Brief Summary of Studies that Estimate the Economic Impact of Changes in Climate and Water Availability

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1. Overview

As is well known, water management infrastructures and institutions have evolved to help communities cope with a moderate range of water supply variability and uncertainty. With few exceptions, U.S. communities, industries and water users regardless of their location have evolved capacities to sustain successfully within the context of their local water supply fluctuations and climate variability that is with a variability that is within their 'norm'. Mild fluctuations, moderate variability, even occasional extremes are typically within the normal realm of expectation. Resilience is a characteristic of communities, industries, organizations, and residents that are moderately to well prepared and capable of responding well to 'occasional' extremes. (Figure 1 from the USGS shows water use patterns across the U.S.) However, as the accumulation of science indicates the climate forcing of anthropogenic greenhouse gas emissions is highly likely to contribute to climate uncertainty (e.g., Parry et al., IPCC FAR, 2007 and others). And if this uncertainty can be expected to lead to more frequent, persistent and intense deviations beyond the prevailing capacities of water users to cope, then the risks and consequences facing water users within communities, industries, and organizations become an economic concern.

Both human and natural systems are vulnerable to such changes, and to their conflation with other significant stressors like population growth, loss of habitat and biodiversity, resource scarcity etc. Water systems are particularly sensitive to climatic changes. Both surface- and ground-water supplies can be affected by extreme or persistent changes in the amount and timing of precipitation, temperature driven processes such as evaporation and vegetative evapotranspiration, snowmelt, vegetation cover, and streamflow patterns. Water users are also directly and indirectly affected by extreme and or persistent changes in climate, for example, as rising temperatures increase consumptive irrigation requirements for many crops including irrigated lawns and gardens. And in municipal water systems an increase in seasonal temperatures would likely be experienced as an increase in the effective length of 'summer' and its inherently higher water demands as well as greater 'peak' demands and the associated strain on water delivery capacity and infrastructure.

In this brief abstract, we survey the literature on economic impacts to water systems and resources, with a focus on national and region-wide estimates and on the most

recent studies where they have been conducted. There are far more studies linking climate change and hydrology than those considering economic endpoints. In fact there are surprisingly few studies that complete the linkages between climate change, water and economic consequences. We have tried to access and include as many as we could identify.

2. National Scale Estimates

Examining climate change impacts on water resources on a national scale is quite daunting and there are few examples to draw upon. This is really not at all surprising. There is tremendous variation in water resources and water systems across the U.S. Not only variation across regions but tremendous complexity within regions, and within particular watersheds. Such variation and complexity hinders the development of a comprehensive and consistent assessment of economic impacts on a national basis. Estimation approaches such as large-scale statistical studies that have been used in other sectors such as agriculture (e.g., Mendelsohn et al., 1994) are not well suited with so much uncontrolled variation. Enumerative or aggregation approaches to measuring economic impacts that build a national level estimate by aggregating impacts from each of the nation's watersheds is conceivable in concept but very difficult and costly to execute. Perhaps the closest example of this approach is Hurd et al. (1999a, 2004) where national-level estimates were derived on the basis of only a few large-scale regional estimates and some rather heroic assumptions about the comparability and conformability of some very different regions. Finally, a third way has recently been used to take aim at this difficult problem. Researchers at Sandia National Laboratories have used REMI (Regional Economic Impact, Inc.) in conjunction with a system-dynamics hydrology model and estimated precipitation changes based on the SRES A1B scenario to estimate state-level economic impacts from reduced precipitation.

Research on climate change and its potential economic impacts has steadily evolved from static models based on fixed marginal values to models that capture market dynamics. Early studies by Cline (1992), Fankhauser (1995), and Titus (1992) associated fixed economic values with projections of physical changes (e.g., runoff), with no attempt to account for changes in the marginal value of water or the response of water use to changes in marginal value. Both Cline's (1992) estimated cost of $7 billion and Fankhauser's (1995) estimated cost of $13.7 billion to consumptive water users in the United States are driven by an assumed 10% decrease in water availability. Titus (1992) estimated costs ranging from $21 to $60 billion, including impacts to nonconsumptive users (primarily hydropower and water quality losses), which he observed would most likely exceed the magnitude of impacts to consumptive users.

Hurd, Callaway, Smith and Kirshen (1999a, 2004) approached the problem from a region-specific perspective. Using models of the hydro-economy for four major water resource regions (shown in Figure 2a) and driven by simulated streamflow changes for a set of 15 incremental climate change scenarios, and an extrapolation model based on comparable regions they developed national level estimates of economic damages

related to water resources and climate change. They estimated total annual damages to consumptive and non-consumptive water users by as much as $43.1 billion (1994$) under an incremental level of climate change where temperatures rose by 5 deg C and 0 change in precipitation (estimates shown in Figure 2b).

In assessing the potential for climate change to affect water availability on a national scale -- specifically the impacts of reduced precipitation, Sandia National Laboratory (Backus et al., 2010) estimates there is a 50-50 chance that cumulative direct and indirect macro-economic losses in GDP through 2050 will exceed nearly $ 1.1 trillion (2008$), not including flood risks. That is approximately 0.2% of the cumulative GDP projected between 2010 and 2050. They estimate a 50-50 chance of non-discounted annual losses of $60 billion (2008$) by 2050. Their estimation process uses the MIROC3.2 (medium resolution) and the A1B emissions scenario as a motif to guide the assignment of state-level precipitation changes and then uses results from the remaining GCM runs to characterize and assess uncertainty. Water availability changes are assessed at the county-level using Sandia Water Hydrology model. State-level impacts on economic activity changes are analyzed using REMI. [REMI and other input-output type model the changes in economic flows into and out from a region. They do not measure or estimate economic costs and benefits in a theoretically consistent manner. For example, these models do not estimate changes in willingness-to-pay associated with changes in water availability but rather they simulate the economic consequences that are entailed by such changes. For example, in the same way that a disaster can stimulate regional economies as recovery and rebuilding efforts create jobs and raise incomes. In a similar fashion, persistent and severe water shortages can lead to adaptive responses, like building dams and power plants to replace storage and hydropower generation, thus stimulating employment and incomes.

Figure 3 shows the estimated cumulative state-level economic impacts from 2010 through 2050 (green areas show net GDP increases - particularly in California and PNW).

Although there are considerable differences in the above approaches used to estimate national-level annual economic impacts of climate change on water resources, there is a remarkable consistency in the order of magnitude and share of GDP as shown here:

Cline (1992)	$7 billion (~ 0.1% of 1992 US-GDP $6.3 trillion)
Titus (1992)	$21 - 60 billion (~ 0.3 - 0.9% of 1992 US-GDP $6.3 trillion)
Fankhauser (1995)	$13.7 billion (~ 0.2% of 1995 US-GDP $7.4 trillion)
Hurd et al. (1999a, 2004)	$9.4 - 43.1 billion (~ 0.13 - 0.58% of 1995 US-GDP $7.4 trillion)
Backus et al. (SANDIA, 2010)	$ 60 billion (~ 0.4% of 2009 US-GDP $14.1 trillion)

3. Regional Estimates

There are several region-scale estimates. These include the regions underlying the national-estimates of Hurd et al., namely the Colorado River, Missouri Basin, Delaware basin, and Appalachicola-Flint-Chattahoochie in the Southeast, and the state-level assessments provided in the Sandia report (Backus, 2010), as shown in Figure 3. Additional economic studies include California (Lund et al, 2003; Medellin et al., 2006), the Pacific Northwest (Climate Impacts Group, 2009), and the Upper Rio Grande (Hurd and Coonrod, 2007).

California.

Medellin et al. (2006) perform a comprehensive assessment of climate change impacts on California water users. An example of their findings uses the relatively dry GFDL-A2 to estimate a 27% decrease in water availability and with modeled adaptive responses they find "an average annual scarcity of 17%". Water deliveries to agriculture fall by 24% and urban deliveries fall by 1%. They break down the impacts across three categories: scarcity costs, operating costs, and additional policy costs if interregional water transfers are limited. "Of the $360 million/year in average water scarcity costs for 2050 with dry climate warming, $302 million/year results from lost agricultural production and $59 million/year is from urban water shortages. … Dry climate warming imposes an additional increase of $384 million/year in system operating costs. … With the climate warming, the costs of policies limiting interregional water transfers increases to $250 million/year." All together, these costs amount to $994 million per year, or less than 0.1% of California's $1.5 trillion/yr economy.

Columbia River & Pacific Northwest.

The Climate Impacts Group at University of Washington assessed the impacts of climate change on the Pacific Northwest and the state of Washington, averaging across 20 GCMs under both SRES B1 and A1B (Climate Impacts Group, 2009). Snowpack reductions were significant, with snow water equivalent falling by as much as 65%. Although annual runoff shows an increase of 6% there is a reduction of 43% in runoff during the summer irrigation season by the 2080s. Without adaptation water delivery shortages to agriculture in the Yakima River basin, for example, could be significant. Estimated deliveries fall by as much as 77% by the 2080s. In the 2020s, regional hydropower production increases by 0.5-4% in winter, decreases by 9-11% in summer, with annual reductions of 1-4%.Economic losses of between $23 million and $70 million are estimated, with significantly greater probabilities of annual net operating losses for junior water rights holders.

Rio Grande.

Hurd and Coonrod (2007) estimate economic impacts of climate change on water resources in the Upper Rio Grande (primarily New Mexico, El Paso, Tx, and the San Luis Valley of Southern Colorado). Under the relatively dry scenario (GFDL), runoff change was estimated

to fall by 28% (using WATBAL) and annual direct economic damages in 2080 were estimated at $100 million using a hydro-economic model of the watershed. This loss is approximately 0.2% of the estimated GSP of $60 billion.

Colorado River.

Christensen and Lettenmaier (2007), did a similar research on the Colorado River hydrology with the average of 11 GCM ensembles and two SRES emission scenarios: A2 and B1 (reference). Annual runoff reduction was between 0.0 (2020 B1) and 11.0 (2080 A2) percent. Average annual delivery shortage was estimated to be between 0.22 BCM/Yr (115.8%) and 1.2 BCM/Yr (631.5). Energy Production is estimated to increase during 2020s by the maximum of 120.5 GWh/Yr (1.4%) and experience a reduction during the rest of the century which will result in a maximum of 1573.6 GWh/Yr (18.5%) of negative production during 2080s.

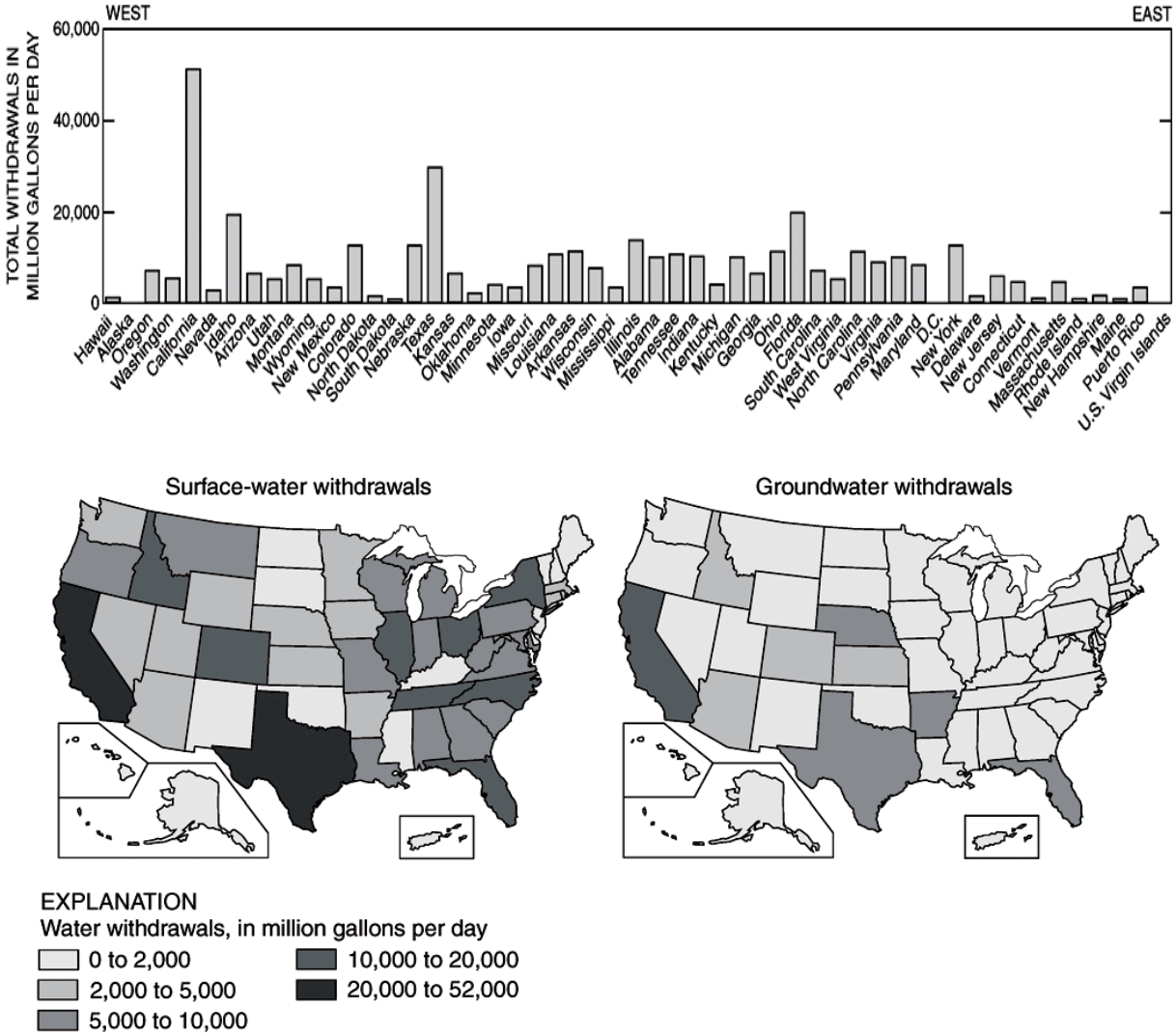
Hurd et al. (1999a), following the work of Booker and Young, modeled the hydro-economy of the Colorado River basin and the impacts of climate change using incremental climate change scenarios and the VIC hydrology model. From an annual baseline of $7.7 billion (1994$) they estimated economic losses for a 5 deg C rise with no change in precipitation of nearly $1.2 billion when runoff was estimated to fall by 35%. Under a 2.5 deg C rise and a 10% reduction in precipitation the losses approached nearly $1.4 billion (1994$).

Other Regions.

A few other regional studies of economic climate change impacts have been documented. Our survey is neither exhaustive nor comprehensive, though literature searches do not find many that are geographically broad. This does not indicate that there are not likely to be significant impacts in other regions. Exhibit 4 shows some of the other basins modeled by Hurd et al. (1999a) and the estimated changes in runoff and economic impact.

Exhibits

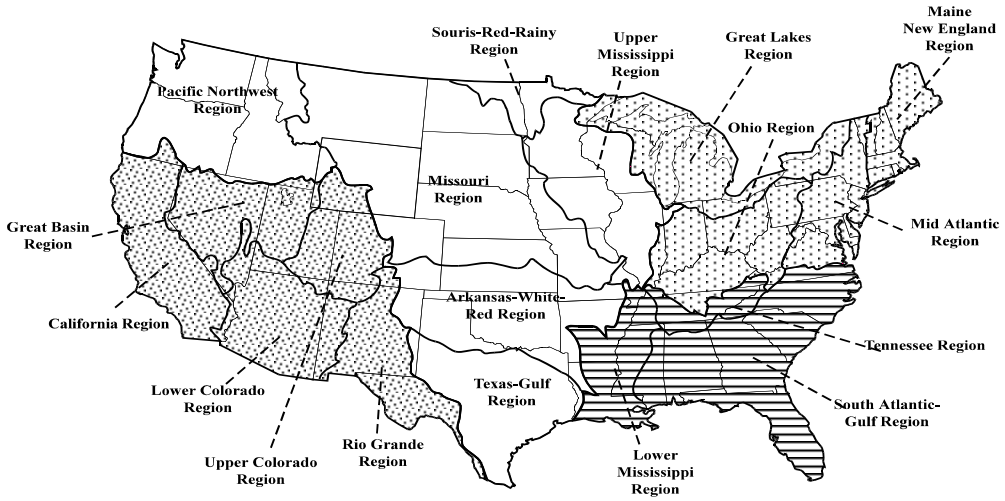
Exhibit 1. Estimated Use of Water in the United States in 2000 Including Surface Water and Groundwater Withdrawals source: USGS (2000)



Source: USGS (2000).

Exhibit 2. a. U.S. Water Resource Regions and the Regional Associations and b. Estimated National Level Impacts of Climate Change on Water Resources from Hurd et al. (1999a, 2004)

a.



b.

Estimated Total Economic Welfare Impacts on U.S. Water Resource Users (billions of 1994$)				
		Nonconsumptive Use		
Climate Scenario	Consumptive Use	Hydropower	Other Nonconsumptive Sectors*	Total
Baseline	88.5	14.7	28.7	132.00
+1.5°C +15%P	0.085	0.69	8.98	9.76
+2.5°C +7%P	-0.98	-2.75	-5.68	-9.41
+5.0°C	-4.29	-7.42	-31.4	-43.11
* Not including damages from thermal heat pollution.				

Exhibit 3. Excerpted from Backus et al. (2010), Cumulative GDP climate-change risk (40 years from 2010–2050) from reduced precipitation for the ensemble of A1B climate scenarios (in billions of dollars at a 0% discount rate).

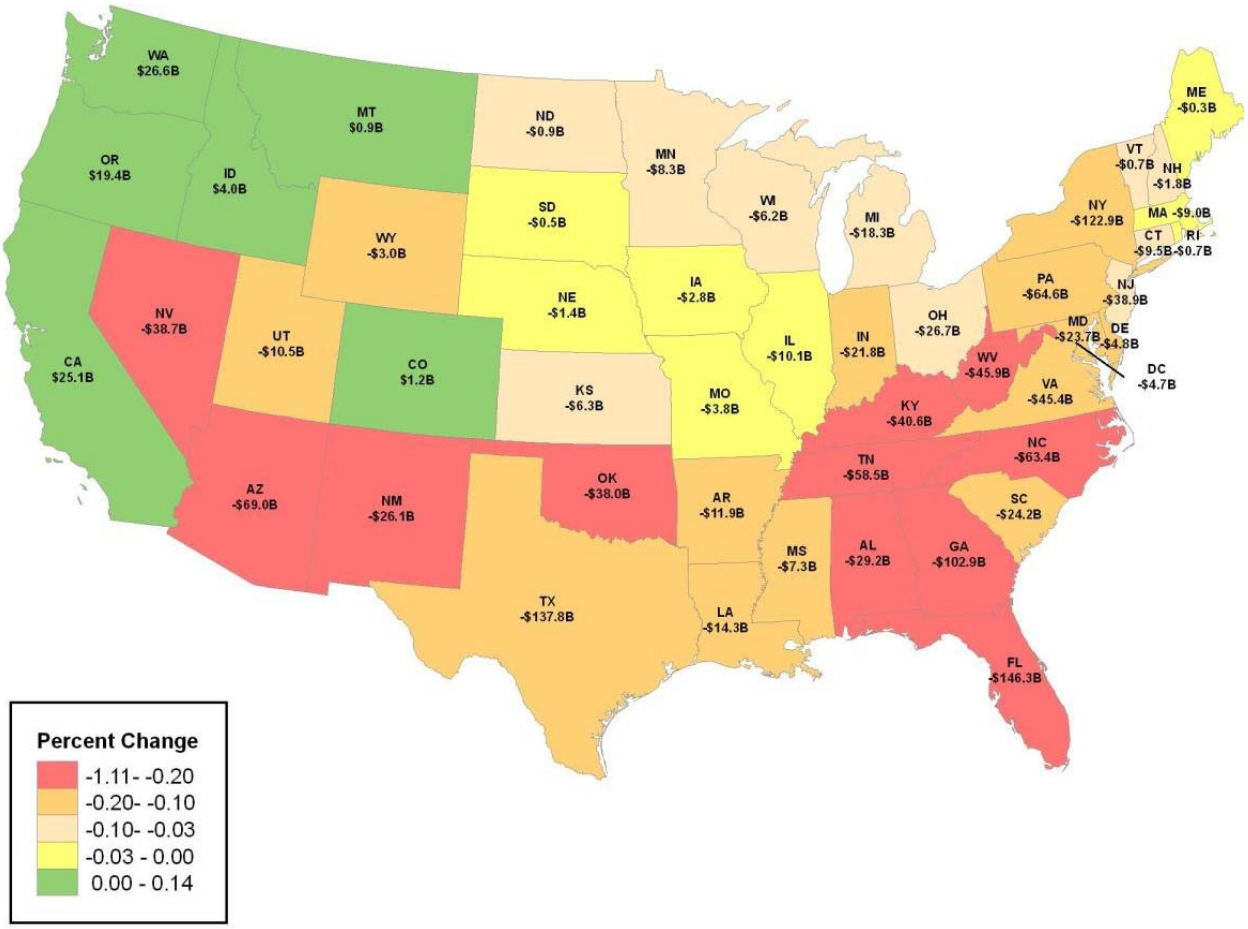


Exhibit 4. Estimated Regional Changes in Runoff and Economic Welfare under Selected Incremental Climate Changes

	Watershed			
	Colorado	Missouri	Appalachicola-Flint-Chattahoochie	Delaware
Baseline				
Runoff (kaf/yr)	17,058	56,651	24,363	13,660
Welfare (million 1994$)	$7,744	$10,804	$2,225	$6,565
Climate Change Scenario and Changes from Baseline				
+2.5 deg C, +7% P				
% Runoff chg (kaf/yr)	- 4.2%	- 9.1%	- 0.3%	- 4.1%
Welfare chg (M1994$)	- $102	- $519	- $15 (1)	- $22
+2.5 deg C, -10% P				
% Runoff chg (kaf/yr)	- 37.9%	- 42.5%	- 27.5%	- 33.2%
Welfare chg (M1994$)	- $1,372	- $2,041	- $12 (1)	- $187
+5 deg C, 0% P				
% Runoff chg (kaf/yr)	- 34.7%	- 42.4%	- 23.5%	- 33.9%
Welfare chg (M1994$)	- $1,193	- $2,239	- $31 (1)	- $207

(1) The estimated changes in welfare for the AFC basin show a mixture of effects including changes in flooding and water quality which confound simple comparison across scenarios. For example, a possible consequence of warmer and drier mean climate might be an expected reduction in average annual flood damages as represented in the above results. However, this analysis does not take into account possible changes in climate variability i.e., greater frequency and intensity of extreme events.

Source: Adapted from: **Hurd, B. H., J. M. Callaway, J. B. Smith, and P. Kirshen**. 1999a. "Economic Effects of Climate Change on U.S. Water Resources." In *The Impact of Climate Change on the United States Economy*. ed. Robert Mendelsohn and James NeumannCambride, UK: Cambridge University Press, 133-177.

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