FUTURE WATER SHORTAGE COSTS IN THE COLORADO RIVER BASIN

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INTRODUCTION

In performing an analysis of climate change using the Colorado River Open Source Simulator (CROSS), analyzing the results using different price elasticities of demand allows the researcher to examine different consumer and producer responses to future long run shortages in the Colorado River Basin. The CROSS model allows users to manually control several factors pertaining to future streamflows in the Colorado River Basin, including the average streamflow, climate change variables, percent reduction in usage due to conservation, and evaporation rate increase. The simulator then models future streamflow scenarios based on historical flow data combined with manual inputs to give researchers a better understanding of the effects of water shortages for Colorado River users.

Each CROSS run was performed using a different future climate change scenario and a different set of percent changes representing a reduction in flow due to climate change. Eleven different General Circulation Models (GCMs) were broken down to determine their percentage adjustment for climate change in three future time periods representing the next 111 years of climate change in the Colorado River Basin. The eleven GCM scenarios are climate prediction models from several countries and research organizations around the world.

GCM STREAMFLOW REDUCTIONS

These eleven models represent the most consistent and objective in terms of the future simulation period and emission scenarios used as well as providing the basis for the most thorough climate study of the Colorado River Basin to date (see Christensen, 2007). The GCM scenario statistics provided a percentage reduction in streamflow due to climate change for three thirty year periods (see Table 1), which were run through CROSS to determine the change in future streamflow. This was done twice for each GCM to reflect two different future scenarios: A2, which represents large damages stemming from uncontrolled global warming, and B1 which represents a climate where actions have been taken to mitigate climate change. These percent reductions were calculated against a long run historical streamflow average of 14.6 maf (million acre-feet) per year.

Table 1: Future streamflow reductions for each GCM. The negative figures in the chart correspond to future streamflow increases relative to the historical streamflow average of 14.6 maf.

% Δs	**CNRM**	**CSIRO**	**GFDL**	**GISS**	**HADCM3**	**INMCM**	**IPSL**	**MIROC**	**MPI**	**MRI**	**PCM**
A2											
2010-2039	0.056	0.119	0.133	-0.028	0.143	-0.057	-0.032	0.154	0.203	-0.007	-0.107
2040-2069	0.429	0.074	0.192	-0.092	-0.021	-0.155	-0.011	0.348	0.179	0.068	0.018
2070-2099	0.351	0.114	0.184	0.165	0.077	0.104	0.097	0.385	0.019	0.086	-0.070
B1											
2010-2039	0.026	-0.014	0.106	0.057	-0.036	0.024	-0.001	0.242	0.116	-0.047	0.003
2040-2069	0.170	0.118	0.189	0.173	0.057	0.109	-0.012	0.275	0.180	-0.008	-0.131
2070-2099	0.356	0.071	0.084	0.213	0.102	-0.177	0.151	0.253	0.124	0.051	-0.057

Using CROSS, a long-run estimate of shortages and economic damages was performed using a combination of six different price elasticities of demand, representing a range of values encompassing high, low, and average elasticities for water usage in municipal and agricultural settings. The experiment itself was conducted with data derived from Christensen and Lettenmaier (2007) for the A2 and B1 climate scenarios. These eleven different scenarios, along with the base scenario, totaled 23 runs in all and averaged likely streamflow changes over the next 111 years. The increase or decrease in streamflow was then translated into shortage costs (CROSS having estimated future demand), translated into total welfare changes, which was then used to determine a present value for all future shortage costs.

The CROSS results were used to formulate data on the total present value of climate change, expressed as a change in welfare. The formula used to calculate the total welfare change is

$$\Delta W = P_0 \, \Delta x \, (1 + (1/2\eta)(\Delta q/q_0))$$

where η = elasticity of demand, q = quantity, and P = price. In this climate change scenario, the change in welfare does not represent a change in total benefits; rather, it represents the area under the demand curve between the original quantity demanded and the new quantity demanded after CROSS incorporates future demand estimates. The shift in welfare reflects how water consumers in the Colorado River Basin are worse off due to shortages, the total economic value of which is measured by this equation. Subsequently, the total for each year of each respective GCM was discounted at 4% (Nordhaus, 2008) to the present and the figures combined to determine the total future change in welfare for each climate change scenario representing the total shortage cost.

PRICE ELASTICITY OF DEMAND IN CROSS

Normally, when there is a shortage of a particular resource (in this case, water), price will increase to reflect a decrease in supply. To account for differing consumer and producer responses to this price increase, three estimates of elasticity were used for each to show the entire spectrum of prices under differing elasticity conditions. Because we are looking at water shortages in the long run, a higher price elasticity of demand was used as an example, which is inherently higher than a short run estimate. The following figures were input into the base scenario in CROSS:

Agricultural Elasticity Estimates:
- -0.97 (Howitt, et al. [1980])
- -0.22 (Hooker and Alexander [1998])
- -0.04 (Hedges [1977])

Municipal Elasticity Estimates:
- -0.0101 (Martìnez-Espiñera [2004])
- -0.33 (Olmstead [2007])
- -0.491 (Martìnez-Espiñera [2004])

These elasticities represent a broad spectrum of adjustments to demand for water under shortage conditions, ranging from nearly perfect inelasticity to relatively elastic demand for both agricultural (producer) and municipal (consumer) usage. In general, demand for water is nearly inelastic because of its low cost at the margin and its necessity in everyday life. In future shortage situations, these values were chosen as a representative range of possibilities due to increased water prices due to increased demand and decreased supply. To form a clearer picture of all future demand possibilities under all 23 scenarios, a wide range of elasticity estimates covering the high, low, and average estimates was chosen.

Ultimately, six elasticity values were chosen to give an adequate representation of a possible range of real-world values. Agricultural estimates are higher due to the flexibility of growers and crops chosen (e.g. choosing a less irrigation-intensive crop in response to higher prices for water); while municipal elasticities are generally lower due to typical consumptive behavior. Water is a staple in residential life, used in dozens of manners in a typical home, so municipal demand is unlikely to decrease dramatically. According to Scheierling (2006), the mean price elasticity of demand for water is -0.48, so calculated values were chosen high, low, and at the mean.

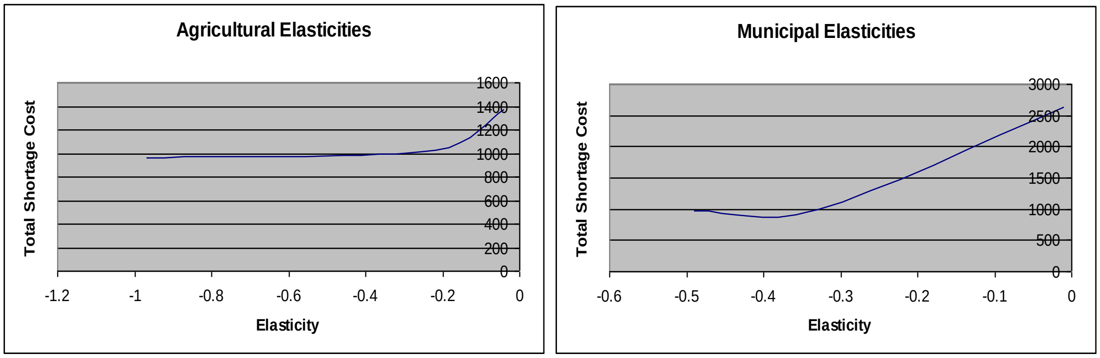
The base runs were conducted using a P_0 = \$100 and reflect the present value of the next 111 years of streamflow shortages in the Colorado River Basin, discounted to the present at 4%, the accepted value for discounting due to climate change (see Nordhaus, 2008). The streamflow percentage reduction factors to account for climate change were kept at 0% for all three thirty year periods. A climate change-free future allows us to view the future costs of shortages created by continuously increasing demand. The impact of climate change is measured in the GCM models, which will ultimately be compared to these base values for each elasticity to account for the damages caused by climate change.

Table 2: Base shortage costs under chosen elasticities. Total cost is listed in millions of dollars. Each total cost represents the next 111 years (without climate change) of shortage costs discounted to the present at 4%. The first three figures (-0.97, -0.22, -0.04) represent agricultural elasticities. The last three figures (-0.491, -0.33, -0.0101) represent municipal elasticities.

Elasticity	-0.97	-0.22	-0.04	-0.491	-0.33	-0.0101
Total Cost	$964.74	$1024.41	$1371.7	$981.81	$998.68	$2628.27

The total cost of the water shortage in both basins increases as demand becomes less elastic. These base values are the values to which the results of the GCM modeling runs will be compared against to measure the damages caused by future climate change.

Figure 1: Graphical analysis of chosen elasticities against total shortage costs. Emphasis is placed on the increase of the total shortage cost as the elasticity approaches zero. See preceding paragraphs for an explanation of the x and y axis values.



Both the Table 2 and Figure 1 illustrate that as the elasticities move closer to perfect inelasticity (at 0), the total cost of the shortages increases exponentially because of unchanged habits combined with limited supply.

At this point, the different elasticities chosen for producers (agricultural) and consumers (municipal) come into play again. As shown in Figure 1, producers have a lower sensitivity to higher water prices. This could possibly be attributed to several factors, most notably a profit motive, in continuing their water purchases despite a price increase. Crops will always need water, and although some producer may switch in times of high prices, staple economic crops of the Southwest will continue to be grown in spite of high water prices. Irrigation of agricultural crops accounts for 80% of all water usage in the Western United States, while municipal activities require 20% (Scheierling, 2004). It is easier, therefore, for consumers to alter their water usage patterns than agricultural users, presumably due to consumption habits, imposed rationing, or a combination of the two.

ELASTICITY AND TOTAL COST

Subsequently, these six elasticities were run through the CROSS model for each climate change scenario.

Table 3: GCM total cost (expressed in millions of dollars) corresponding to each chosen elasticity. 11 A2 and B1 scenarios are given in terms of present cost of 111 years of shortage costs, climate change percentages included in calculation. See Table 1 for a description of those values. The first three figures (-0.97, -0.22, -0.04) represent agricultural elasticities. The last three figures (-0.491, -0.33, -0.0101) represent municipal elasticities.

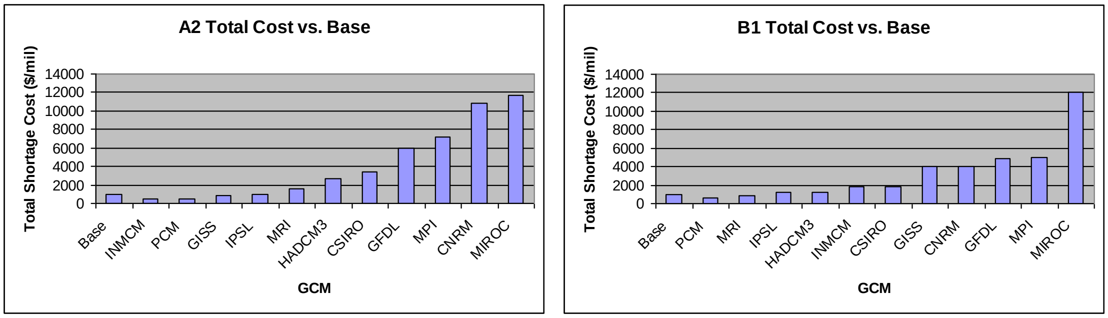
A2 Scenario	**TC -0.97**	**TC -0.22**	**TC -0.04**	**TC -0.491**	**TC -0.33**	**TC -0.0101**
CNRM	7442.29	10868.53	30809.30	8422.76	9391.44	102960.19
CSIRO	2895.89	3361.98	6074.59	3029.27	3161.04	15889.52
GFDL	4710.59	5919.50	12955.37	5056.54	5398.33	38413.00
GISS	770.71	841.87	1256.06	791.07	811.19	2754.71
HADCM3	2360.33	2689.47	4605.04	2454.52	2547.58	11536.06
INMCM	447.11	473.05	624.03	454.53	461.87	1170.31

IPSL	873.36	933.60	1284.19	890.60	907.63	2552.73
MIROC	8193.58	11697.34	32089.22	9196.23	10186.83	105872.39
MPI	5541.59	7165.60	16617.37	6006.32	6465.47	50816.32
MRI	1388.99	1523.24	2304.61	1427.40	1465.36	5131.79
PCM	517.92	541.17	676.49	524.57	531.15	1166.11

B1 Scenario	**TC -0.97**	**TC -0.22**	**TC -0.04**	**TC -0.491**	**TC -0.33**	**TC -0.0101**
CNRM	3186.66	4041.48	9016.52	3431.28	3672.95	27017.53
CSIRO	1674.29	1881.57	3087.94	1733.61	1792.21	7452.87
GFDL	3946.32	4842.16	10055.96	4202.68	4455.95	28920.86
GISS	3313.64	4019.69	8128.88	3515.68	3715.30	22997.03
HADCM3	1152.40	1259.32	1881.57	1183.00	1213.23	4133.06
INMCM	1664.15	1843.08	2884.45	1715.36	1765.94	6652.38
IPSL	1118.10	1222.30	1828.75	1147.91	1177.37	4023.05
MIROC	8546.72	12008.11	32153.38	9537.25	10515.87	105044.23
MPI	4092.14	5037.86	10541.97	4362.77	4630.15	30457.26
MRI	753.24	795.05	1038.38	765.20	777.02	1918.84
PCM	627.89	651.27	787.33	634.58	641.19	1279.65

As the data shows, the trend of larger costs incurred as a result of shortages with an elasticity closer to zero continues. For example, the total cost in the CNRM scenario nearly triples as the elasticity increases from –0.97 to -0.04.

Figure 2: Total shortage cost of each GCM measured against the base for an agricultural elasticity of -0.22. Figures listed are the total of -0.22 elasticity for each CNRM measured against the corresponding value for the base shortage costs listed in Table 2. The base is listed first for comparison's sake. The values in this chart are derived from Table 3 and measured in millions of dollars.



Clearly, the average total shortage cost is much greater for the A2 scenario ($5.8 billion) than the B1 scenario ($4.4 billion), reflecting its original purpose of a future marred by uncontrolled climate change. These graphs also illustrate the inherent differences in the A2 and B1 scenarios regarding the intensity of climate change. The costs associated with A2 are significantly higher overall than B1. To further examine this data in relation to the base climate change values for the next 111 years, we can now graph the total cost of a given GCM scenario minus the cost of the base value (listed in Table 2) for each elasticity, then examine the damages for each scenario, which is done in the following table:

Table 4: GCM additional cost relative to the base values (see Table 2) for each chosen elasticity. Values are expressed in millions of dollars. The total cost figures represent the base cost in Table 2 subtracted from the corresponding GCM value in Table 3. The first three figures (-0.97, -0.22, -0.04) represent agricultural elasticities. The last three figures (-0.491, -0.33, -0.0101) represent municipal elasticities.

A2 Scenario	**TC -0.97**	**TC -0.22**	**TC -0.04**	**TC -0.491**	**TC -0.33**	**TC -0.0101**
CNRM	6477.55	9844.12	29437.60	7440.94	8392.75	100331.92
CSIRO	1931.15	2337.56	4702.89	2047.45	2162.35	13261.24
GFDL	3745.85	4895.09	11583.67	4074.72	4399.64	35784.72
GISS	-194.03	-182.54	-115.64	-190.75	-187.49	126.44
HADCM3	1395.59	1665.06	3233.34	1472.70	1548.89	8907.79

INMCM	-517.63	-551.36	-747.67	-527.28	-536.82	-1457.96
IPSL	-91.38	-90.82	-87.51	-91.22	-91.06	-75.54
MIROC	7228.84	10672.93	30717.52	8214.41	9188.14	103244.12

P_0 **Total Shortage Costs**

MPI	4576.85	6141.19	15245.67	5024.50	5466.78	48188.05
MRI	424.25	498.83	932.91	445.59	466.67	2503.51
PCM	-446.82	-483.24	-695.21	-457.25	-467.54	-1462.16

B1 Scenario	**TC -0.97**	**TC -0.22**	**TC -0.04**	**TC -0.491**	**TC -0.33**	**TC -0.0101**
CNRM	2222.44	3077.26	8052.30	2467.06	2708.73	26053.31
CSIRO	710.07	917.35	2123.72	769.39	827.99	6488.65
GFDL	2982.10	3877.94	9091.74	3238.46	3491.73	27956.64
GISS	2349.42	3055.47	7164.66	2551.46	2751.08	22032.81
HADCM3	188.18	295.10	917.35	218.78	249.01	3168.84
INMCM	699.93	878.86	1920.23	751.14	801.72	5688.16
IPSL	153.88	258.08	864.53	183.69	213.15	3058.83
MIROC	7582.50	11043.89	31189.16	8573.03	9551.65	104080.01
MPI	3127.92	4073.64	9577.75	3398.55	3665.93	29493.04
MRI	-210.98	-169.17	74.16	-199.02	-187.20	954.62
PCM	-336.33	-312.95	-176.89	-329.64	-323.03	315.43

Ultimately, regardless of the scenario, an increase in costs due to shortages is inevitable in any future climate change scenario, as evidenced by the figures in Table 4. That price increases as the elasticity moves closer to zero, and is shown in both agricultural and municipal values.

MARGINAL BENEFIT OF WATER (P_0)

The other constant in the model (besides the interest rate of 4%, which remained unchanged) is the price per acre foot, P_0, which was also changed in the experiment. The following values for P_0 were run through the model (J. Booker, personal communication):

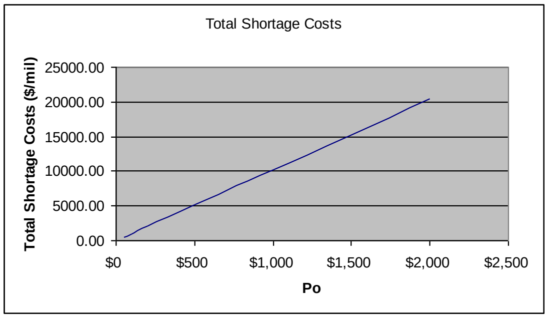
Table 5: Water prices. Prices shown are accurate.

$P_{0\ (agricultural)}$ =	$50	$100	$200
$P_{0\ (municipal)}$ =	$500	$1,000	$2,000

A higher price corresponds with damages resulting from the loss of the ability to use the water. Producers are more flexible with their growing techniques or can switch to a less irrigation-intensive crop, while municipal consumers expect water in their homes and businesses daily for drinking, cooking, toilets, and the like. As expected, this representative range of prices scaled linearly with a P_0 of $100, as shown in this graph for the base value when tested under the representative prices:

Figure 3: Agricultural Price vs. shortage cost. Price values are shortage cost in millions of dollars, elasticity of -0.22

Table 6: Agricultural Price vs. shortage cost. Price values accurate, are accurate, total shortage cost in millions of $, elasticity of -0.22



$50	512.21
$100	1024.41
$200	2048.83
$500	5122.07
$1,000	10244.14
$2,000	20488.28

Any values chosen for the value of P_0 for agricultural or municipal price and elasticity combinations would scale linearly with the values shown here. The relationship between base price and shortage cost can be expressed algebraically as:

$y = 10.244x$

The r^2 value of this graph is 1.

PROPORTIONALITY OF USAGE

In normal conditions, usage can be represented as either agricultural or municipal. Irrigation of agricultural crops accounts for 80% of all water usage in the Western United States, while municipal activities require 20% (Scheierling, 2004). For the base shortage costs with an elasticity of -0.97 and a P_0 of $100, the total cost was $964.74 million. Therefore, one can reasonably assume that under the base scenario, agricultural shortages will cost roughly $771.79 million, while municipal shortages will cost roughly $192.95 million. As with the representative range of prices and elasticities, this proportion and total cost will scale as well. A proportion of 80/20 gives a rough approximation of the distributed costs of climate change in the Colorado River Basin.

CLIMATE CHANGE IMPLICATIONS

It is clear that climate change will have an adverse effect on the water availability and price over the next century in the Colorado River Basin. A range of possible consequences of climate change, shown in the twenty-two GCMs for the A2 and B1 scenarios, have illustrated that increasing shortages in the Colorado River Basin will be costly to the population of the Basin, ranging from $447 million (INMCM, $\eta = -0.97$) to $32 billion (MIROC, $\eta = -0.04$) for agricultural costs and $454 million (INMCM, $\eta = -0.491$) to $106 billion (MIROC, $\eta = -0.0101$) for municipal costs for the A2 scenario and $627 million (PCM, $\eta = -0.97$) to $32 billion (MIROC, $\eta = -0.04$) for agricultural costs and $634 million (PCM, $\eta = -0.491$) to $105 billion (MIROC, $\eta = -0.0101$) for municipal values in the B1 scenario in present value for costs over the next 111 years. It is virtually certain that climate change will exacerbate a river system already pushed to its limits by current demand.

The future of the Colorado River Basin is sure to reflect the increased shortages. Rationing will most likely become the norm, as demand will far outstrip supply as the population in the region continues to grow and temperatures continue to rise. Agriculture will most likely receive the largest impact from rationing, resulting in decreased output or a switch to less irrigation and water-intensive crops. Municipal users will no longer have the luxury of unlimited water, and rationing will adversely affect the standard of living to a certain degree. The artificial greenery of the Southwest, which requires so much water in an unnatural environment, will most likely begin to disappear as important water resources are diverted away from lawn watering to more important consumptive activities. The region will continue to see change in the Colorado River Basin water situation for decades and centuries to come.

REFERENCES

Christensen, N.S. and D.P. Lettenmaier (9 July 2007). “A multimodel ensemble approach to assessment of climate change impacts on the hydrology and water resources of the Colorado River Basin,” *Hydrology and Earth System Sciences*, 1417-1434.

Hedges, T.R (1977). “Water Supplies and Costs in Relation to Farm Rescue Decisions and Profits on Sacramento Valley Farms.” Giannini Foundation Research Report No. 322.

Hooker, Mark and Alexander, Wendy (1998). “Estimating the Demand for Irrigation Water in the Central Valley of California.” *Journal of American Water Resources*, 34, 497-505.

Howitt, R.E., et. al. (1980) “A Reevaluation of Price Elasticities for Irrigation Water.” *Resources*, 16, 623-628.

Nordhaus, William (2008). *A Question of Balance*. New Haven: Yale University Press.

Olmstead, Sheila M (Sept. 2007). “Water demand under alternative price structures.” *Journal of Environmental Economics and Management*, 54, 181-198

Martinez-Espiñera, Roberto (2004). “An estimation of residential water demand using co-integration and error correction techniques.” *Journal of Applied Economics*, 0, 161-184

Scheierling, Susanne M (Aug. 2004). “Determining the Price-Responsiveness of Demands for Irrigation Water Deliveries versus Consumptive Use.” *Journal of Agricultural and Resource Economics*, 29

------------ (Aug. 2004). “Irrigation Water Demand: A Meta Analysis of Price Elasticities.” *American Agricultural Economics Association Annual Meeting*, 1-27.