Optimal Management of Basin Water Allocation in the Presence of a Terminal Lake: The Case of the Great Salt Lake Basin

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Introduction

- Terminal lakes and their associated river basin systems in many parts of the world are under serious threat from rising populations, economic growth, and climatic variability.
- Increasing upstream water consumption patterns lowered the Great Salt Lake elevation by 11 ft and reduced its volume by 48% since the pioneers colonized Salt Lake Valley in 1847. The lake's water levels will continue to decline under future development goals of the state [1].
- Agriculture has been the largest contributing sector, with upstream irrigation accounting for more than 60% of the reduced water flows to the lake [1].
- In March 2019, the Utah Legislature and the Governor adopted the Concurrent Resolution to Address Declining Water Levels of the Great Salt Lake seeking for policy that supports effective ways to maintain or raise lake levels, while appropriately balancing economic, social, and environmental needs [3].

Figure 1. The Great Salt Lake Basin [2]

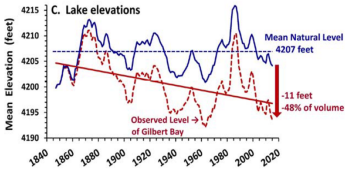

Figure 2. The Great Salt Lake elevation [1]

Overview & Objectives

- A framework is developed for determining the economically efficient allocation of water from a river basin across different sectors in the presence of a terminal lake.
- This framework may be used to guide policymakers for the management of economic growth and climate related pressures on water resources of the basin while assuring sustainability of its terminal lake.
- An illustrative application of the framework to the Great Salt Lake basin is provided. The primary goal is to explore the social welfare gain from cooperation between upstream and downstream water users. Impacts of economic development and climate change on the benefits from such cooperation are also studied with the help of sensitivity analysis.

Methods

- Sustainability of the terminal lake is achieved by requiring total water inflows to equal total water outflows, thereby stabilizing lake water stock and elevation levels. The imposition of this constraint at each time period also allows for static analysis of the basin water allocation problem.
- River water diversions to support upstream agriculture, industry, and residential sectors reduce water inflows to the Great Salt Lake, while water drawn from the lake for mineral extraction constitutes a water outflow. Shrimp production from the lake does not consume significant water.
- Residential sector water consumption is given high priority and determined by exogenous factors related to economic development, like local population needs, and past year average water usage.
- Social welfare from water allocation at the basin level is computed under two scenarios: non-cooperative management and cooperative management.
- In the non-cooperative management scenario, water diversions by upstream agriculture and industry are determined by their profit maximization goals without regard to consequences for downstream mineral extraction industry, which is likely to suffer most given the sustainability constraint.
- Cooperative management maximizes overall net benefits from water allocation subject to the sustainability constraint and achieves economic efficiency.
- The model's parameters are estimated mostly using data from the published literature [1,4,5] and various government reports provided by USDA, NOAA, and USGS. Reasonable assumptions are used in the exceptional cases where the desired data are missing.

Results of Case Study

Management alternatives	Location	Sector	Water used (million gallons)	Net benefit	Total net benefit
Non-cooperative management	Upstream	Agriculture	826,534	398,659,941	
		Residential	80,670	-	
		Industry	2,277	15,549,613	
	Downstream	Mineral extraction	67,819	600,992,737	
		Shrimp harvesting	0	912,958,407	
					1,368,462,994
Cooperative management	Upstream	Agriculture	804,955	397,160,513	
		Residential	80,670	-	
		Industry	2,254	15,548,004	
	Downstream	Mineral extraction	89,412	971,959785	
		Shrimp harvesting	0	41,295,032	
					1,425,963,335
		Increase in total net benefit from cooperation			**57,500,341**

- Sensitivity analysis examines the impact of possible changes in natural water diversion, and residential water demand, with extent of change in each parameter determined as follows:
  - Utah is expected to receive 9% less than its historical (1971-2000) snow water equivalent (SWE) by the end of 2070 [6]. As a result, the Great Salt Lake basin is projected to receive an approximately 8.1% decline in streamflow [7,8].
  - Bear River Development Act is estimated to divert about 30% of its total water for northern Utah residents, and the Bear river basin contributes 32% of the total inflow to the Great Salt Lake. The resulting impact of the Act on upstream residential demand would be to increase it by 9.6%.

8.1% Natural Water Diversion Increase

Management alternatives	Location	Sector	Water diverted (million gallons)	Net benefit	Total net benefit
Non-cooperative management	Upstream	Agriculture	826,534	398,659,941	
		Residential	80,670	-	
		Industry	2,277	15,549,613	
	Downstream	Mineral extraction	62,840	883,479,881	
		Shrimp harvesting	0	41,295,032	
					1,338,984,467
Cooperative management	Upstream	Agriculture	800,111	396,411,873	
		Residential	80,670	-	
		Industry	2,248	15,547,200	
	Downstream	Mineral extraction	89,291	971,939,697	
		Shrimp harvesting	0	41,295,032	
					1,425,193,803
		Increase in total net benefit from cooperation			**86,209,336**

9.6% Residential Water Demand Increase

Management alternatives	Location	Sector	Water diverted (million gallons)	Net benefit	Total net benefit
Non-cooperative management	Upstream	Agriculture	826,534	398,659,941	
		Residential	88,414	-	
		Industry	2,277	15,549,613	
	Downstream	Mineral extraction	60,074	864,534,371	
		Shrimp harvesting	0	41,295,032	
					1,320,038,958
Cooperative management	Upstream	Agriculture	797,421	395,930,731	
		Residential	88,414	-	
		Industry	2,245	15,546,684	
	Downstream	Mineral extraction	89,219	971,926,786	
		Shrimp harvesting	0	41,295,032	
					1,424,699,234
		Increase in total net benefit from cooperation			**104,660,276**

Discussion and Conclusions

- Total social net benefit is greater with cooperative management under steady-state conditions, the extent of improvement being dependent upon circumstances.
- Cooperative management shows an increase of 32% in water allocation to the downstream mineral extraction industry, and with a corresponding increase of 4.2% in overall net benefit.
- Under an adverse climate change scenario with 8.1% reduction of water inflow to the lake by 2070, cooperative management increases social welfare 6.4% relative to non-cooperative management.
- With impact of the Bear River Development Act taken into account, cooperative management is expected to add 7.9% to social welfare as compared to non-cooperative management.
- On the whole, this study suggests that involvement of policymakers to guide water allocation decisions can improve social welfare, while sustaining the Great Salt Lake. The proposed model can also be modified suitably and applied to other basins with a terminal lake.
- By encouraging more efficient use of water, policies leading to emulation of the cooperative management scenario may very well provide a low cost and environmentally friendly strategy for satisfying the water needs of a basin that faces the urgency of saving a drying lake.
- Finally, we caution that the application results presented should be viewed as illustrative. One important reason is data limitations. Some of the assumptions underlying the model and its scope also need to be extended.
  - First, current lake elevation may not be at the socially optimal level. Also, the socially optimal lake elevation may change over time. Future research should develop a dynamic approach to the problem of determining these steady-states and the paths that lead to them.
  - Second, the dynamic model should allow for lake salinity level control as well as management of sediment and pollution at the lake level.
  - Third, incorporation of specific mechanisms for influencing farm level adoption of conservationist irrigation technologies and soil conservation efforts would allow for explicit ways to direct upstream behavior and increase the usefulness of the model for policy purposes.

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