Water Resources

SUBSECTORS

Inland Flooding

Drought

Water, a resource that sustains life across the globe, is a vital component of a productive economy, providing a critical input to production in a number of key economic sectors.[1] In the U.S., water is used in many ways, including for human consumption, agricultural irrigation, power plant cooling, and hydropower generation. In addition, rivers, lakes, and oceans allow for navigation, fishing, and recreation activities. Water also plays an array of vital roles in ecosystems, which in turn provide crucial services that support human life. Analyzing the effects of climate change on water resources can be particularly challenging as climate variables affect both the supply and demand of water in different ways, and the impacts vary over space and time.

HOW IS WATER VULNERABLE TO CLIMATE CHANGE?

The water cycle is inextricably linked to climate, and climate change has a profound impact on water availability at global, regional, and local levels. As temperatures rise, the rate of evaporation increases, which makes more water available in the air for precipitation but also contributes to drying over some areas.[2] Further, climate change will result in increased intensity of precipitation events, leading to heavier downpours. Therefore, as climate change progresses, many areas are likely to see increased precipitation and flooding, while others will experience less precipitation and increased risk of drought. Some areas may experience both increased flooding and drought. Many of these meteorological changes, along with their associated impacts, are already being observed across the U.S. These changes, combined with demographic, socioeconomic, land use, and other changes, affect the availability, quality, and management of water resources in the U.S.[3]

WHAT DOES CIRA COVER?

The CIRA analyses estimate impacts and damages from three water resource-related models addressing flooding, drought, and water supply and demand (see the Health section of this report for water quality impacts). The models differ in the component of the water sector assessed and geographic scale, but together provide a quantitative characterization of water sector effects that no single model can capture. As the water cycle is sensitive to changes in precipitation, the analyses use a range of projections for future precipitation (see the CIRA Framework section for more information). Finally, future work to improve connectivity between the CIRA electricity, water, and agriculture analyses will aid in better understanding potential impacts to these sectors.

Water Supply and Demand

Inland Flooding

KEY FINDINGS

① Warmer temperatures under climate change are projected to increase precipitation intensity in some regions of the contiguous U.S., raising the risk of damaging floods.

② The effect of global GHG mitigation on flooding damages is sensitive to projected changes in precipitation. The flooding analysis using the IGSM-CAM climate model, which projects relatively wet conditions for most of the U.S., estimates that mitigation will result in a reduction in flood damages of approximately $2.9 billion in 2100 compared to the Reference. Using the drier MIROC model, the analysis projects that mitigation will result in disbenefits of approximately $38 million in 2100.

Climate Change and Inland Flooding

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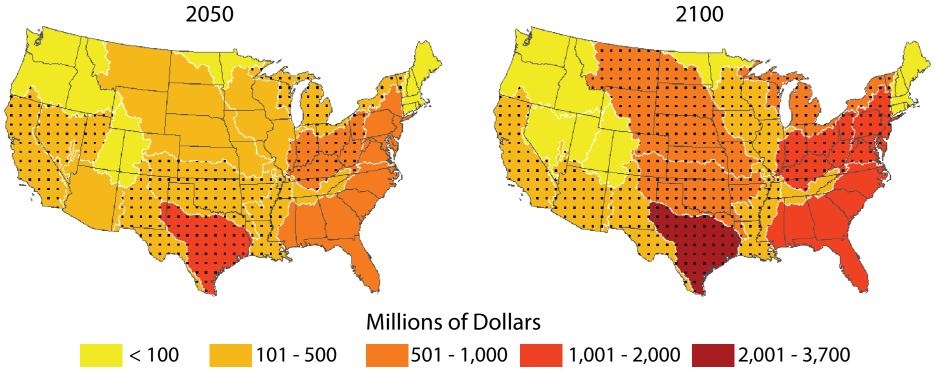
Extreme precipitation events have intensified in recent decades across most of the U.S., and this trend is projected to continue.[4] Heavier downpours can result in more extreme flooding and increase the risk of costly damages.[5] Flooding affects human safety and health, property, infrastructure, and natural resources.[6] In the U.S., non-coastal floods caused over 4,500 deaths from 1959 to 2005 and flood-related property and crop damages averaged nearly $8 billion per year[7] from 1981 to 2011.[8] The potential for increased damages is large, given that climate change is projected to continue to increase the frequency of extreme precipitation events and amplify risks from non-climate factors such as expanded development in floodplains, urbanization, and land-use changes.[9]

Risks of Inaction

Without GHG mitigation, climate change under the IGSM-CAM projections is estimated to increase monetary damages associated with inland flooding across most of the contiguous U.S. Figure 1 presents the projected flood damages in 2050 and 2100 under the Reference scenario. As shown, substantial damages are projected to occur in more regions over time. By 2100, damages are projected to be significantly different from the historic period (at a 90% confidence interval) in 11 of the 18 large watersheds (2-digit hydrologic unit codes). The greatest damages are projected to occur in the eastern U.S. and Texas, with damages in these regions ranging from $1.0-$3.7 billion in 2100.[10] Projections of increased flood damages across most of the U.S. are consistent with the findings of the assessment literature.[11]

Figure 1. Estimated Flood Damages Due to Unmitigated Climate Change

Estimated flood damages under the Reference scenario in 2050 and 2100 for the IGSM-CAM climate model (millions 2014$). Results are presented for the 18 2-digit hydrologic unit codes (HUCs) of the contiguous U.S. Stippled areas indicate regions where the projected damages are significantly different from the historic period (at a 90% confidence interval).



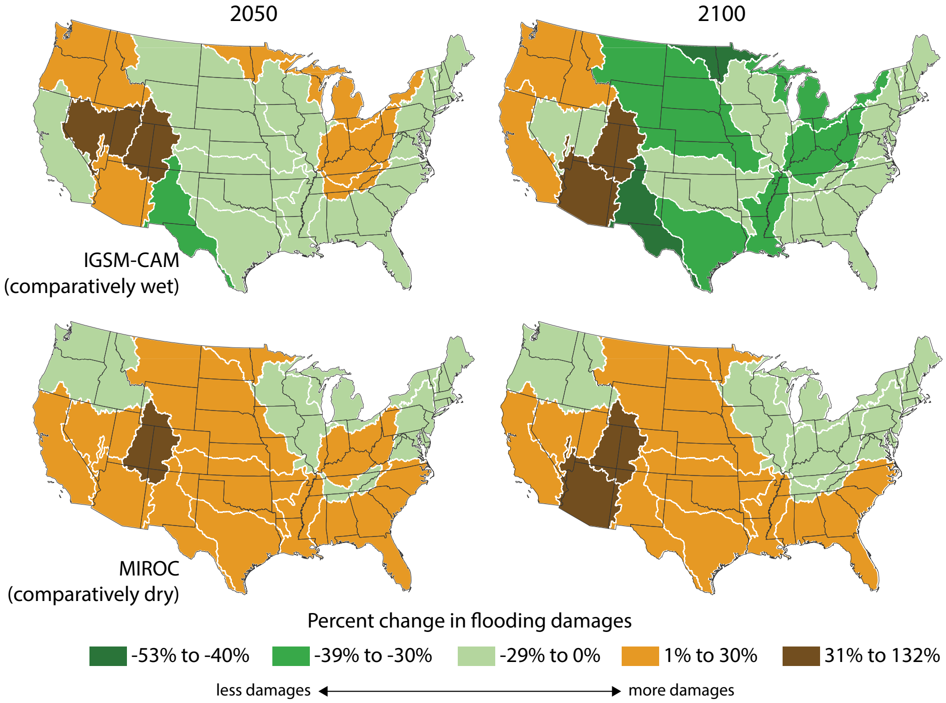
Reducing Impacts through GHG Mitigation

Under the relatively wetter IGSM-CAM climate projections, global GHG mitigation is projected to result in increased flooding damages compared to today, but decreased damages compared to the Reference scenario in most regions of the contiguous U.S. As shown in Figure 2, damages are reduced in 10 out of 18 regions in 2050 and in 14 out of 18 regions in 2100, with particularly pronounced differences between the scenarios in 2100. In 2100, the modeled reduction in damages is approximately $2.9 billion. By the end of the century, substantial benefits are projected over much of the Great Plains and Midwest regions, where damages are estimated to be reduced between 30% and 40% in many states. The four regions not showing benefits of GHG mitigation under the IGSM-CAM projections are located in the western part of the U.S., which also faces the highest risk of drought, as described in the Drought section of this report.

Figure 2 also presents results using the MIROC climate model, which projects a drier future compared to the IGSM-CAM model. Under the MIROC projections, flooding damages are generally reduced under both the Reference and Mitigation scenarios and, as a result, there are modest disbenefits of mitigation across most of the contiguous U.S. in 2050 and 2100. In 2100, damages are projected to increase nationally by $38 million under the Mitigation scenario compared to the Reference.

Figure 2. Change in Flooding Damages Due to Global GHG Mitigation

Percent change in flooding damages for the Mitigation scenario compared to the Reference. Results are presented for the 18 2-digit HUCs of the contiguous U.S. Negative values, shown in green, reflect reductions in flooding damages from global GHG mitigation.



APPROACH

The CIRA analysis quantifies how climate change could affect inland flooding damages in the contiguous U.S. Given the complexities inherent in projecting national flood damages, including the need for small watershed-scale hydrologic modeling, the results presented in this section should be considered first-order estimates. The analysis estimates changes in inland (non-coastal) flood damages following the approach described in Wobus et al. (2013).[12] Specifically, the analysis applies statistical relationships between historical precipitation and observed flood damages in each region of the U.S. to estimate the probability of damaging events occurring in a given year for the baseline period (1983-2008). Flood probabilities are then updated based on precipitation projections for specific events (i.e., 1-, 3-, 5-, and 7-day precipitation totals) under the Reference and Mitigation scenarios to estimate future flood damages. The analysis relies upon climate projections from two climate models: IGSM-CAM, which projects a relatively wetter future for most of the U.S., and the drier MIROC model. Damages are aggregated to the 18 U.S. Geological Survey National Water Resource Regions (WRRs) for two future periods (2050 and 2100), and are then statistically compared to modeled damages for the historic period. Importantly, the estimated damages do not include impacts on human health or economic disruption. The approach assumes that the distribution of monetary damages from flooding, including the effects of non-climate risk factors, will not change in the future.[13] Finally, the value of damages occurring in the future is scaled to account for changes in wealth using projected increases in per capita income in the two CIRA scenarios.

For more information on the CIRA approach and results for flooding damages, please refer to Strzepek et al. (2014)[14] and Wobus et al. (2013).[15]

Drought

KEY FINDINGS

1. In the absence of global GHG mitigation, climate change is projected to result in a pronounced increase in the number of droughts in the southwestern U.S.
2. Global GHG mitigation leads to a substantial reduction in the number of drought months in the southwestern U.S. in both climate models analyzed. The effect of GHG mitigation in other regions is highly sensitive to projected changes in precipitation.
3. The reduction in drought associated with GHG mitigation provides economic benefits to the crop-based agriculture sector ranging from $9.3-$34 billion through 2100 (discounted at 3%).

Climate Change and Drought Risk

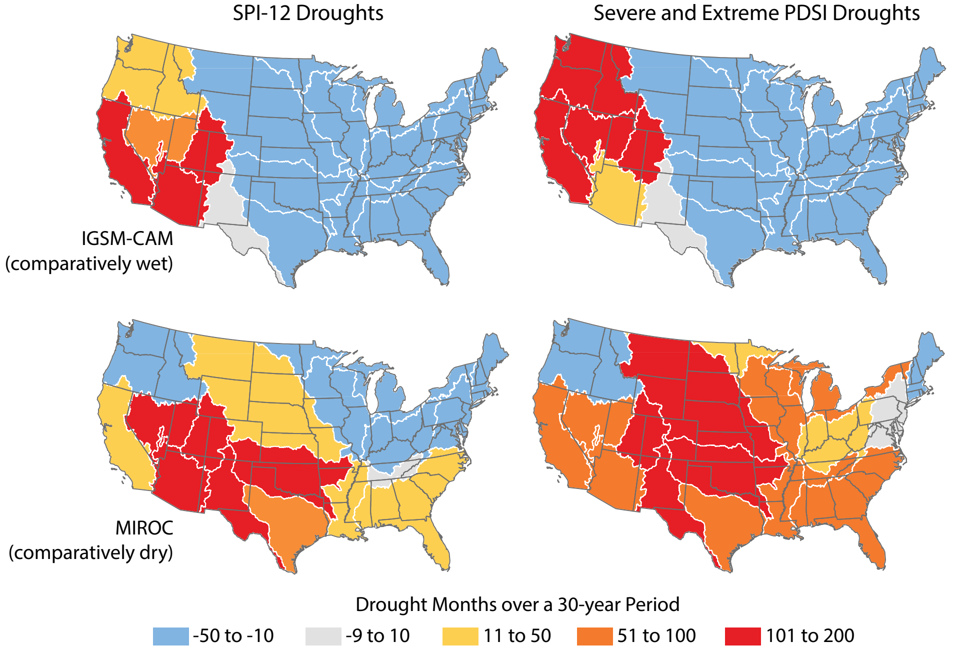
Climate change-related impacts on temperature and precipitation are expected to alter the location, frequency, and intensity of droughts in the U.S., with potentially devastating socioeconomic and ecological consequences.[16] Already, many U.S. regions face increasing water management challenges associated with drought, such as disruptions in navigation and water shortages for irrigation. In recent decades, recurring droughts across the West and Southeast have had significant socioeconomic and ecological impacts.[17]

Risks of Inaction

Without global GHG mitigation, climate change threatens to increase the number of droughts in certain regions of the U.S. The CIRA analysis uses multiple climate projections, each with unique patterns of regional change, to estimate the change in the number of SPI and PDSI droughts (see Approach for descriptions).[18] As discussed in the CIRA Framework section of this report, the IGSM-CAM projects a relatively wetter future for most of the contiguous U.S., while the MIROC model projects a drier future. Figure 1 shows that, although the climate models estimate different outcomes with respect to drought risk for the central and eastern U.S., they both project that the Southwest will experience pronounced increases in both SPI and PDSI drought months. Some areas of the country that are projected to experience increases in drought by 2100 are also projected to experience higher flooding damages (see the Inland Flooding section). This finding should not be interpreted as a conflicting result, and is consistent with the conclusions of the assessment literature,[19] which describe the drivers of these changes as more intense yet less frequent precipitation, and increases in evaporation due to higher temperatures.[20]

Figure 1. Effects of Unmitigated Climate Change on Drought Risk by 2100

Projected change in number of SPI and PSDI drought months under the Reference scenario over a 30-year period centered on 2100. Results are presented for the 18 2-digit hydrologic unit codes (HUCs) of the contiguous U.S. Changes occurring in the grey-shaded areas should be interpreted as having no substantial change between the historic and future periods.



Reducing Impacts through GHG Mitigation

Global GHG mitigation leads to a substantial reduction in drought risk for many parts of the country (Figures 2 and 3). Under the IGSM-CAM climate projections, GHG mitigation substantially reduces drought occurrence across the western U.S., while under the MIROC model, drought is reduced over a majority of the country. Both climate models project reductions in drought in the Southwest, where the risks of increased droughts were highest under the Reference.

The overall decrease in the number of droughts under the Mitigation scenario, particularly in the West, results in substantial benefits to the crop-based agriculture sector. Through 2100, the present value benefits of GHG mitigation in the agricultural sector reach $9.3 billion (discounted at 3%) using the IGSM-CAM climate projections, compared to the Reference. Using the drier MIROC climate model, the Mitigation scenario provides benefits to the agriculture sector of approximately $34 billion (discounted at 3%). Projections from both climate models estimate higher economic benefits of GHG mitigation in the southwestern U.S., where drought frequency is projected to increase most dramatically in the absence of GHG mitigation.

Figure 2. Percentage Change in Number of Severe and Extreme Drought Months with and without GHG Mitigation

Change in number of PDSI drought months under the Reference and Mitigation scenarios over a 30-year period centered on 2100 in the contiguous U.S. Under both climate models, GHG mitigation results in fewer drought months compared to the Reference.

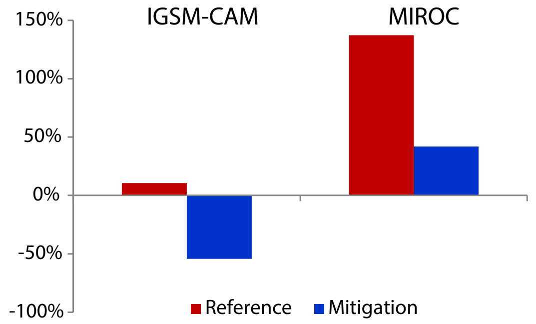
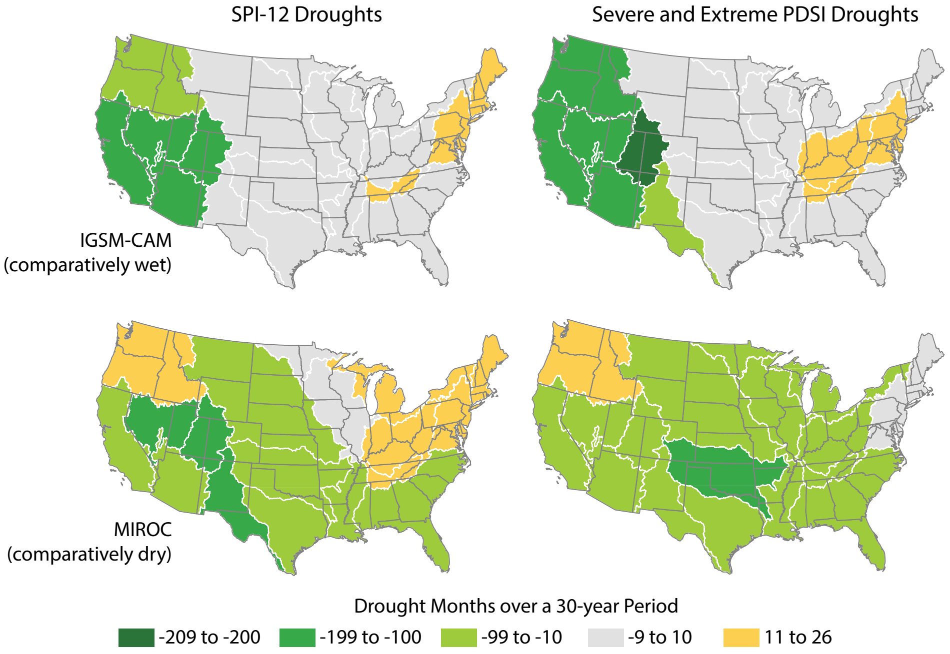


Figure 3. Effect of Global GHG Mitigation on Drought Risk by 2100

Estimated change in number of SPI and PDSI drought months under the Mitigation scenario compared to the Reference over a 30-year period centered on 2100. Results are presented for the 18 2-digit HUCs of the contiguous U.S. Shades of green represent reductions in the number of drought months due to GHG mitigation. Changes occurring in the grey-shaded areas should be interpreted as having no substantial change between the historic and future periods.



APPROACH

The CIRA analysis estimates the effect of climate change on the frequency and intensity of droughts across the contiguous U.S. The approach is based on the methodology from Strzepek et al. (2010).[21] It relies on two drought indices for both the historical and two 21st century time periods. The drought indices account for changes in key climate variables: the Standardized Precipitation Indices (SPI-5 and SPI-12) measure meteorological drought based on change in precipitation from the historical median, and the Palmer Drought Severity Index (PDSI) uses precipitation and temperature data to estimate the relative changes in a particular region's soil moisture. Drought risk is calculated for 99 sub-basins or watersheds in the contiguous U.S. and aggregated to 18 2-digit HUC regions.

The analysis then estimates the effect on crop-based agriculture of the change in frequency and intensity of droughts under the CIRA climate projections. This approach projects impacts using a sectoral model that relates historical drought occurrence with impacts on crop outputs.[22] The resulting relationships are then applied to climate projections under the CIRA Reference and Mitigation scenarios using the IGSM-CAM and MIROC climate models to estimate the economic impacts of climate change and effects of GHG mitigation.[23] This analysis only monetizes the impacts of drought on crop-based agriculture, and does not include other damages (e.g., decreased water availability, ecosystem disruption). Therefore the results estimated here likely underestimate the benefits of GHG mitigation for this sector.

For more information on the CIRA approach and results for the drought sector, please refer to Strzepek et al. (2014)[24] and Boehlert et al. (2015).[25]

Water Supply & Demand

KEY FINDINGS

1. Unmitigated climate change is projected to have profound impacts on both water availability and demand in the U.S., compounding challenges from changes in demographics, land use, energy generation, and socioeconomic factors.

2. Without global GHG mitigation, damages associated with the supply and demand of water across the U.S. are estimated to range from approximately $7.7-$190 billion in 2100. The spread of this range indicates that the effect of climate change on water supply and demand is highly sensitive to projected changes in runoff and evaporation, both of which vary greatly across future climate projections and by U.S. region.

3. Global GHG mitigation is estimated to substantially decrease damages compared to the Reference. Projected benefits under the Mitigation scenario range from $11-$180 billion in 2100, depending on projected future climate. Importantly, global GHG mitigation is projected to preserve water supply and demand conditions more similar to those experienced today.

Climate Change and Water Supply and Demand

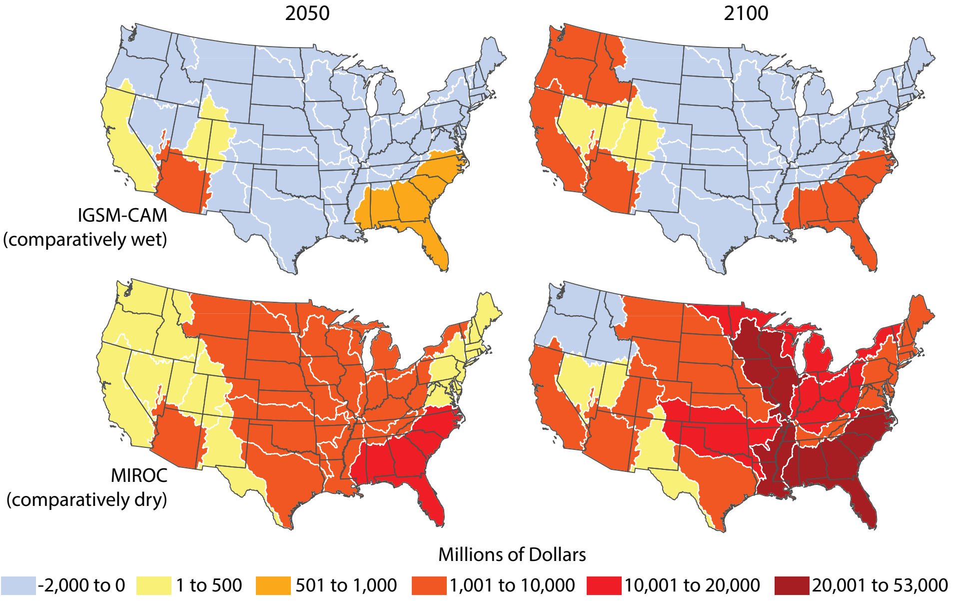
Water management in the U.S. is characterized by the struggle to balance growing demand from multiple sectors of the economy with increasingly limited supplies in many areas. Unmitigated climate change is projected to have profound impacts on both water availability and demand in the U.S., compounding challenges from changes in demographics, land use, energy generation, and socioeconomic factors. As temperatures rise and precipitation patterns become more variable, changes in regional water demand and surface and groundwater supplies are expected to increase the likelihood of water shortage for many areas and uses.[26]

Risks of Inaction

The effect of climate change on water supply and demand is highly sensitive to projected changes in runoff and evaporation, both of which vary across future climate projections and by U.S. region (Figure 1). Despite these variations, increased damages of unmitigated climate change are projected in the Southwest and Southeast regions under both climate models, and these damages increase over time. These projections are consistent with the findings of the assessment literature.[27] Using climate projections from the IGSM-CAM model, the analysis estimates damages at $7.7 billion in 2100. Despite the majority of U.S. regions showing modest increases in welfare (economic well-being) in 2100, the damages in the Southwest and Southeast are much larger in magnitude, and therefore drive the national total. Highlighting the sensitivity of this sector to the climate model used, the drier MIROC model estimates that net damages could be substantially larger, at approximately $190 billion in 2100.

Figure 1. Projected Impacts of Unmitigated Climate Change on Water Supply and Demand

Estimated change in economic damages under the Reference scenario in 2050 and 2100 compared to the historic baseline for the IGSM-CAM and MIROC climate models (millions 2014$). Results are presented for the 18 2-digit hydrologic unit codes (HUCs) of the contiguous U.S. Yellow, orange, and red areas indicate increased damages, while blue areas indicate decreased damages.



Reducing Impacts through GHG Mitigation

Global GHG mitigation is projected to substantially reduce damages compared to the Reference (Figures 2 and 3), and importantly, preserve water supply and demand conditions more similar to those experienced today. The IGSM-CAM model estimates that damages are $7.7 billion under the Reference scenario in 2100, while the Mitigation scenario results in an increase in welfare (collective economic well-being of the population) of $3.4 billion. Therefore, mitigation is estimated to result in a total increase in welfare of $11 billion in 2100 compared to the Reference. Using the drier MIROC model, the Mitigation scenario yields damages of approximately $19 billion in 2100; however, this represents avoided damages of approximately $180 billion compared to the Reference scenario (numbers do not sum due to rounding).

Figure 2. Economic Damages Associated with Impacts on Water Supply and Demand with and without Global GHG Mitigation

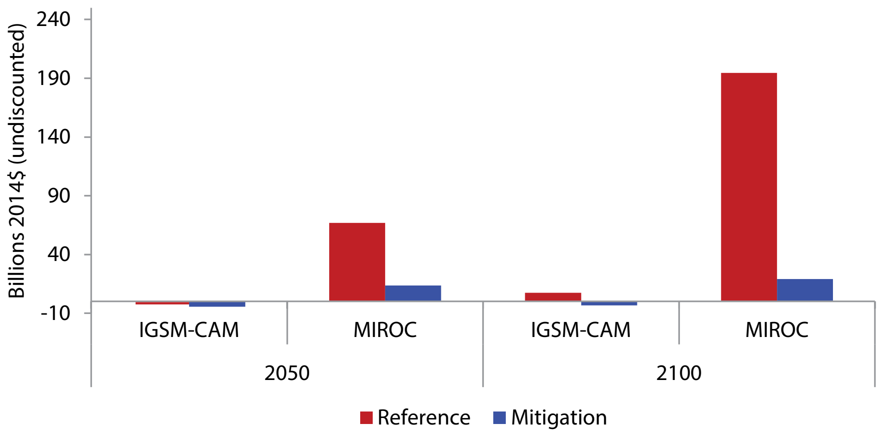
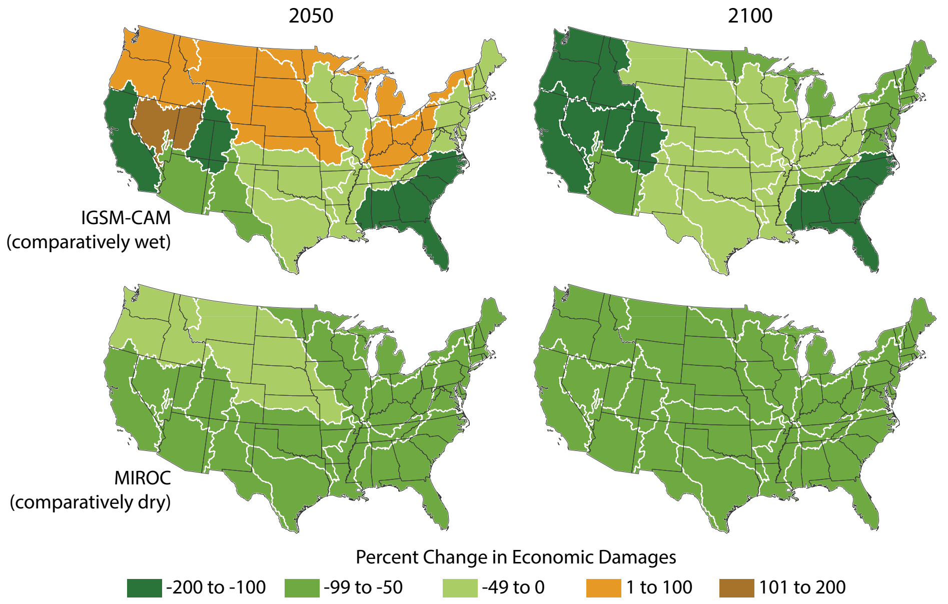


Figure 3. Projected Impacts of GHG Mitigation on Water Supply and Demand

Estimated percent change in economic damages under the Mitigation scenario in 2050 and 2100 relative to the Reference. Results are presented for the 18 2-digit HUCs of the contiguous U.S. Negative values (shown in green) indicate decreases in damages, or positive economic benefits, due to global GHG mitigation.



APPROACH

The CIRA analysis estimates the economic impacts associated with changes in the supply and demand of water, based on a national-scale optimization model developed by Henderson et al. (2013).[28] The model simulates changes in supply and demand in 99 sub-regions or watersheds of the contiguous U.S. based on changes in runoff and evaporation, population, irrigation demand, and other inputs that vary over time. Economic impact functions are applied for a range of water uses including irrigated agriculture, municipal and domestic water use, commercial and industrial water use, hydroelectric power generation, and in-stream flows.[29] The benefits from water use are maximized according to a wide range of constraints, such as storage and conveyance capacities, historic irrigated acreage, and renewable recharge capacity for groundwater. Economic damages are incurred in the model when any one of the water uses specified above does not receive sufficient volume to sustain the baseline activity level. Impacts are summed across all uses in each sub-region and reported as changes in economic welfare. Finally, the optimization model is driven by climate projections from the IGSM-CAM, as well as the MIROC climate model, which projects a relatively drier future for the contiguous U.S. compared to other climate models.[30]

For more information on the CIRA approach and results for the water supply and demand analysis, please refer to Strzepek et al. (2014)[31] and Henderson et al. (2013).[32]