Policies to Achieve Sustainability in the Colorado River Basin under Climate Change Conditions and Growing Demand: A Hydro-economic Analysis.

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Introduction

- The Colorado River Basin (CRB) is overallocated since total water demand exceeds water availability in an average year. The excessive pressure that faces the basin makes the water system vulnerable to failure, economic losses, conflicts between regions and water users, and the degradation of ecosystems (Rushforth et al., 2022; Munia et al., 2016).
- Undue water withdrawals allowed by water management, legal restrictions established on historical facts, and decreased water availability due to climate change are producing a crisis in the basin.
- The agricultural sector, urban centers, hydropower production, and aquatic ecosystems compete for the exhaust water resources in the basin. Projections of population and economic growth point out additional water demand expansions and projections of climate streamflow reductions.

Objective

- This paper presents a novel Hydro-economic model of the CRB (HEM-CRB) at the basin-wide level that captures the temporal and spatial relationship of water availability and use. The model has the capacity to analyze current and future water management concerns and provide information on water management alternatives. The evaluation of water allocation under climate change conditions, modification of the 1922 treaty, leasing of water rights allowed to the Tribes, and environmental flows are potential subjects of analysis with the HEM-CRB.

The Colorado River Basin Region

- The CRB spans over more than 637,000 square kilometers in the United States and Mexico and provides water to 40 million people in the seven states of Arizona, California, Nevada (Lower Basin), Colorado, New Mexico, Utah, Wyoming (Upper Basin), and Mexico (Figure 1). Water withdrawals for agriculture irrigate nearly 5 million acres and maintain livestock in the basin, which embodies 15 percent of crop production and 13 percent of the livestock in the United States (CRS, 2023). The hydropower capacity in CRB is 4,600 megawatts, contributing cheap and low-emission energy to the grid. The aquatic ecosystems that depend on the CRB water provide recreational and environmental services to society.
- The natural resources, between 1906 and 2007, in the CRB are, on average, 18,500 cubic hectometer (hm^3), 1 hm^3 equals a million of cubic meters. The US Bureau of Reclamation (USBR) reports that the 21st-century average flow of the Colorado River (15,300 hm^3) is already about 18% lower than the 20th-century average (18,700 hm^3) (Figure 2).

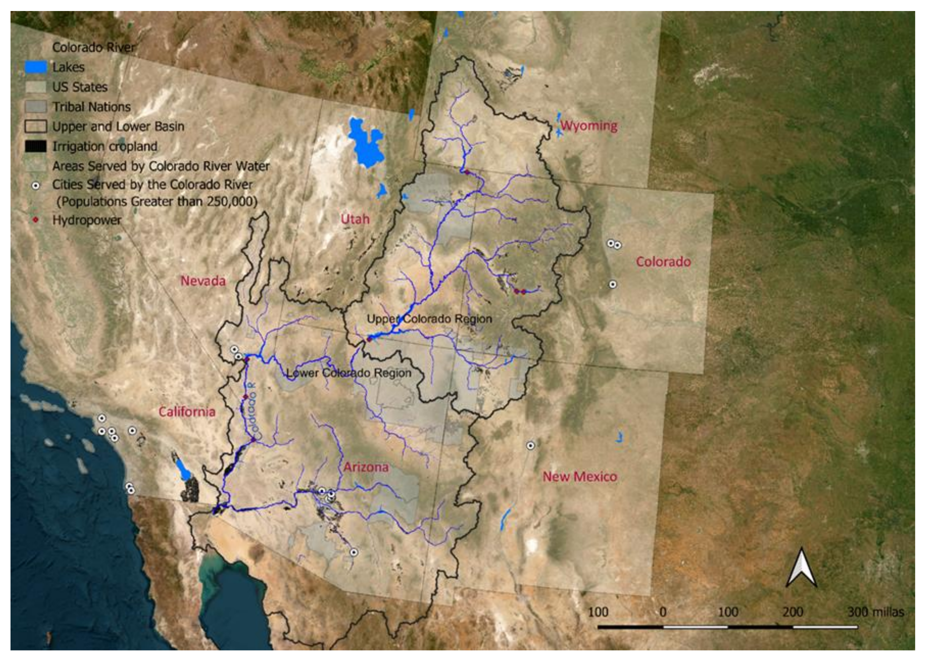

Figure 1. Colorado River Basin, water users and administrated division. Source: produced by the authors using the National Map and RISE datasets from USGS and USBR

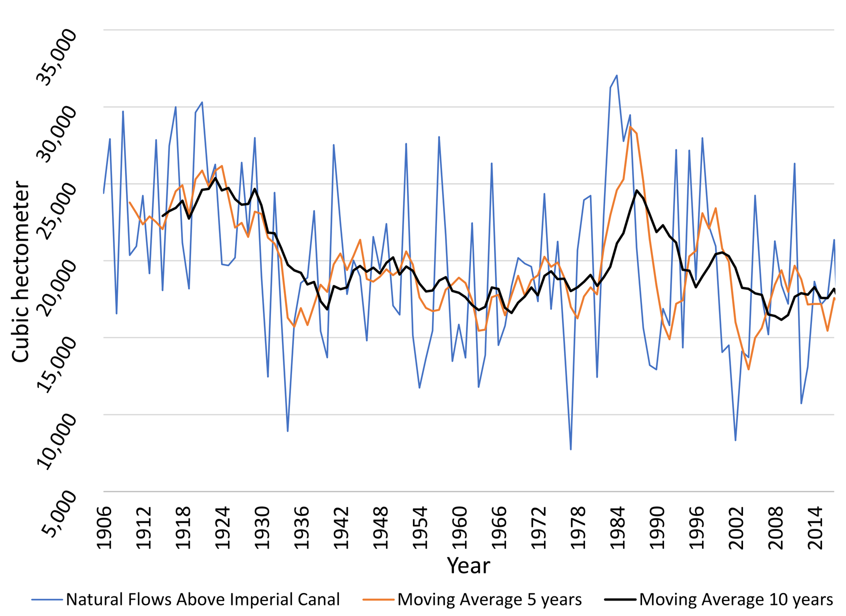

Figure 2. Natural flow (1906-2019) in the Colorado River above All American Canals (USBR, 2023)

The Colorado River compact of 1992

- The Colorado River Compact of 1922 (Compact) and its subsequent agreements regulate the use and management of the Colorado River among the seven basin states, Native American Tribes, and Mexico. The Colorado River Compact of 1922 divides the CRB flows between the upper and lower River basins, and the 1944 Treaty between the United States and Mexico guarantees water delivery to Mexico. Natural resources were overestimated at 20,400 hm^3 and allocated among the Upper Basin States (9,300 hm^3), the Lower Basin States (9,300 hm^3), and Mexico (1,900 hm^3).
- The Compact mainly overlooked environmental concerns and Tribal water rights. Ten Tribes with reserved water rights in the CRB formed The Colorado River Basin Tribes Partnership, also known as the Ten Tribes Partnership (Partnership), to advocate for and reserve the tribal water rights. The Partnership has reserved water rights to divert nearly 2,500 hm^3 of water per year from the Colorado River and its tributaries with additional 1,000 hm^3 unresolved claims.
- Agriculture is currently the dominant water use in the U.S. Southwest, followed by municipal and industrial use. Despite the reduction in use per capita, population growth pushes the water demand in urban centers (Figure 3). The CRB water demand scenario by 2060 indicates an increase in water use in all sectors, except for agricultural demand. In a favorable scenario, water demand is increasing 1,200 hm^3, and 3,700 hm^3 in the worst cases. Population growth is the main driver of water demand, with the current water demand growing from 1,200 hm^3 to 3,100 hm^3 (USBR, 2012).

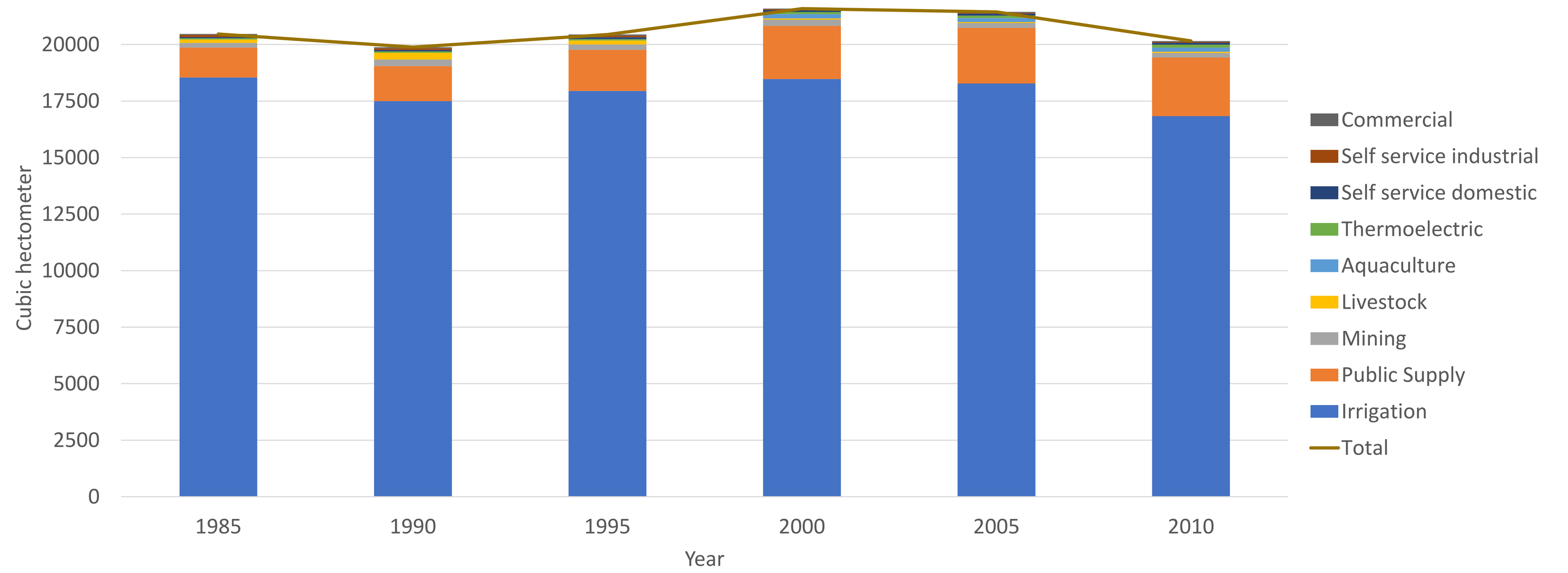

Figure 3. Water withdraws by sector between 1985 and 2015 (USGS 2018)

Hydro-Economic Modelling

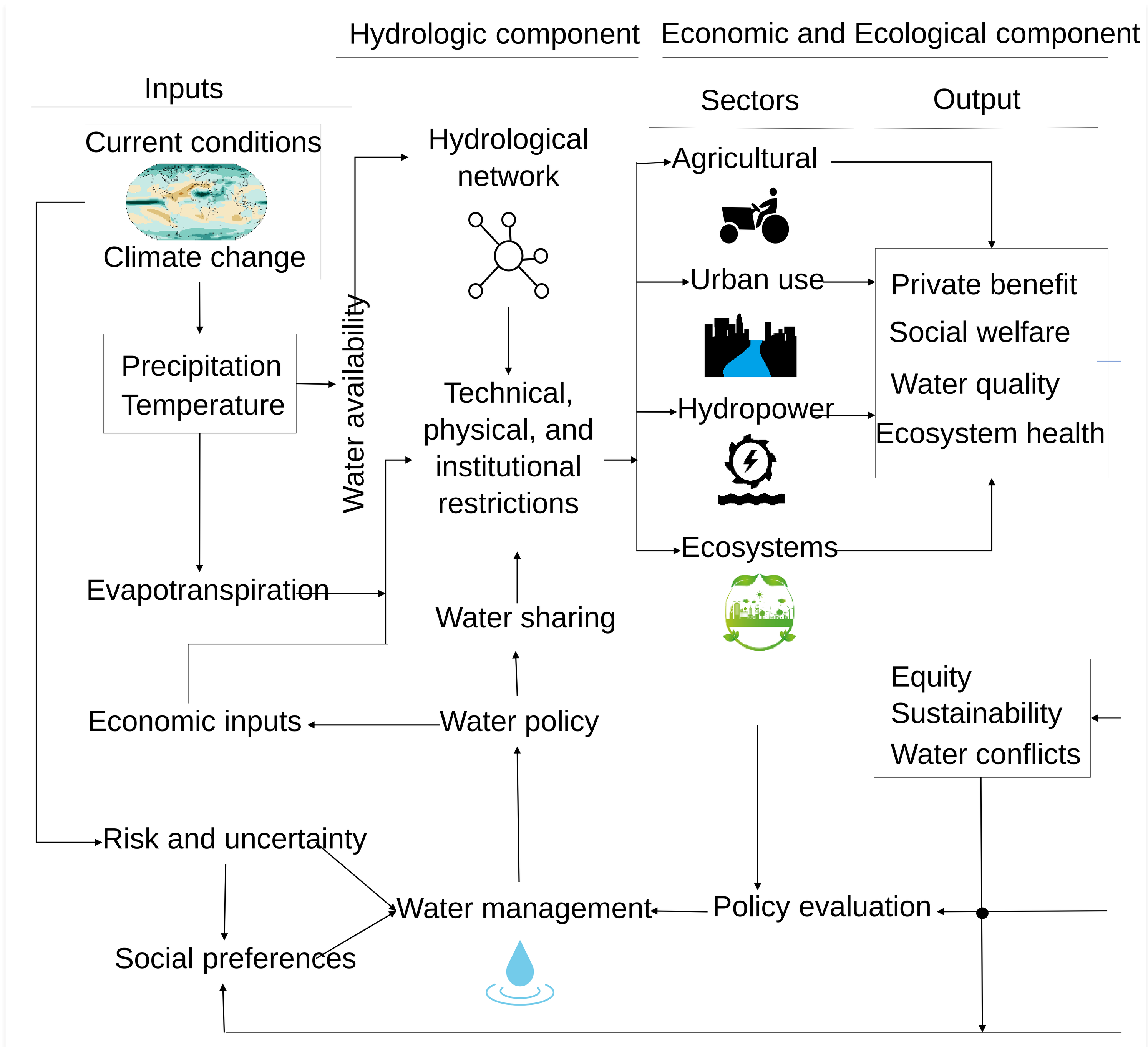

Figure 4. Modeling framework of the hydro-economic model

Hydrologic component

- The hydrologic-reduced model is a node-link network that represents water flows in the river basin. The principles of flow continuity and mass balance are simple hydrologic concepts that underpin the hydrologic form. The water flows are routed through a network that connects nodes where surface water, dams, and aquifers fulfill the principle of mass balance.

Irrigation water use

- Irrigated agriculture is observed at the irrigation district level. It is assumed that the irrigation district is the decision maker. Agricultural activities maximize benefits from crop production subject to land, water, and technological constrains

$$\max(\Pi_{irr}) = P_{crop} * Yield(L) * L - C_{no\,water} * L - C_{water} * L \qquad \text{s.t.: } W = B_w L$$

Where Π_irr are Irrigation benefits; L: Land, B_w: Water requirements; W: water; $C\_(no\ water)$: Cost other than water cost; C_water : Water cost; P_crop: Price of water,;$Yield(L)$: Yield is a quadratic function of land calibrated by PMP

Urban water use

- In the urban centers, the water use maximizes the economic surplus, the sum of consumer and producer surpluses.

$$\max(\Pi_{urb}) = \left(a_{du}W_{du} - \tfrac{1}{2}\, b_{du}W_{du}^2 - a_{su}W_{su} + \tfrac{1}{2}\, b_{su}W_{su}^2\right)$$

Where: Water is W, subindex ud means urban demand, and subindex su means urban supply

Hydropower production

- Hydropower water use maximize benefit from electricity production. Electricity depends on dam height and water flow turbinated by the facility.

$$\max(\pi) = P_e * E - C_f - C_v * E$$

P_e : Electricity Price, C_f : Fix Cost, C_v : Variable Cost

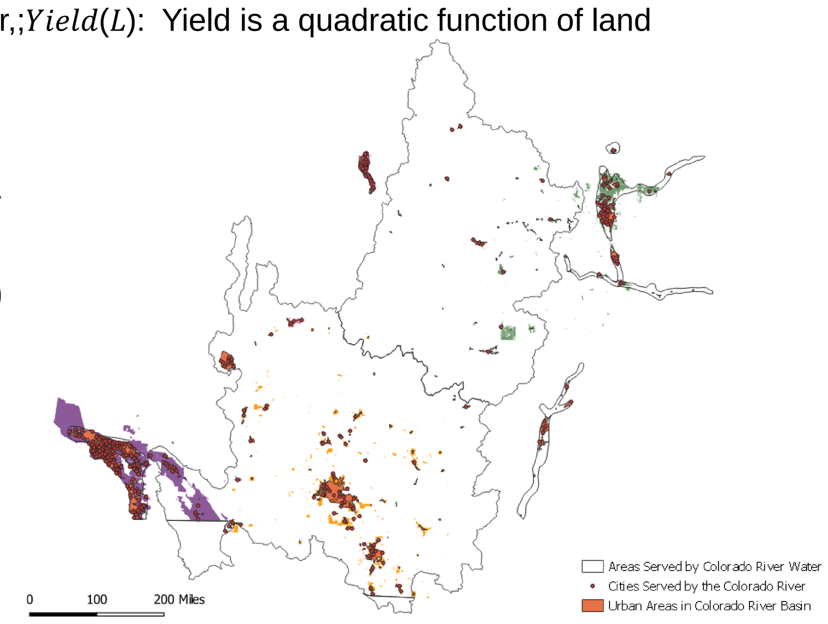

Figure 5. Cities served by the CRB

Data

- The urban centers included in the model comprise the main urban centers inside the basin and the areas served by the Colorado River outside of the basin. The number of cities sum 379 with a total population of 33.4 million inhabitants.
- The hydro-economic model of the Colorado River includes 2.6 million acres of irrigated land, distributed among 25 irrigation units around the 7 states of the Colorado River Basin. The model distinguishes 39 crops irrigated under 3 different irrigation systems: flood, sprinkler and drip.
- The hydropower production capacity of the 9 plants included in the model sum up 4,223MW, around 95 percent of capacity installed in the basin.

References

Rushforth, R.R., Zegre, N.P., Ruddell, B.L., 2022. The Three Colorado Rivers: Hydrologic, Infrastructural, and Economic Flows of Water in a Shared River Basin. JAWRA J. Am. Water Resour. Assoc. 58, 269–281. https://doi.org/10.1111/1752-1688.12997

Munia, H., Guillaume, J.H.A., Mirumachi, N., Porkka, M., Wada, Y., Kummu, M., 2016. Water stress in global transboundary river basins: significance of upstream water use on downstream stress. Environ. Res. Lett. 11, 014002. https://doi.org/10.1088/1748-9326/11/1/014002

USBR, 2012. Colorado River Basin Water Supply and Demand Study. USBR.

USGS, 2018. Maupin, M.A., Ivahnenko, T., Bruce, B., 2018. Estimates of water use and trends in the Colorado River Basin, Southwestern United States, 1985–2010: U.S. Geological Survey Scientific Investigations Report 2018–5049, 61 p. (Scientific Investigations Report), Scientific Investigations Report.

Results of the Run Base

Benefits, water use and land from irrigation water user

- The agricultural sector diverts 11,000 hm^3 which provides 1,773 million dollars of net income. Three States account for 84% of water use and 90% of net income. In the basin, the average net income is 1,600$/acre, and it varies by state between 560$/ha and 2,900$/ha

Table 1. Cropland, water applied and net income from irrigation at the baseline

State	Cropland (1000 ha)	Cropland distribution (%)	Water applied (hm^3)	Water applied distribution (%)	*Irrigation net income (Millions of $)	Net income distribution (%)
A	409	38.86	4,436	40.13	609.3	34.37
B	224	21.25	2,225	20.13	670.1	37.80
C	250	23.76	2,762	24.99	315.7	17.81
D	22	2.06	199	1.80	29.6	1.67
E	5	0.52	68	0.62	8.1	0.46
F	81	7.68	866	7.84	105.0	5.92
G	62	5.88	497	4.49	35.0	1.97
CRB	1,053		11,053		1,772.8	

*Net income accounts the revenue from crop production minus cost production (excluding land rent).

- Results show that the 60 percent of crop land produces 90 percent of the net income, and 6 percent of higher value crops amount 40 percent of the total net income in the basin. In the same line, the results show that 10 percent of water use produces 50 percent of the total net income in the Basin, reaching a shadow price of 0.2M$/hm^3. Results point to potential improvements in water use efficiency from interstate water exchange.

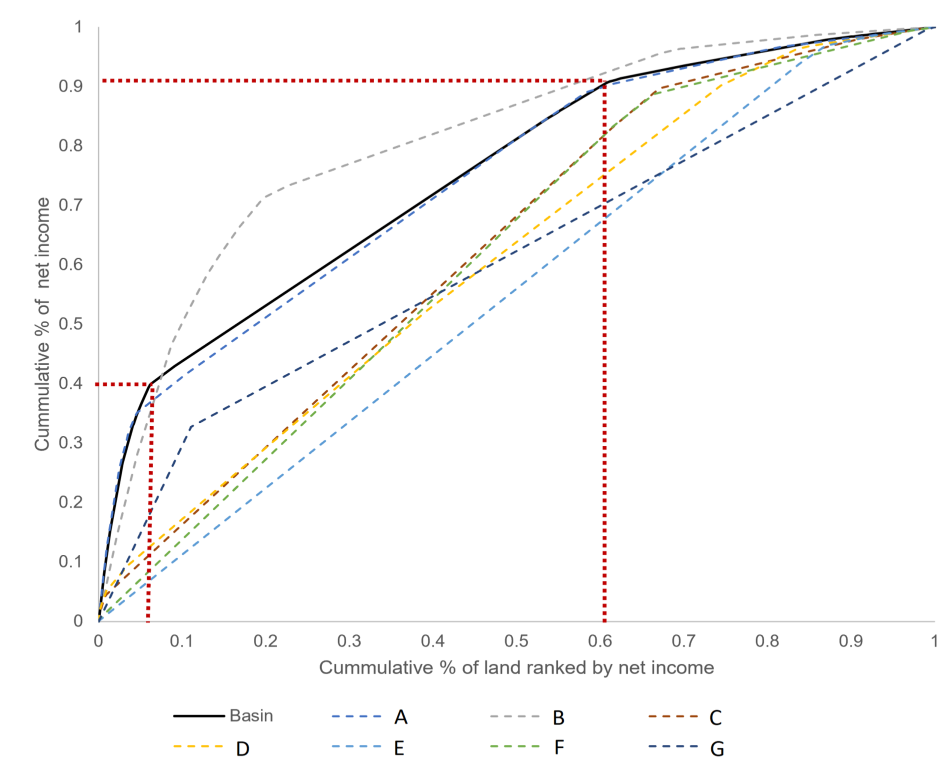

Figure 6. Concentration curve by irrigation district and Colorado river basin

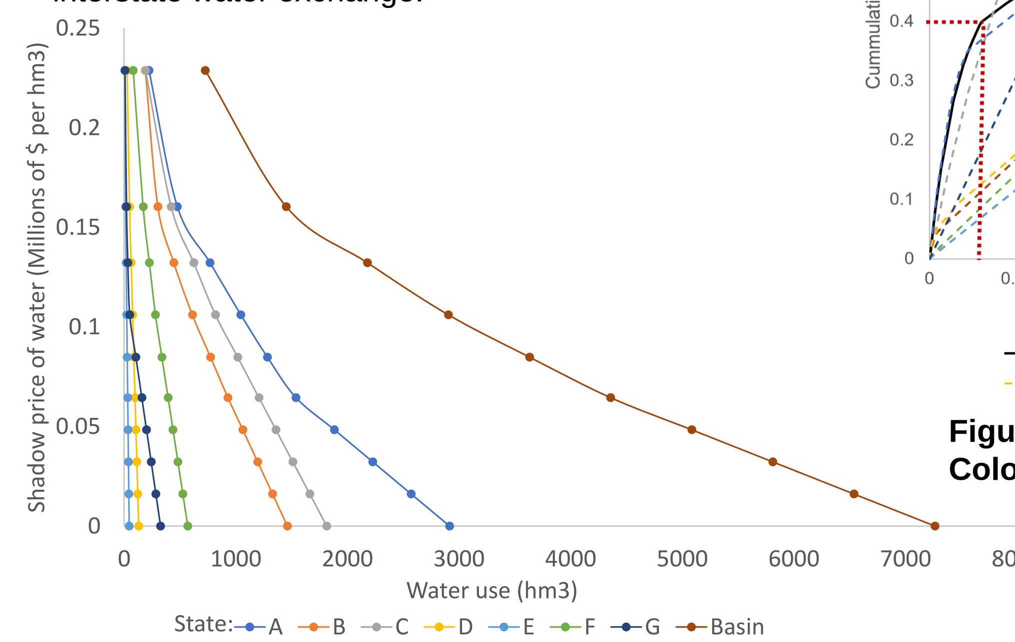

Figure 7. Shadow price of water in Colorado River Basin (Millions of dollars per hm^3)

Economic surplus from urban water

- The urban water use for the domestic sub-sector is estimated at 648 hm^3, which produces an economic surplus of 18,328 million of dollars. The non-domestic use of water in the urban centers are fixed in 971 hm^3. Then, the total urban use included in the model is 1,600 hm^3. The lower basin concentrates the higher share of the population, led by California and Arizona, that represent the 75 percent of the population and 86 percent of the economic surplus.

Table 2. Main variables of the urban water use (Domestic use)

State	Number of cities	Population (Thousand)	Population (%)	Water urban use (hm^3)	Water use (%)	Benefits (Million of dollar)	Benefits (%)
CA	205	18,781	0.563	350	0.540	13,384	0.730
AZ	65	5,936	0.178	145	0.223	2,358	0.129
CO	54	3,878	0.116	62	0.095	861	0.047
NV	11	2,085	0.062	39	0.060	747	0.041
UT	32	1,726	0.052	33	0.050	180	0.010
NM	9	880	0.026	18	0.027	742	0.041
WY	3	101	0.003	3	0.004	57	0.003
CRB	379	33,391	1	648	1	18,328	1

Benefits from hydropower production

- The nine biggest hydropower plants produce 10,225GWh per year with an annual benefit of 874 million dollars per year, but the three bigger ones account the 84 of the benefits. Hydropower production avoids emissions of greenhouse gas. The CO2 emissions avoidance reaches 5.6 Million Mt.

Table 3. Mean hydropower production and benefits from 2012 to 2020

	Installed capacity (MW)	Energy production (MWh/year)	Benefits (Million of dollar)	Avoid Emmsions (Million Mt)
CRB	4,223	10,225,997	874	5.6

Conclusion

- This paper presents a novel hydro-economic model of the Colorado River Basin (HEM-CRB) that analyzes the current conditions in the Basin. To the best of our knowledge, this is the first model of the CRB at the wide-basin level that includes the water used for irrigation, urban centers, hydropower production, and care about environmental flows and Tribal water rights. The HEM-CRB captures the temporal and spatial relationship between water availability and water demand, showing the economic benefit of water use. The HEM-CRB will be used to assess the modification of the 1922 treaty and the leasing of water rights allowed to the Tribes. Water reductions due to climate change and increased water use due to population growth are also examined to identify the performance of water policy alternatives.