SUSTAINBLE OPTIMIZATION OF AGRICULTURAL WATER MANAGEMENT IN PAJARO VALLEY, CALIFORNIA

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INTRODUCTION

Water resources management challenges linked to agricultural industrialization, population growth, and climate change are well illustrated in California were its primary economic sector is agriculture. The highly manipulated hydrologic regime in this state has allowed for expansive growth but led to the depletion of water resources.

- Industrialization
- Population Growth
- Agriculture Industrialization
- Climate Change

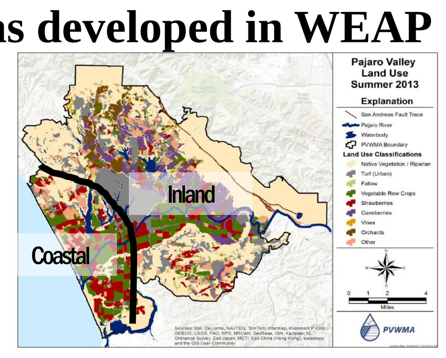
Agricultural water demands account for 80% of state-wide water use and continue to grow while water supply becomes less reliable in both quantity and quality (Hanak et al, 2011). Agricultural operations throughout the state use various adaptive management strategies to address resource management concerns based on social and environmental conditions

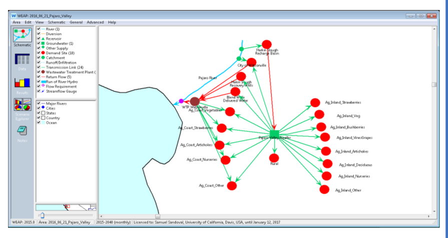
METHODS

Pajaro Valley Planning Area → Groundwater Simulation Model → Optimization Model → Model Coupling

Pajaro Valley groundwater model was developed in WEAP

- Area distribution: inland / coastal
- Studied crops:berries, vegetables, grapes, artichokes, apples, nurseries, and others.
- Timeline
  - 1966 to 2015 (Simulation of historic data)
  - 2016 to 2040 (Future Projection)
- Scenarios
  - Baseline (No water management)
  - Optimized (Water management)





Groundwater simulation model follows the Equation 1.

$$\Delta S_i = I_i - O_i$$

Where ΔS_i is the change in storage, I_i is the inflows and O_i is the outflows of the system. All variables are set in a yearly basis i

- Inputs
  - Recharge
  - Agriculture land and water use
  - Urban water use
- The simulation model was compared with the Integrated Hydrologic Model of Pajaro Valley by the USGS. Model validation was confirmed by the index of agreement (d=0.932) and the coefficient of efficiency (NSE=0.699)

Linear optimization model

- The objective function determines the optimal annual crop pattern by using limited water resources which could bring maximum agricultural benefit (Equation 2).

$$max\ F = \sum_{i=1}^{8}[B_i^n A_i^n - (A_i^n \times CD_i)CW_{in}] + \sum_{i=1}^{5}[B_c^n A_c^n - (A_c^n \times CD_c)CW_{cn}]$$

B: Monetary benefit (cost – revenue)
A: Allocated crop acreage
$CD_{i/c}$: Crop duty (inland/coastal)
$CW_{i/c}$: Cost of water (inland/coastal)
n: type of crop

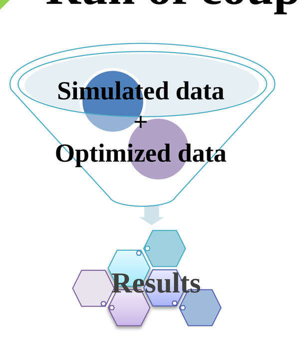
Linear programming model constraints
1) Minimum and maximum acreage
2) Land availability
3) Available water
4) Water demand

- **Economic budget estimation**

Profits were determined as net benefits by estimating costs and benefits.

- Annual cost of production
- Annual revenue per crop
- Energetic and water price

Run of coupled model

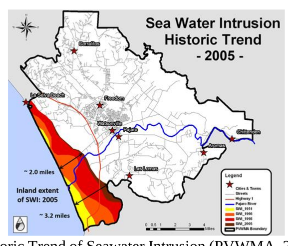


- Water use limitation by scenario
  - Baseline: 2016-2040 → 62.9 MCM
  - Optimized: 2016 → 62.9 MCM
    Every 5 years → reduction of 4.9MCM
    2030 - 2040 → 49.3 MCM
- The average of 50 projections of groundwater storage with a time frame window of 25 years was set as future scenario from 2015-2040

STUDY CASE: Pajaro Valley, California

Pajaro Valley (PV) is highly productive agricultural area uses groundwater as its primary water supply and has dealt with a historic imbalance between water pumping and aquifer recharge since the 1950s. This reoccurring imbalance has led to overdrafted aquifers, seawater intrusion, and salinization.

- **90%** of the water use for irrigation is groundwater
- PV basin is the 8th most overdrafter basin in CA
- Recorded seawater intrusión since 1950



Historic Trend of Seawater Intrusion (PVWMA, 2013)

RESULTS

Historic and future optimized projections of groundwater model

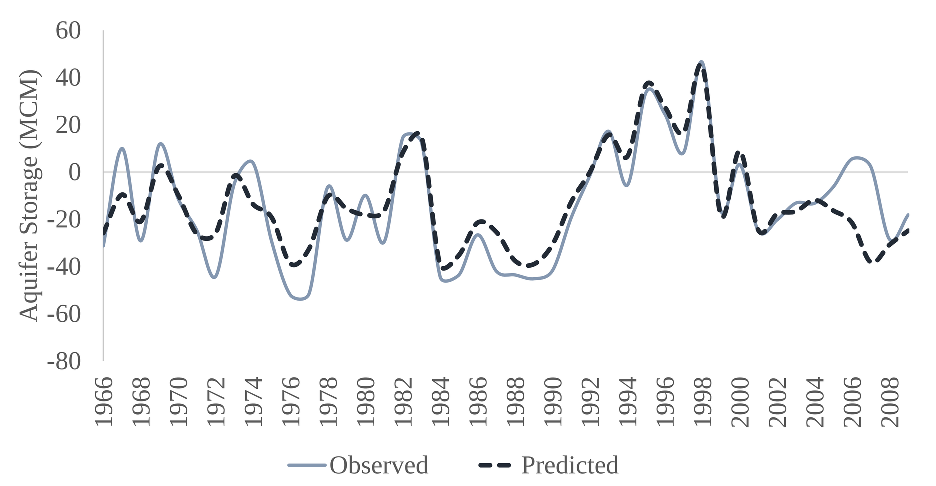


Figure 1. Historic net groundwater storage. Comparison between the USGS observed model and the predicted model. Statistical analysis model validation: *NSE* (0.699) and *d* (0.932).

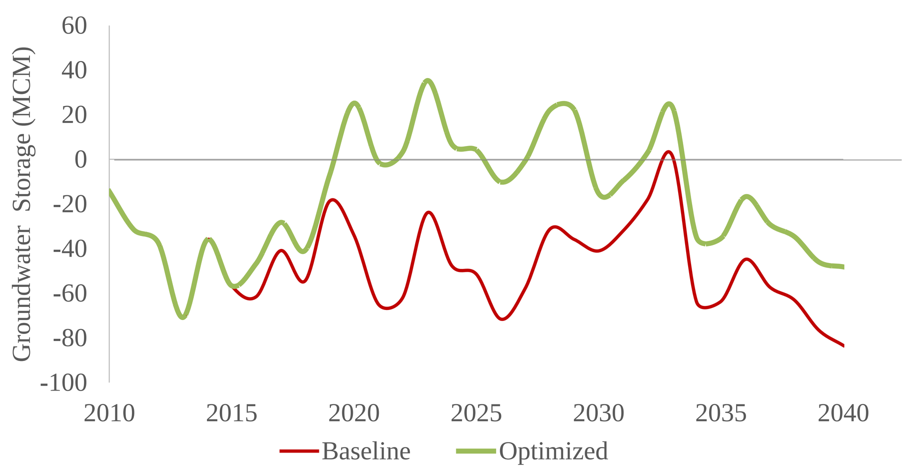


Figure 2. Future projection of the net groundwater storage. Comparison between baseline and optimized model scenarios.

Impacts in crop allocation, food production and economy

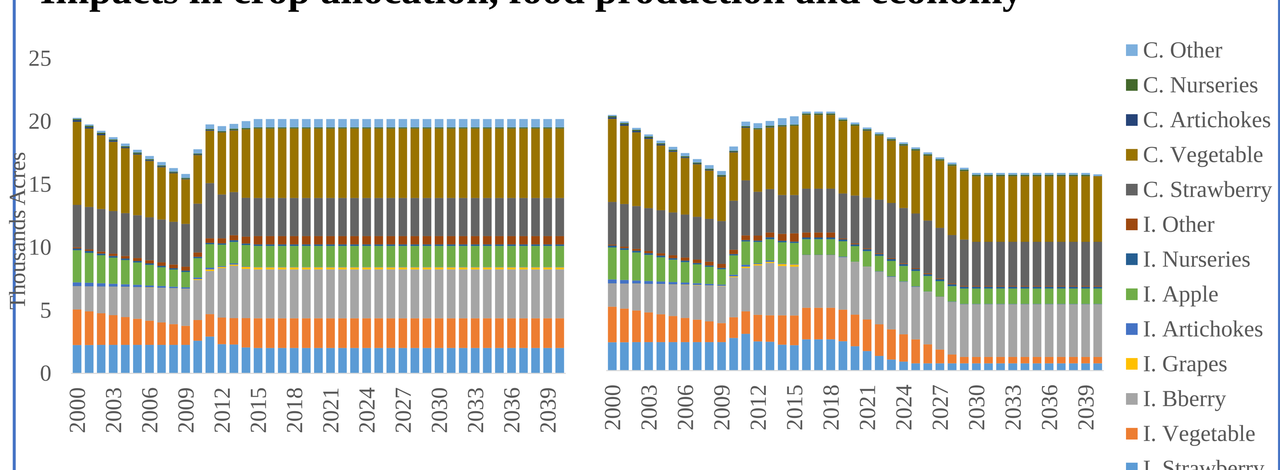


Figure 3. Projected agricultural land use under baseline scenario (left) and under optimized scenario (right)

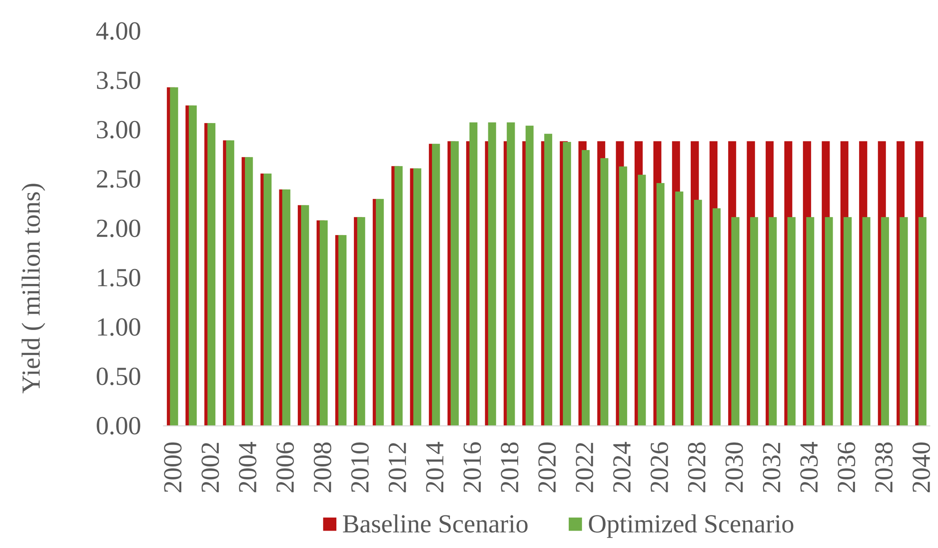


Figure 5. Food production (yield) comparison between baseline and optimized scenario.

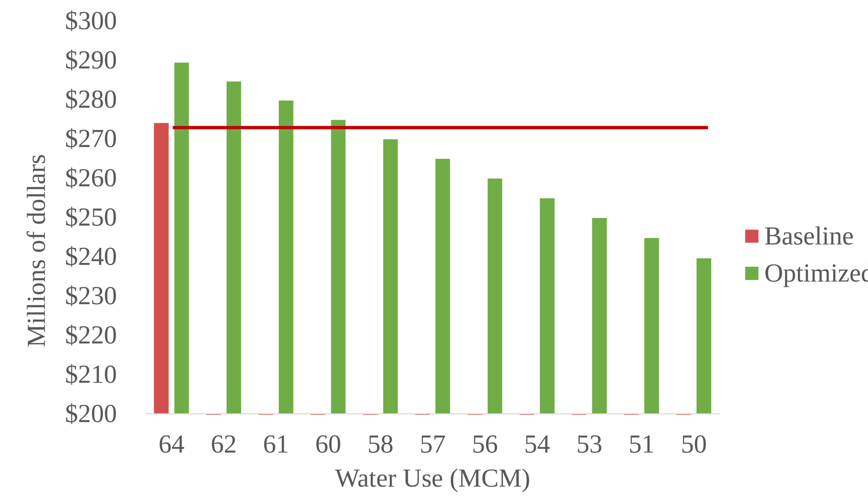


Figure 6. Total profit projection based on available water for baseline and optimized scenario. Water use for baseline scenario is constant in time

RESEARCH OBJECTIVE

Build a simulation-optimization model to serve as a sustainable agriculture water management tool in Pajaro Valley California.

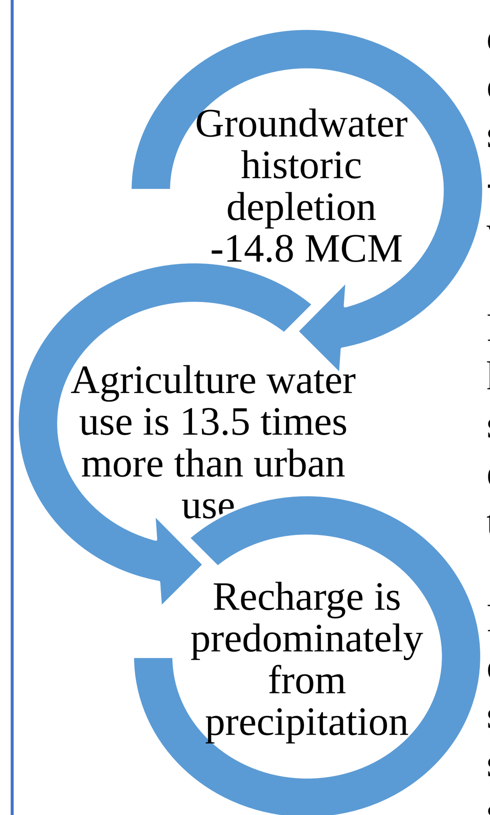
HOW?

By identifying the agricultural carrying capacity of a single groundwater basin that maximizes the agricultural profit while preventing groundwater overdraft.

Carrying capacity: Land use that results in a safe yield for the underlying aquifer (i.e. maximum amount of water that can be withdrawn without causing overdraft).

DISCUSSION

Groundwater model



The groundwater simulation model gives a detailed outline of how much water is pumped out and replenished into the aquifer. Results shows a historic depletion from 1966-2009 of -14.8 MCM leading to overdraft and sea water intrusion.

Population growth and intensive agriculture have a great impact on the outflows of the system. However, agriculture pumpage can extract as much as 98.6 MCM, which is 13.5 times more than urban water use.

Recharge depends merely on climatic conditions and the net groundwater system shows how very wet periods help the aquifer storage to recover while water demands grow steadily every year.

Optimized scenario

Results of the optimal scenario over 25 years (2015-2040) show that agricultural production must change to prevent groundwater overdraft and aquifer depletion. The **baseline projection** showed aquifer depletion could increase by ~240% in a period of 25 years.

Historic 42 years projection	15 years projection	25 years projection
-15.7 MCM	Optimized: -2 MCM Baseline: - 46 MCM	Optimized: -10 MCM Baseline: - 47 MCM

However, an **optimal and sustainable scenario** can be accomplished with:

- 15% reduction of total agricultural acreage
- 8.5% reduction in food production
- 4% average profit loss

→ Aquifer depletion reduced by 79%

Groundwater depletion can be reduced by the optimal allocation of crop land and available water while ensuring the maximum profit.

CONCLUSION

Groundwater depletion can
1) be modeled through a mass balance model based on land use, and
2) be reduced by the optimal allocation of crop land and available water while ensuring consistent agricultural profit.

This case study shows that land use changes and water conservation practices are key strategies for addressing sustainable groundwater management in California. Optimization techniques allowed us to evaluate the agricultural carrying capacity of Pajaro Valley groundwater basin. An integrated and future portrait of water demands, water supply and economics revealed significant room to apply hydro-economic modelling in agriculture study areas where hydrologic, social and economic niches converge.

Next steps: Model the impact of sustainable best management practices, new groundwater legislation, and climate change on the carrying capacity.

References:
Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). *Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56*. • Bardsley, W. E., & Purdie, J. M. (2007). An invalidation test for predictive models. *Journal of Hydrology, 338*(1-2), 57-62. doi:10.1016/j.jhydrol.2007.02.019 • Bolda, M. P., Tourte, L., Klonsky, K. M., & Moura, R. L. D. (2010). *Sample costs to produce strawberries, Central coast region*. • Census, U. S. D. (2014). *Historical Population of Watsonville, Santa Cruz County, CA* • Hanson, R. T., Schmid, W., Faunt, C. C., Lear, J., & Lockwood, B. (2014). *Integrated Hydrologic Model of Pajaro Valley, Santa Cruz and Monterey Counties, Califrnia*. • PVWMA. (2013). *2012 Basin Management Plan Update*.