**Determining Economic Benefits of Urban and Agricultural Water Use in California in regions supplied by the Lower Colorado River Basin**

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<https://github.com/fugalmatt/CEE-6410-Fugal/tree/main/Project%20Work>

**Abstract:**

This report details the expansion of the model described in “Lake Mead Water Bank based on the Principle of Divide Reservoir Inflow” (Rosenberg 2024). The additions to the model seek to show economic output associated with agricultural and urban water use in California within the Lower Basin of the Colorado River. Using crop production, municipal water usage, and urban economic output data, the model calculates the value of agricultural and urban water usage based on management allotments to both uses for each management area.

**Introduction and Problem Statement:**

This report first describes the problem that the model and model expansions seek to address. Next, the report describes the model formulation for the problem. It then describes the additions made to this project over previous work. The report will then detail the major findings of the model to date. After this, it will discuss the proposed next steps for the model progression. Finally, this report will cover the expected challenges in completing the model additions.

Water models serve various purposes for stakeholders, helping them understand the effects of resource allocation and management decisions and to visualize conflicting objectives. These models are especially valuable in addressing societal challenges associated with water use. According to the ASCE Code of Ethics, civil engineers developing such models must consider society’s current and anticipated needs while striving to enhance the quality of life for humanity. This project addresses these principles by focusing on integrating economic output into water models, highlighting the monetary benefits of water use.

Building on the existing immersive online model developed by David Rosenberg (Rosenberg 2024), this project incorporates economic factors that reflect the value of water in agricultural and urban contexts. The model accounts for revenue generated per acre-foot of water allocated to agriculture and the economic output of urban users, represented by nonfarm labor wages and the municipal water usage associated with those laborers. This contribution aims to support more informed decision-making by combining economic metrics with existing water modeling tools.

**Literature Review:**

The economic and resource challenges posed by water scarcity are multifaceted and intensifying due to climate change, population growth, and competing demands across sectors. Research highlights the influence of climate change on hydrologic systems and underscores the importance of integrating multi-sector, multi-scale economic considerations to develop adaptive water management strategies. The economic impacts of water scarcity are not solely dictated by physical water availability but are significantly affected by global trade dynamics and market adaptations (Dolan et al. 2021).

Sustainable water use in agriculture has been extensively studied over the past 25 years. Bibliometric analysis reveals an exponential growth in publications, particularly in environmental and agricultural sciences, with leading contributions from countries like China and the United States. This research emphasizes the role of sustainable management practices in mitigating water scarcity's long-term effects (Belmonte-Ureña et al. 2018).

Regional case studies provide valuable insights into water use trends and their implications for policy and management. Water use in California has stabilized since the 1980s, driven by urban and agricultural efficiency measures (Cooley n.d.). The trends observed in California offer potential lessons for other western U.S. states in assigning economic values to water activities and optimizing resource allocation. Irrigation dominates water use in the Colorado River Basin, accounting for 83-90% of consumption (Maupin et al. 2018).

Scarcity and management challenges are particularly notable in regions with strained water resources, such as the Colorado River Basin. Discrepancies in water use reporting methodologies between the U.S. Geological Survey and the Bureau of Reclamation suggest opportunities for improving water use estimation and management through enhanced collaboration (Bruce et al. 2019). Both agencies could achieve more accurate and actionable data by reconciling differences in sector definitions and estimation methods, especially for critical sectors like irrigation and municipal use.

The water crisis in the Colorado River Basin exemplifies the severity of resource challenges in arid regions. Research has quantified the substantial decline in reservoir volumes due to overuse and reduced inflows, projecting further reductions due to climate change (Shmidt et al. 2023). Proposed solutions include reducing water usage by up to 2.5 million acre-feet per year, reallocating storage between major reservoirs, and reworking water laws to ensure proportional distribution. These measures, coupled with urban and agricultural efficiency improvements, could stabilize the basin’s water supply amidst ongoing challenges.

Innovative models and frameworks are also contributing to optimizing water use. Models can examine deficit irrigation and water leasing strategies to maximize economic returns for farmers, emphasizing the variability of crop water needs and the influence of leasing prices (Varzi et al. 2019). While the model requires refinement for broader adoption, it offers a promising avenue for guiding water pricing and resource allocation.

Immersive, collaborative modeling approaches show reservoir operations in response to changing hydrologic and societal conditions. This methodology complements existing models by provoking stakeholder engagement (Rosenberg 2024).

Running an immersive model requires proper water valuation method selection to ensure reasonable results. The valuation of water in municipal applications involves balancing affordability, efficiency, and sustainability (Young 2005). The selected findings detailed below are relevant to the project.

1. Water Valuation for Municipal Water Demand
   1. Components:
      1. Water demand is divided into household consumption, public services, and commercial uses. Demand for essential uses (e.g., drinking, sanitation) is less elastic, while discretionary uses (e.g., lawn irrigation) are more sensitive to price changes.
   2. Elasticity:
      1. Municipal water demand is generally price inelastic, but higher elasticity for non-essential uses provides an opportunity for conservation-focused pricing strategies.
   3. Pricing Structures
      1. Uniform Pricing: A flat rate per unit. It is simple but does not promote conservation.
      2. Increasing Block Rates: Prices increase with usage, encouraging efficiency among high-volume users.
      3. Seasonal Pricing: Higher rates during peak demand (e.g., summer) reflect increased supply costs.
   4. Cost Recovery and Equity
      1. Infrastructure Sustainability:
         1. Cost-recovery pricing is essential for maintaining municipal water systems. Underpricing water leads to underinvestment in infrastructure, resulting in long-term inefficiencies.
      2. Equity Considerations:
         1. Pricing must ensure water remains accessible for all socio-economic groups. Inadequate access to water has direct public health implications, indicating the need for policy design.
      3. Conservation Policies
         1. Municipal water conservation efforts are essential for long-term sustainability. The chapter identifies several strategies:
         2. Incentives: Rebates for water-efficient appliances.
         3. Public Education: Awareness campaigns on water-saving practices.
         4. Seasonal Restrictions: Limits on non-essential water uses like outdoor irrigation.
         5. Technology: Advanced metering to monitor usage and identify inefficiencies.

Young primarily focuses on pricing water effectively for municipal water supply managers to best serve their jurisdiction. As such, little is learned about quantifying the value created by urban water users monetarily. Thus, the additions to the model use median nonfarm salary multiplied by nonfarm population to quantify the benefit generated from urban water use limits defined in California AB 1668 and SB 606.

Agricultural water valuation requires considering both inductive and deductive methods (Young 2005). The following list covers both approaches, considering their practicality and relevance to specific valuation models, followed by the method selected for the model.

1. Inductive Methods for Agricultural Water Valuation
   1. Water Rights Market Evaluation
      1. This method evaluates the buying and selling power of water, so it does not apply to this model. Our focus is on the productive value of water in irrigation, not on market transactions, which are addressed in the crop in the immersive model.
   2. Land Value Method
      1. This method calculates the economic impact of ceasing irrigation based on land-use changes. However, given the assumption that land use does not permanently change (irrigation may stop but can be reinstated), this method is also excluded.
   3. Hedonistic Property Value
      1. This technique assesses water’s value through property price changes but is omitted here because it does not meet the model's needs.
2. Deductive Methods for Agricultural Water Valuation
   1. Residual Method
      1. The most frequently used approach in irrigation valuation, the residual method, calculates water's contribution to profit by focusing on the value of outputs (crop production). This aligns with the model's objective of evaluating profit while accounting for costs and returns.
      2. This method avoids bias, as pricing is based on established data.
      3. It effectively distinguishes between high-value crops (e.g., vegetables, fruits, vines) and basic crops (e.g., rice, wheat, corn), reflecting the diversity of agricultural outputs.
      4. A notable observation is that over 60% of irrigated land in California is still dedicated to basic crops, so the model will maintain this as a recommended comment in crop selection so as not to disrupt food production requirements for the Lower Basin
   2. Alternative Cost Method
      1. This method, which evaluates the costs of switching from surface water to groundwater, is excluded from the model due to its lack of relevance to the specific focus on surface irrigation.

Based on the various methods presented by Young, the Residual Method is used to evaluate the agricultural water value most suitable for the model's purposes.

Together, these studies demonstrate the importance of integrated, data-based approaches to water allocation, which allow stakeholders to balance competing demands.

**Model Formulation:**

1. Model Choices:
   1. The model introduces two new choices based on water allotted to each entity. First, users determine a percentage of their allocated water for agricultural use and a percentage of their allocated water for urban use. Based on whether entities select to use water for agricultural use, they may select up to three crops best suited to grow in their areas. Each crop is assigned a percentage of agricultural land used in the area, with no more than 40% of the total available land allotted to high-value crops, as indicated by the dropdown menu.
2. Computations
   1. Based on the spreadsheet sample section below, new calculations will be the urban benefit (Equation 1) and agricultural benefit (Equation 2) using the following equations:
   2. Zurban and Zag represent benefit in US dollars, Curban and Cag represent the value of water for their respective uses, and Xurban and Xag represent the quantity of water used for each purpose.
3. State Variables:
   1. The new computations assume available water is a state variable. This state variable is calculated using the existing immersive model based on user selections.
4. Outputs:
   1. The final outputs of this model will be the benefit generated from crop growth and urban productivity expressed in dollars.
5. Feedback to next step:
   1. There is no feedback to the next timestep.
6. Model Overview (Spreadsheet Layout)
   1. Figure 1 shows a sample spreadsheet layout with sample calculations from a modeling session held by the authors.



Figure 1 - Spreadsheet Sample with Modeling Session Results

**Contributions over Previous Work:**

This project considers urban and agricultural water allotment of California’s water allocation for the Lower Basin of the Colorado River. Modelers can allocate water for either urban or agricultural use. The spreadsheet has also been updated to include the ability to select the two to three most common crops planted for each year for each state and the proportions of agricultural water allocated to each crop.

The spreadsheet includes data on the common crops for Californian farms using water from the Colorado River from Imperial Valley Irrigated Lands Coalition (Turner 2024), their yield and unit price from Riverside County (Riverside 2022), and their water demands from the California Natural Resources Agency (Shakouri 2024). Users can select up to three common crops from a list of common crops grown in California each year. Users can allocate the volume of water for agricultural use and then further assign the percentage of agricultural water used for each of the three crops. The spreadsheet will then calculate the crops’ gross profit based on the volume of water assigned.

The spreadsheet also includes data from the US Bureau of Labor Statistics (BLS) (BLS 2024) for population data and average income. Bills from the California State Water Resources Control Board were used to estimate the volume of water required per urban user serviced. The model user can allocate the amount of water for urban use, which the model will then use to calculate the total amount of urban water users serviced and the associated total income.

**Major Findings:**

Running an immersive session yielded comments on both the economic activity generated by agricultural and urban water use and the limitations of the model. Using a random combination of low and high-value crops, keeping in mind the recommendation that no more than 40% of crops grown are high-value crops, the results showed that the ratio of urban-generated benefit to agricultural-generated benefit ranged from 11.4 to 139.

More interestingly, the modeling session provoked discussion on the model's limitations. Agricultural users noted that urban water use is not fully productive, as much of the water supply is used for landscape irrigation and not daily living. The model in its current state does not reflect this, as there is insufficient data to determine how water is used in urban environments. Installation of dual-metered systems, tracking both culinary or domestic use and irrigation use separately, could help address this limitation. Urban users also noted that reducing the maximum water use permitted under AB 1668 and SB 606 does not necessarily correlate with a reduction in urban productivity. Finally, users noted that productivity at a personal level can be related to the surrounding environment, as appealing or well-landscaped work environments may allow individuals to work more effectively than unappealing work environments.

**Conclusion:**

This model incorporates agricultural and urban data for the state of California to create an immersive model that allows for experimentation and discussion of California’s allocation of water from the Colorado River. It builds on the contributions, data, and ideas of several sources, using a more generalized immersive model as a base to explore these concepts. The model uses the data to estimate the economic output of various water allocation strategies as an indicator of their feasibility and benefits.

**Annotated Bibliography:**

Title: Los Angeles area economic summary.

Author: U.S. Bureau of Labor Statistics. (2024, December 3).

Key Points:

* Retrieved from <https://www.bls.gov/regions/economic-summaries.htm>
* Provides nonfarm population and wage data for the Los Angeles section of the area supplied by Lower Basin diversions

Title: Riverside area economic summary.

Author: U.S. Bureau of Labor Statistics. (2024, December 3).

Key Points:

* Retrieved from <https://www.bls.gov/regions/economic-summaries.htm>
* Provides nonfarm population and wage data for the Riverside section of the area supplied by Lower Basin diversions

Title: Enrolled bill text for AB 1668 and SB 606: Making water conservation a California way of life.

Author: California State Water Resources Control Board. (n.d.).

* States the maximum water use in urban areas is 55 gal/person/day as of December 2024.
* Retrieved from <https://waterboards.ca.gov/water_issues/programs/conservation_portal/docs/enrolled_ab1668_sb606.pdf>

Title: Statewide Agricultural Water Use Data 2016\_2020

Authors: Gholam Shakouri, Scott Hayes

Key Points:

* Retrieved from <https://data.cnra.ca.gov/dataset/agricultural-water-use-data-2016-2020>
* Provides Evapotranspiration of Applied Water (ETaw) data for common crops in California using Colorado River Water

Title: Evaluating the economic impact of water scarcity in a changing world

Authors: Flannery Dolan, Jonathan Lamontagne, Robert Link, Mohamad Hejazi, Patrick Reed, Jae Edmonds

DOI: [10.1038/s41467-021-22194-0](https://doi.org/10.1038/s41467-021-22194-0)

Key Points:

* Climate change, basin-level water resources, and adaptive capacities of managed systems influence water scarcity.
* The study links a global human-Earth system model, a global hydrologic model, and a metric for economic surplus loss due to resource shortages.
* Major hydrologic basins can experience significant economic impacts due to global trade dynamics and market adaptations.
* Market adaptation can magnify economic uncertainty relative to hydrologic uncertainty.
* The study emphasizes the need to consider multi-sector, multi-scale economic teleconnections in addressing water scarcity.

Title: Economic Analysis of Sustainable Water Use: A Review of Worldwide Research

Authors: Luis Jesús Belmonte-Ureña, Encarnacion Pajares, Juan F. Velasco-Muñoz, José A. Aznar-Sánchez, Isabel M. Román-Sánchez

DOI: 10.1016/j.jclepro.2018.07.066

Key Points:

* The study reviews 25 years of international research on sustainable water use in agriculture.
* A bibliometric analysis was conducted, sampling 2084 articles.
* Results indicate exponential growth in the number of articles published per year.
* Environmental Science and Agricultural and Biological Sciences are the main categories of research.
* China, the U.S., Australia, India, and Germany are the leading countries in this field.
* The study emphasizes the importance of sustainable water management practices to address water scarcity.

Title: Urban and Agricultural Water Use in California, 1960–2015

Authors: Heather Cooley

DOI Number: Not applicable

Key Points:

* The study covers water use trends from 1960 to 2015, focusing on urban and agricultural sectors.
* Data from the California Department of Water Resources (DWR) was used for analysis.
* Total water use in California has stabilized since the 1980s.
* The report discusses the factors influencing these trends and their implications for future water management.
* Report can help assign economic values to various activities associated with water use in California. Results may be generalized to other Western states.

Title: Estimates of Water Use and Trends in the Colorado River Basin, Southwestern United States, 1985–2010

Authors: Molly A. Maupin, Tamara Ivahnenko, and Breton Bruce (2018)

DOI: <https://doi.org/10.3133/sir20185049>.

Key Points:

This report comprehensively describes the estimations for all water use from the Colorado River Basin between 1985 and 2010 and the estimation methods used by the USGS. Total water usage averaged 17 million acre-ft per year, 78% of which was surface water usage, and was evenly split between upper and lower basin water use. Irrigation was the largest water user, accounting for 83-90% of the usage; this was followed by public-supply usage accounting for 6-13%. Hydroelectric usage was not accounted for, as any losses were attributed to reservoir evaporation, which the USGS does not report. The water usage of all the states in the basin was tracked, with water usage being greatest in Arizona and Colorado and smallest in California, Nevada, and New Mexico. Data was collected from various sources, with federal and state agencies being the biggest contributors; the compilation method for the data varied by state.

Title: Comparison of U.S. Geological Survey and Bureau of Reclamation Water-Use Reporting in the Colorado River Basin

Authors: Brenton W. Bruce, James R. Prairie, et al. (2019)

Doi: <https://doi.org/10.3133/sir20185021>.

Key Points:

This report summarizes the methods used by the USGS and Bureau of Reclamation in estimating water usage in the Colorado River Basin and how future cooperation may lead to improved estimations. The two agencies differ on the categorization of water use. Both agencies use similar categorizations for livestock, thermoelectric cooling, and mining water usage, but they differ in defining irrigation, municipal, and industrial water usage, and interbasin water transfers. The agencies also differ on methods for estimating the upper and lower basin water use; the USGS uses similar methods in the upper and lower basin as they use in the rest of the US, while the Bureau of Reclamation uses estimations of diversions in the lower basin and models for estimating water usage in the upper basin. Additionally, the USGS mainly focuses on the volume of water withdrawn by each of its 12 defined sectors. In contrast, the Bureau of Reclamation focuses on how each of its ten defined sectors uses water. The USGS and Bureau of Reclamation use various estimation methods, with each agency having methods that are better suited for some water use estimations; this report suggests that combining methods used and working together to create new and improved methods will benefit both agencies in estimating water usage in the basin.

Title: The Colorado River water crisis: Its origin and the future

Authors: John C. Shmidt, Charles B. Yackulic and Eric Kuhn (2023)

Doi: <https://doi.org/10.1002/wat2.1672>.

Key Points:

This report covers the severity of the water shortage in the Colorado River Basin and potential solutions to the issue. Between 2000 and 2020, water usage in the basin was approximately 1.5 million acre-ft per year, more than inflows on average, leading to a 33.5 million acre-ft decline in volume in Lake Mead and Lake Powell between 2000 and 2023. This is primarily due to the decrease in inflow into the basin, with the average annual inflow between 2000 and 2023 being 13% less than between 1930 and 1999. The yearly inflow is expected to continue to decline because of climate change, with an estimated 1-3 million acre-ft per year decline by 2050. To accommodate the decrease in inflow, water usage would need to be reduced by 1.5 million acre-ft per year to stop the depletion of Lake Mead and Lake Powell, with a roughly 2.5 million acre-ft per year decrease required to refill the reservoirs. Opportunities to reduce water usage are available for mid-size urban areas, specifically for populations between 100,000 and 1,000,000 people; reduction in agricultural use is also possible, with the lower basin proposing to subsidize farmers by $1 billion. Combining storage into solely one of the two reservoirs (Lake Mead or Lake Powell) should also be considered to aid in water management. This report suggests that part of the solution will need to be reworking the water law to be a proportional distribution of water to account for further projected decreases in inflow.

Title: Optimal Water Allocation under Deficit Irrigation in the Context of Colorado Water Law

Authors: Manijeh Mahmoudzadeh Varzi, Thomas J. Trout, et al. (2019)

DOI: 10.1061/(ASCE)IR.1943-4774.0001374.

Key Points:

This report describes a model to optimize water usage for a farm with a single crop based on water leasing and deficit irrigation practices. A farm in the South Platte Basin was assessed as a case study for using this model and for the effectiveness of deficit irrigation. The case study found that for the water leasing prices for that area and time, the optimal water use was to use deficit irrigation or to lease all water; this was due to high water leasing prices. The case study looked at sunflower and maize crops and found that deficit irrigation was viable for maize for a broader range of leasing prices than for sunflowers because the sunflowers' water usage is less “concave,” this can be more generally applied that crops with more “concave” water usage are more viable for deficit irrigation. This model was found to be too imprecise and challenging for individual farmers, but it is still a viable method for defining water leasing prices.

Title: Lake Mead Water Bank based on the Principle of Divide Reservoir Inflow.

Author: David E. Rosenberg (2024)

DOI: <https://github.com/dzeke/ColoradoRiverCollaborate/tree/main/LakeMeadWaterBankDivideInflow>.

Key Points:

This repository provides a description of the existing model, which we are supplementing with this project.

Title: Determining the Economic Value of Water

Author: Robert A. Young (2005)

Key Points:

* Chapters 5 and 7 provide the basis for calculating the value of water when used for municipal (urban) and agricultural use.