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Managing Water Demands for a Rapidly Growing City in Semi-Arid Environment: Study of Las Vegas, Nevada

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Abstract: This study evaluates the effect of climate change and population growth on the water supply and demand for Las Vegas Valley (LVV), located in semi-arid region in southern Nevada. Colorado River is main source of water supply for LVV. The impact of climate change on Colorado River flow was modeled using ensemble of projections from global climate models for different emission scenarios. Various scenarios of population growth and water conservation were evaluated for future. With the projected population growth and no demand management policies, the LVV would not be able to meet the water demand in the near future. With changing climate, water supply reliability also decreased significantly. However, with the combination of reduced population growth rate and water conservation policies, the Colorado River supply could meet the future demand of the LVV. The reduction in water demand in 2035 was estimated to be 30.6%, i.e., 327 million cubic meters (MCM) for 'status quo' population growth and 38%, i.e., 408 MCM for 50% of the projected growth.

Key words: Climate change · Water demand management · Colorado River

INTRODUCTION

Rapidly growing population and development is resulting in increased demand for water for agriculture, industrial, municipal and environmental uses. Climate variability and change is impacting both water supply and demand [1, 2]. Climate change can increase the frequency of floods and droughts [3-10]. Planning and management for water resources is more challenging in arid and semi-arid regions because of periodic droughts.

Southwestern United States has experienced significant population growth [11] and drought caused by changing climatic conditions [12-16]. The Colorado River Basin (CRB) has experienced a sustained drought since early 2000's. The Colorado River supplies water to seven basin states and also to Mexico. These basin states are Wyoming, Utah, New Mexico, Colorado, Arizona, Nevada and California.

Considering the long term inflows, the Colorado River was over-allocated in 1922. Since the allocation, the population of the basin states has increased by about seven-fold, resulting in significantly increasing the water demands.

The majority of the climate studies report reduction in flows in the CRB in future. The flow in the CRB has high seasonal and inter-annual variability [17, 18]. With capacity to store four years of average annual flows, Lake Mead and Lake Powell, have been able to meet the demand of the basin states during short term droughts and low-flow years. However, recent long-term droughts have seriously compromised the capacity of water infrastructure to meet demands.

Las Vegas Valley (LVV) is located in southern Nevada and the Colorado River is the main source of its water supply. While Nevada has a fixed allocation from Colorado River, the population of LVV has more than doubled in past 20 years to reach 2 million, resulting in significant increase in water demand.

In this study a system dynamics model was developed to evaluate different water conservation policies. Risks to future water supply, considering currently available water resources, were evaluated with and without implementing water conservation policies. Different scenarios for population growth rate, water supply and demand were considered and risk analysis was performed to evaluate the reliability of the water supply.

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Water System of Las Vegas Valley: The Las Vegas Valley, with a drainage area of about 4142 square kilometers, is a semi-arid region at an elevation of 549 m above mean sea level. The summer average high temperature in the LVV is 43ºC during July and August. The average annual rainfall in the valley is less than 13cm.

Lake Mead, located on the Colorado River, supplies 90% of the water used in the LVV, the remaining 10% comes from groundwater. Nevada has an annual consumptive use allocation of 370 million cubic meters (MCM) from the Colorado River. Nevada is allowed to withdraw, from Lake Mead, an additional amount equivalent to the return flow credit. These credits are for returning the highly treated waste water, from indoor use, back to the Colorado River. Because of return flow credits, water conservation impacts water supply. Also the conservation in outdoor or indoor water use has different implications for water supply.

The Southern Nevada Water Authority (SNWA) is the agency responsible for managing water resources in the LVV. This agency has considered a variety of options to augment supply or reduce demand in response to growing population, changing climatic conditions and increasing water demands. Two options are considered to increase water supply. One involves groundwater extraction in northern Nevada and transfer to LVV through a 500 Km long pipe line. Second option involves building a desalination plant in California or Mexico to deliver water locally and receive an equivalent amount left in Lake Mead by the recipient entity. Both options are politically and economically expensive. The options implemented to reduce water demand include: rebate programs for desert landscaping, water smart appliances, watering schedules, reuse and pricing. Current system wide water use in LVV is about 900 liters per capita per day (lpcd), which is high compared to other cities in the Southwest with comparable climatic conditions. This offers an opportunity for further water conservation in the LVV.

MATERIALS AND METHODS

The Main Data Used in the Study Was Global Climate Model Outputs, Water Demands by End Uses and Population: Bias-corrected monthly data for temperature and precipitation, at 2° latitude-longitude, was obtained from an ensemble of 16 global climate models, derived from CMIP3, to evaluate impact of climate change on streamflow. From same ensemble of 16 GCMs, bias-corrected and down-scaled monthly temperature data at 1/8° latitude-longitude were used to evaluate the impact of climate change on water demand. Three emission scenarios were used. These emission scenarios differ in terms of carbon dioxide (CO_2) concentration by 2100. Scenarios A1b, A2 and B1 were categorized as the middle emission path, the higher emission path and the lower emission path, respectively.

Both the total resident population of the Las Vegas Valley, about 2 million in 2010 and the tourist population, nearly 37.3 million tourists in 2010, were considered.

System Dynamics Modeling: A system dynamic model was developed to evaluate the effect of population growth, climate change and water conservation policies on the water demand and supply in the LVV. SD has been used for a number of water resources management studies [19-24]. Some publications have provided a review of SD applications in water resources [25, 26]. Several water management models have been developed for the LVVV using system dynamics modeling approach [27-31,11]. However, this is first study to consider climate change impact on water demand and supply when evaluating water conservation policies. A simplified schematic of the model architecture is shown in Figure 1.

The model is developed in different sectors. The hydrologic water balance sector computes monthly streamflow in the Upper Colorado River Basin (UCRB), which encompasses an area of about 46,102 square kilometers. The inputs to the hydrologic model were monthly precipitation, temperature and potential evapotranspiration; the model generated monthly streamflow as output. The streamflow generated in each sub-basin accumulates at the outlet of the UCRB at Lee’s Ferry in northern Arizona. Runoff estimates using empirical models [32-34, 13, 22] often do not consider projected climate change, however, this was considered in this model. The impact of climate change on the streamflow was evaluated using future temperatures, predicted by the GCMs, in the hydrologic model. The hydrologic water balance model was calibrated and validated for streamflow at Lee’s Ferry. The details of the hydrologic model can be found in Dawadi and Ahmad[35].

The reservoir operation sector regulates the release of water from Lake Powell and Lake Mead. Based on the reservoir’s operating criteria, runoff generated in the UCRB is stored in Lake Powell and released to the Upper Basin states and Lake Mead. From Lake Mead, the allocation for the Lower Basin states and Mexico are released, until Lake Mead is drawn down to 327.7 meters [36]. Nevada’s supply is reduced by about 4.33%, 5.64% and 5.76% when Lake Mead drops below 327.7, 320 and 312 m, respectively. The curtailment criteriais based on

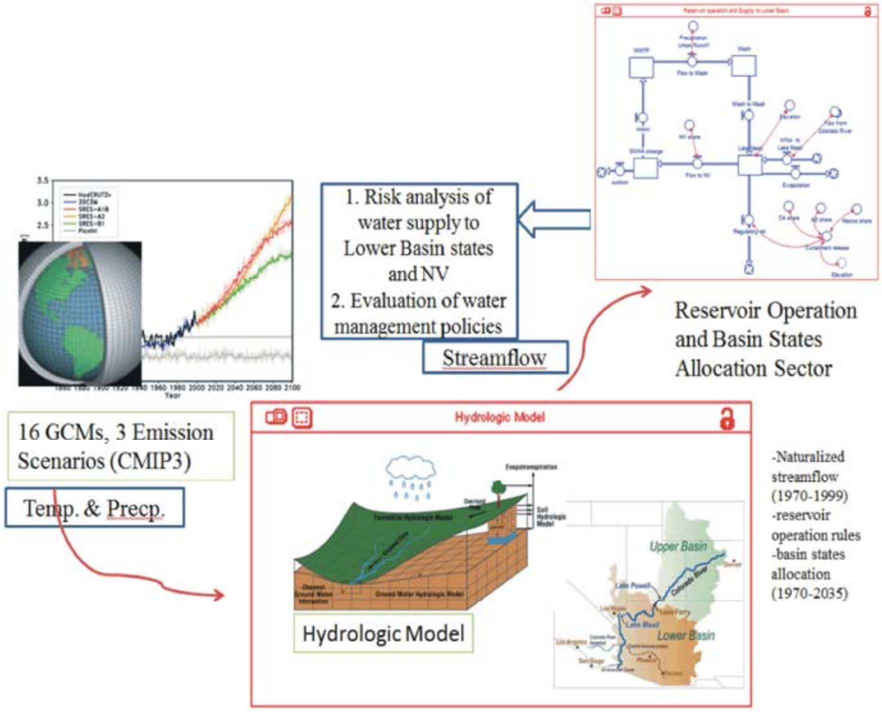

Fig. 1: Model architecture to evaluate water supply and water conservation policies.

the “Record of Decision (ROD) - Colorado River Interim guidelines for Lower Basin shortages and the coordinated operations for Lake Powell and Lake Mead” [36]. The existing two water system intakes become inoperable when water levels in Lake Mead drop down to 320 m and 305 m, respectively. However, a third intake is under construction, which will be able to withdraw water below 305 m. The reservoir operation sector was validated for Lake Mead levels for a period from 1970 to 1999.

The water demand sector computes the water demand for residential use, tourists, golf courses and other needs. Residential demand that includes both indoor and outdoor demand, at 59%, is the highest water use in the LVV.

For indoor demand, water used by each end use was considered. Water savings obtained with each end use were estimated by subtracting the efficient use from the non-efficient use. The total indoor demand was calculated by multiplying the indoor demand per house with the total number of houses.

The outdoor demand includes water used for landscaping and swimming pools. About 30% of the total outdoor use is evaporative loss, about 66% is infiltrated into ground and about 4% becomes runoff [11].

In this study, water management policies were only considered for residential water demand and only residential outdoor water use and golf course water use were affected by climate change.

Water Supply Sector: Water withdrawal from Lake Mead is based upon the water allocation from the Colorado River to Nevada and also on various curtailment criteria once the lake level draws down below 327.7 meters.

Modeling Approach: The model was developed using software STELLA and validated for water demand and Lake Mead levels. The validated model was used to generate the water demand and the water supply for future from 2012 to 2035. Additional details of model can be found in Dawadi and Ahmad [37].

Two Scenarios Were Tested:

- Status quo population growth with no policy implementation and with climate change and
- Status quo population growth with policy implementation and with climate change.

The effect of climate change on the water supply was modeled as change in river flows resulting in the change in the Lake Mead water levels. The effect of climate change on water demand was modeled as the increase in water demand with the increase in future temperature, as predicted by different GCMs.

Five Policies Were Tested: (i) indoor conservation; (ii) outdoor conservation; (iii) indoor and outdoor conservation; (iv) water pricing; and (v) a combination of policies. Indoor conservation involved mandating water-smart appliances in houses constructed after 2012 and retrofitting a selected percentage of existing homes. 50% of the older homes were assumed to be retrofitted. Outdoor conservation involved mandating the desert landscaping in houses constructed after 2012 and conversion of turf grass into desert landscaping in a selected percentage of existing homes, along with the use of covers for residential swimming pools.The impact of population growth was tested by considering growth in population at only 50% of the projected growth rate.

RESULTS AND DISCUSSION

Status Quo Scenario: An increase in water demand by about 43% occurred between 2012 and 2035 i.e., 748 MCM in 2012 to 1069 MCM in 2035. With the population growth only 50% of the projected growth, water demand reached 916 MCM in 2035, an increase of about 22.5% from 2012 levels.

Water demand was compared with and without considering the impacts of climate change for all three emission scenarios. The ensemble average of all the GCMs and emission scenarios showed an increase in demand by 1.9%.

Conservation Policies Scenario: Under status quo population and with indoor conservation, a reduction in demand by about 75 MCM (7%) was obtained in 2035. With outdoor conservation, water demand in 2035 was reduced by about 167 MCM (15.6%). With both indoor and outdoor conservation, water demand was reduced by approximately 243 MCM (22.7%) in 2035 (Table 1).

Different price rise options were tested in the model, varying from increasing the price by 25%, 50%, 75% and 100%. This resulted in a water demand reduction by about 53, 106, 159 and 212 MCM, respectively. Similarly, the combination of policies resulted in a water demand reduction by about 327 MCM (30.6%) in 2035; this is about 48% of the water demand in 2010. The water use with the combination of policies was computed to be 639 lpcd (169 gpcd) in 2035, compared to 919 lpcd in status quo scenario.

With growth in population only 50% of the projected growth, three policies were tested (i) indoor and outdoor conservation, (ii) price rise and (iii) a combination of policies. The results, summarized in Table 1, show the median of the ensemble of GCMs for the A1b scenario.

Table 1: A summary of the annual water demand and reduction in water demand in 2035, with different policies implemented under different population growth rates. Water demand for the status quo scenario is 1069 MCM in 2035. The average of the ensemble of all the GCMs for the A1b emission scenario is reported in this Table.

Description	Demand (MCM)	Demand reduction (MCM)	% demand reduction
Status quo population growth			
Indoor only	994	75	7.0
Outdoor only	902	167	15.6
Indoor and outdoor	826	243	22.7
Price rise (25%)	1016	53	5.0
Price rise (50%)	963	106	9.9
Price rise (75%)	910	159	14.9
Price rise (100%)	857	212	19.8
Combination scenario	742	327	30.6
Population growth only 50 % of the projected growth			
Indoor and outdoor	736	333	31.2
Price rise (50%)	829	240	22.5
Combination scenario	660	409	38.3
No population growth			
Indoor and outdoor	625	444	41.5
Price rise (50%)	673	396	37.0
Combination scenario	558	511	47.8

With a combination of policies and growth in population only 50% of the projected growth, demand was reduced by about 408 MCM (38%). Similarly, with a combination of policies in no population growth, demand was reduced by 511 MCM (47.8%).

Status Quo and Conservation Policies Scenarios: Figure 2 presents the water demand and supply from the Colorado River for status quo and conservation policies for different population growth scenario. For i) status quo population growth and no conservation and no pricing policies and ii) status quo population growth and with indoor conservation, the model estimated that the demand exceeded the supply within few years of simulation start and ensemble average deficit is about 200 and 180 MCM in 2035, respectively.

With outdoor conservation, water demand was estimated to exceed the available supply in 2028. In this case, a water deficit of about 36 MCM occurred in 2035. With both indoor and outdoor conservation, the demand exceeded the available supply in 2029 (Fig. 2b), with an ensemble average deficit of about 25 MCM in 2035. With a 50% price rise, the demand exceeded the available supply in 2016 (Fig. 2c), with a deficit of about 143 MCM in 2035. With the combination of the policies, the demand never exceeded the available supply (Fig. 2d), however, a water surplus of only about 10 MCM was computed in 2035.

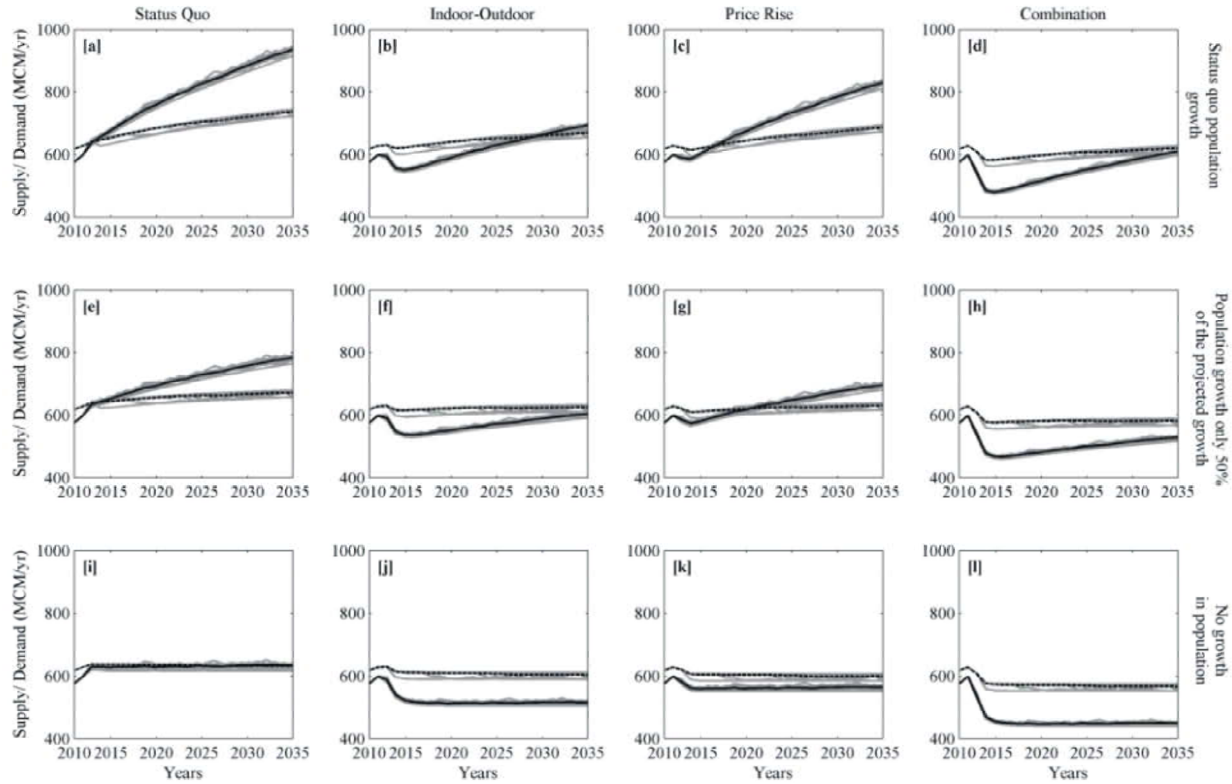

Fig. 2: Water demand and supply from the Colorado River for status quo (without policies), three policies (indicated at the top) and population growth conditions (shown on the right side). The black solid line and black dotted line represent the water demand and the water supply from the Colorado River, respectively. Grey lines indicate the water demand and supply for 16 individual GCMs for the A1b emission scenario.

With growth in population only 50% of projected growth as well as indoor and outdoor conservation, the water demand never exceeded the available supply until 2035 (Fig. 2f). A water surplus of about 20 MCM occurred in 2035. Under the same population growth and a price rise by about 50%, the demand exceeded the available supply in 2020 (Fig. 2g). In this case, a water deficit of about 66 MCM was computed in 2035. With a combination of policies, it was observed that the demand never exceeded the available supply until the year 2035 (Fig. 2h). Under this scenario, the ensemble average water surplus in 2035 was computed to be about 53 MCM.

With status quo (no conservation or pricing policies) and no growth in population, demand did not exceed supply until 2035 for majority of the GCMs. However, for some of the GCMs, demand was observed to exceed supply in the year 2028, with a deficit of approximately 3 MCM in 2035 (Fig. 2i). For all three conservation policies i.e., with indoor and outdoor conservation, a price rise by 50% and combination of policies the water demand never exceeded the available supply until 2035 (Fig. 2j-l). The water surplus of about 87 MCM, 34 MCM and 117 MCM was obtained in 2035, respectively.

For status quo population growth and a combination of policies, there were some GCMs for which the water supply from the Colorado River was not able to meet the requested demand. With the combination of conservation policies, water demand never exceeded the water supply in the population growth only 50% of the projected growth.

CONCLUSIONS

This study used a system dynamics model to capture the effect of interactions among changing climatic conditions, increasing population and policies adopted for water conservation in the LVV on the future water demand and water supply until 2035. The reduction in water demand was analyzed using water conservation and water pricing policies. Conservation policies that were tested included building new homes with water-smart appliances and desert landscaping, replacing existing conventional appliances with water-smart appliances and converting turf landscaping into water-smart landscapes and covering swimming pools in residential homes. The water demand and water supply were compared for different policies and with different population growth scenarios. A risk analysis also was conducted of the water supply from the Colorado River to the LVV.

The major conclusions in this study can be summarized as follows:

- Water demand reached 1069 MCM in 2035 in status quo population growth without any conservation policies.
- A combination of indoor-outdoor conservation and a price rise by 50% reduced water demand by about 30.6% in 2035.
- Outdoor conservation was more effective compared to indoor conservation in the LVV because of return flow credits.
- Climate change reduced the water supply reliability, even if there was no population growth.

Results indicate that significant changes in water use patterns of LVV residents may be required in the future to reduce the water demand. This can be accomplished by implementing various policies that were evaluated in this study, along with educating residents and providing incentives for lower water use. Although the study focused on the LVV, demand management policies used in the study can be considered for other arid and semi-arid regions to achieve the long-term sustainability of water resources.

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