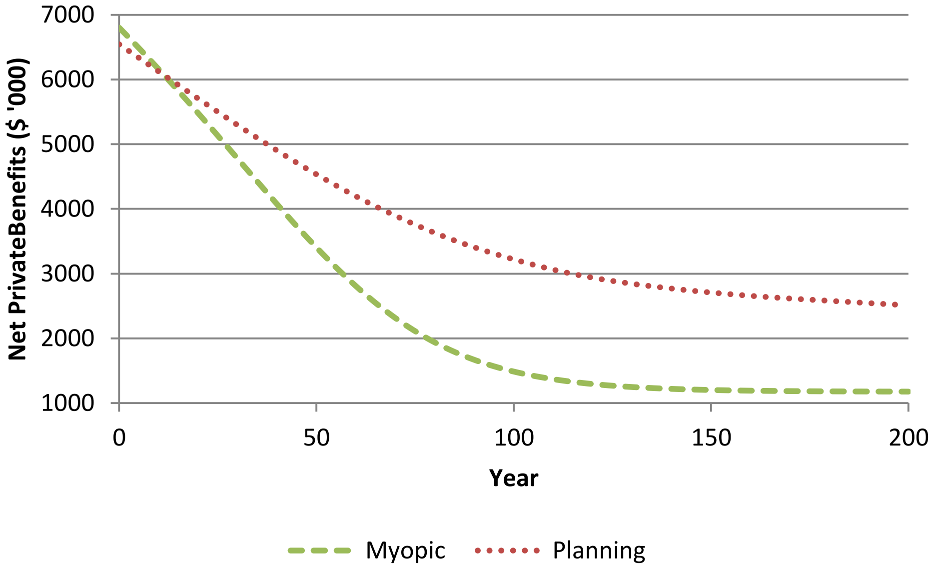
Case Study: Sheridan Co, KS

Baseline Simulated Results

Simulation Results: Water table height(ft)

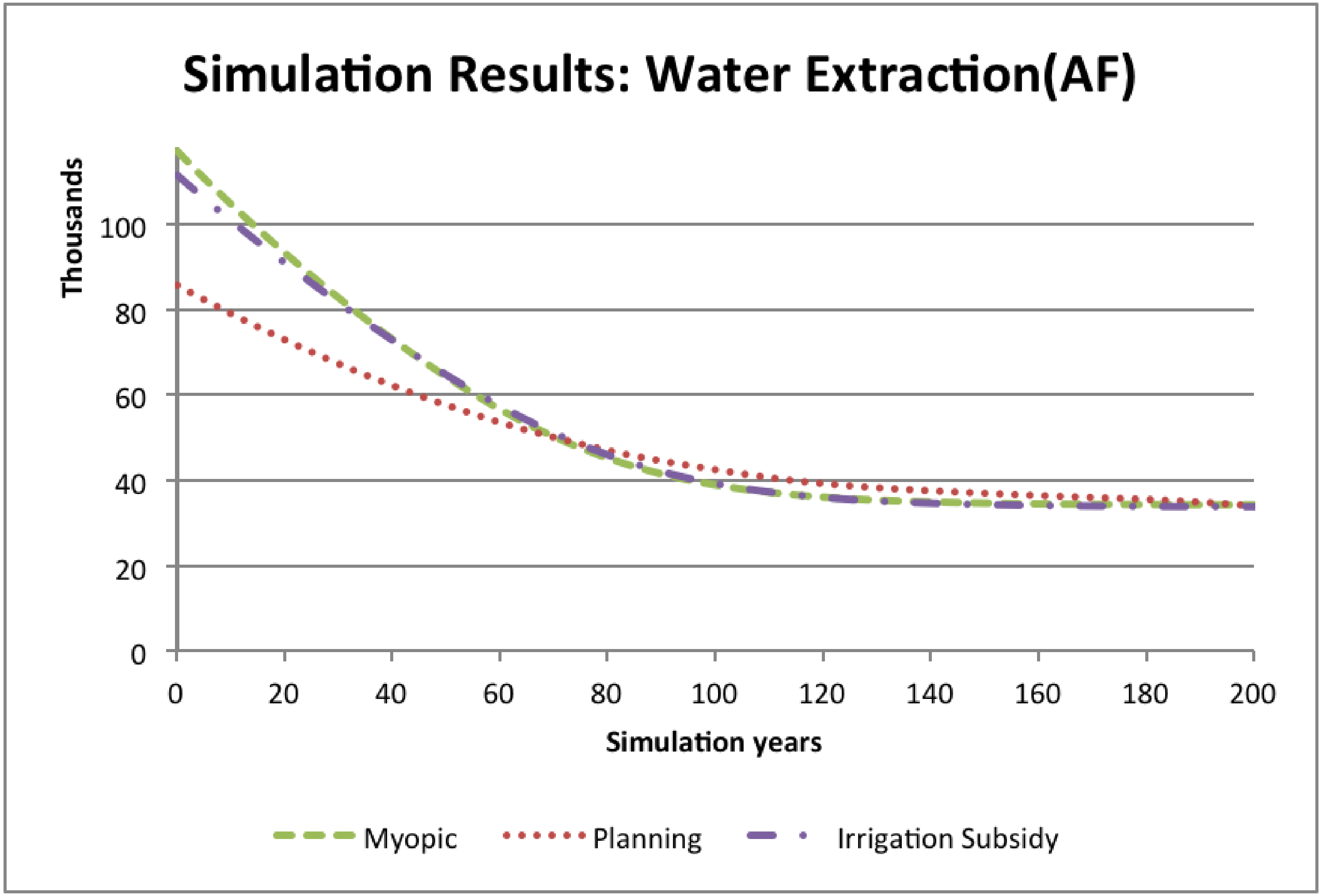


Simulation Results: Net Private Benefits ($)



Case Study: Sheridan Co, KS

Optimization given irrigation capital subsidy



Case Study: Sheridan Co, KS

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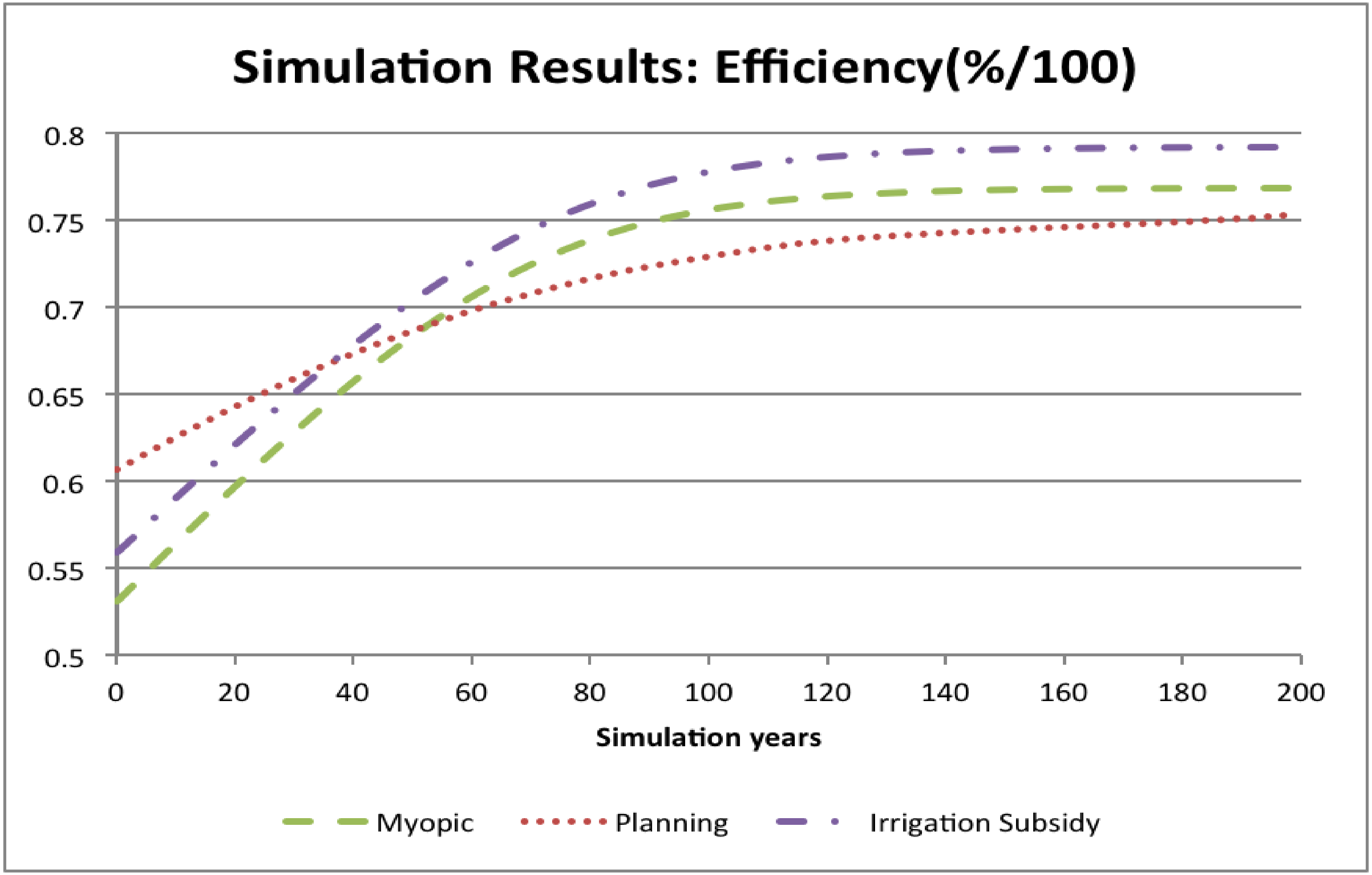

Case Study: Sheridan Co, KS

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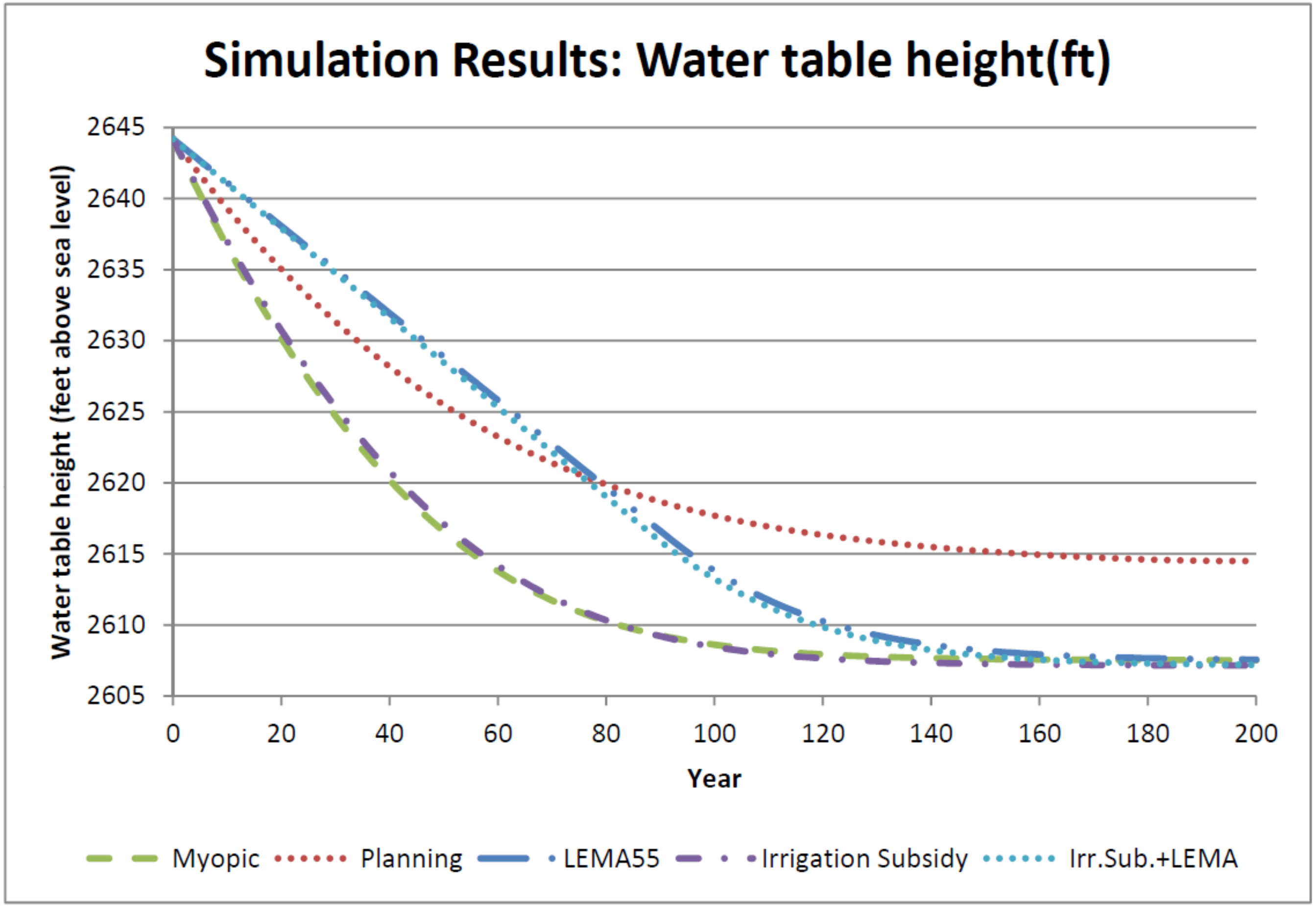
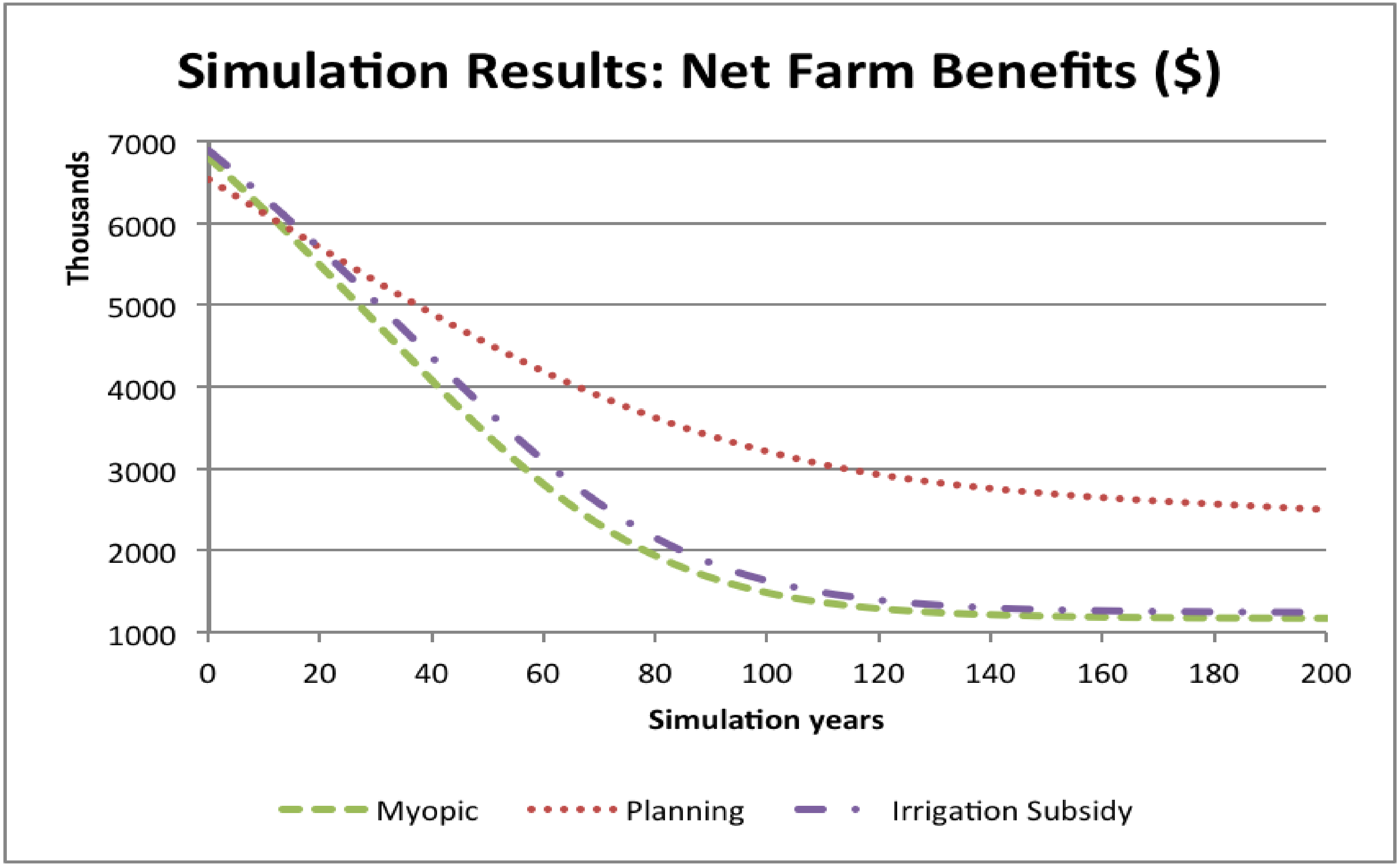


Case Study: Sheridan Co, KS

Optimization given irrigation capital subsidy



Case Study: Sheridan Co, KS

Optimization given irrigation capital subsidy

	Myopic	Planning	Subsidy
Net Farmer Benefits			
NPV ($ millions)	133.1	142.5	138
Gain ($ millions)		9.4	6.1
		7.04%	3.64%
Net Social Benefits			
NPV ($ millions)	133.1	142.5	135.3
Gain ($ millions)		9.4	2.2
		7.04%	1.67%

Case Study: Sheridan Co, KS

Conclusions

- Gains from management are larger than in early studies
- Competitive capital underinvestment in the short run but overinvestment in long-run
- Irrigation capital subsidies result in water savings and small social welfare improvements, capturing nearly 24% of potential surplus.

Q&A

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Case Study: Sheridan Co, KS

Table 2: Crop Water Requirement per acre for Sheridan, KS.

Crop	Area covered	NIR (AI)	NIR(AF)	Weighed NIR(AF)
Corn	86.9%	10.9	0.91	0.79
Soybeans	4.8%	10.1	0.84	0.04
Alfalfa	4.8%	11.8	0.98	0.05
Wheat	2.8%	6.5	0.54	0.01
Sorghum	0.7%	8.6	0.72	0.005
			C_R	0.897204

Table 3: Fitting of efficiency, return flow, and labor loading functions.

Function	Form	Fitted function
Application Efficiency	$e(k) = 1 - \hat{e}_1 exp[-\hat{e}_2 k]$	$e(k) = 1 - 0.551477e^{-0.00297k}$
Return Flow	$\alpha(k) = \hat{\alpha}_1 exp[-\hat{\alpha}_2 k]$	$\alpha(k) = 0.29257e^{-0.00192k}$
Labor Requirement	$L(k) = \hat{L}_1 exp[-\hat{L}_2 k]$	$L(k) = 1.1839e^{-0.00512k}$

Estimated VMP (inverse demand) for water

$$p^w(w,k) = 286.19e(k) - 0.00377e(k)^2 w$$