9.2 RESPONSE OF U.S. WATER RESOURCES TO HADCM2 PROJECTIONS OF CLIMATE CHANGE AND CONSEQUENCES FOR AGRICULTURE

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1. INTRODUCTION

Climate change caused by increasing atmospheric concentrations of greenhouse gases will raise global mean temperatures and have variable impacts on agricultural production in the United States. As agriculture is limited by water supply in many areas. potential changes in the water cycle due to climate change will drive the adaptation of agriculture. The capacity of the atmosphere to hold water increases exponentially with its temperature, increasing evaporation and transpiration rates. Precipitation will also increase as its geographic and temporal patterns change. Although there will be more precipitation overall, not all regions will receive more; some will almost certainly receive less. These expected climatic changes will undoubtedly impact both the supply of and the demand for water. The largest consumptive use of water in the United States is agriculture, the economic sector most likely to be affected by a changing climate. We use climate change scenarios to drive impact assessment models for crop production and water resources. We then link the water resource projections to the crop water demand to identify regions where a change in water supply will most significantly impact crop production.

2. METHODS

Here we report on simulations of agriculture and water resources response to scenarios of climate change derived from the HadCM2 general circulation model (Johns et al., 1997). We examine how the changing supply of water may affect agricultural production and irrigation, one of the more likely ways in which farmers will try to adapt. Baseline climate data from national records for 1961-1990 and the HadCM2 scenario runs for two ten year periods centered on 2030 and 2095 were used to drive the EPIC agricultural and HUMUS hydrological simulation models. HUMUS (Hydrologic Unit Model of the United States; Arnold et al., 1998; Srinivasan et al., 1993), a biophysically based hydrology model, consists of a geographic information system (GIS) that provides data on soils, land use and climate to drive the Soil Water Assessment Tool (SWAT). The hydrology modeling was done at the scale of the 8-digit USGS hydrologic unit area (HUA) (USGS, 1987) of which there are 2101 in the conterminous U.S.

*Corresponding author address: N.J. Rosenberg, Joint Global Change Research Institute, 8400 Baltimore Ave. College Park, MD 20740. e-mail:nj.rosenberg@pnl.gov The variable in HUMUS most comparable to streamflow is 'water yield' which is defined as: runoff + lateral flow + groundwater contribution – transpiration loss – pond abstractions.

EPIC (Erosion Productivity Impact Calculator; Williams, 1995) is a process based agro-ecosystem model used here to simulate corn and alfalfa production with and without irrigation on 204 representative farms across the United States, one representing each USGS 4-digit hydrologic unit area. Both models were run at ambient CO_2 concentrations of 365 and 560 ppm to represent the lack and presence, respectively, of a ' CO_2 fertilization' effect that is known to influence rates of plant photosynthesis and evapotranspiration (ET). The HUMUS results were scaled up from the 8 digit HUA level to the 4 digit HUA level for an analysis of water availability and crop water demand.

3. RESULTS AND DISCUSSION

3.1 Climate Change Scenarios

Temperatures increase across the country under the HadCM2 climate change scenarios by up to 4°C for 2030 and 8°C for 2095 (Figure 1). Temperature increases are modest along the East Coast, higher by 1°C in 2030 and 2.5°C in 2095, and highest in the Southwest where increases reach 8°C in 2095. Precipitation also increases over most of the country (Figure 2). The largest increases occur in the Northeast and Pacific Northwest while southern areas see a decrease in 2030, most significantly along the Gulf Coast. The drying trend persists along the Gulf Coast in 2095. The eastern half of the country as well as the West Coast and Mountain regions experience the largest increase in precipitation - over 175 mm above baseline.

HadCM2 projects increased winter precipitation by 2030 across the US except for the Great Lakes and Souris-Red-Rainy basins (Table 1). Reduced summer precipitation is projected for the western US while precipitation increases almost uniformly across the eastern US. HadCM2 predicts substantial increases in winter precipitation in the west by 2095 - 110% in the Great Basin and 40% in the Pacific Northwest. In the Texas Gulf basin, however, winter precipitation decreases by 24%. The trend to greater spring and summer precipitation continues to 2095, except in much of the western US. While almost all of the country is projected to receive more precipitation in all seasons in 2095 as compared with 2030, summer precipitation is actually projected to be lower in the Upper and Lower Colorado and the Great Basin.

3.2 Water yield

Consistent with the changing patterns of precipitation, the simulation models project increases in the water supply by 2030 and larger increases in 2095 over most of the country (Figure 3). The exception is the Gulf Coast, where water yield declines. The increases in water yield are greater in magnitude and more widespread geographically in 2095. The higher temperatures also cause rates of ET to rise (Figure 4) and alter seasonal patterns of streamflow in mountainous regions. Regional changes in water supply are variable, with some regions experiencing declines and others increases. In some mountainous regions, the higher temperatures cause a greater proportion of precipitation to fall as rain, thereby reducing the mountain snowpacks and shifting the runoff curve to peak earlier in the spring (Tables 2 and 3). As expected with climate change, potential evapotranspiration increases across the basins, with increases in actual ET under the scenarios presented here. The increases in ET are driven by the greater water availability and are highest in wetter basins. The smallest increase in ET is in the Texas Gulf region where water yields decline significantly in the southern part of the basin (Figure 4).

3.3 Agriculture

With more available water, dryland production of corn and alfalfa improves over most of the country. The exception is when the CO_2 fertilization effect is not present - corn yields decline from baseline in western regions while alfalfa yields are less impacted (Table 4). Conditions are projected to be more favorable for irrigated agriculture over much of the country in 2030 and 2095 with the notable exception of the Great Plains.

Simulated irrigated yields of corn generally exceed simulated dryland yields under the baseline climate with no CO₂-fertilization effect. This benefit is evident in the drier portions of the country (southern and northern Plains) and quite substantial in the Pacific and Mountain regions. The advantage accruing to corn irrigation is small in the remainder of the country and even slightly negative in the Delta region. Dryland and irrigated yields of alfalfa are simulated only for five of the ten regions defined by USDA. Under baseline climate with no CO₂effect alfalfa yields are substantially increased by irrigation in the Pacific and Mountain regions and moderately increased in the Northern and Southern Plains and Corn Belt.

3.4 Water Supply and Demand

A proxy indicator was developed using irrigation demand simulated by EPIC and water availability simulated by HUMUS to provide a sense of where in the country, and when, water would be available to satisfy change in irrigation demand for corn and alfalfa production as these are influenced by the HadCM2 scenarios and CO₂-fertilization. Our proxy measure of the relationship between water supply and demand in this study is simple:

$$R_{s/d} = \frac{\Delta (WY - IRR)_{scenario}}{|(WY - IRR)_{baseline}|}$$

 $R_{s/d}$ = Ratio of water supply to irrigation demand WY = annual water yield from HUMUS

IRR = total irrigation demand of the crop during the growing season

WY is calculated by aggregating water yields simulated by HUMUS at the 8-digit basin scale to the 4digit scale. IRR is calculated assuming that the crop root zone is fully replenished whenever 50 mm of moisture has been withdrawn from the soil. Thus the amount of irrigation applied is a function of evapotranspiration rate and length of the growing season. WY is an indicator of the volume of water flowing into streams in a particular basin available for withdrawal for irrigation or other uses. The changes in water yield and irrigation demand are presented in Table 5 while the results of the equation are shown in Figures 5 and 6.

In 2030, despite rising temperatures and because of increased rainfall, much of the Eastern Seaboard and New England show up to 50% improvement in water balance (Figure 5). This is true as well of the Pacific Northwest coast with even greater improvement in coastal Northern California, parts of Idaho, Montana and interior Oregon. The remainder of the country, however, shows a general worsening of the water balance, modest in the East and parts of the intermountain West and severe in several 4-digit basins in the Plains region.

Despite still greater increases in temperature in 2095, large increases in precipitation improve water balance over almost all of the eastern U.S. There is a general improvement along the Pacific coast and interior California and in Arizona and the Great Basin. Improvement in water balance occurs in the eastern Great Plains from Minnesota to northern Texas. The simulations reported above support the expectation that suppression of transpiration by elevated CO₂ will increase the availability of water to run off the land or penetrate to depth and will, thereby, increase water yields. Further, the suppression of transpiration in irrigated crops should decrease irrigation requirement. Both effects contribute to an improvement in the supply/demand situation for irrigation water.

4. CONCLUSIONS

Our simulations show an overall increase in water yield nationally. But since regional changes in annual water yield are tightly linked to precipitation patterns, decreases occur in certain regions. Rising temperatures impact annual water yields by increasing ET, thereby reducing quantities of water available for lateral flow and groundwater recharge. Higher temperatures also shift the seasonal hydrologic cycle through earlier snowmelt. This results in a marked increase in water yield during late winter and early spring and in some cases a reduction in water supply during summer. This effect is most evident in the western basins whose hydrologic systems are dominated by snowmelt. Additionally, seasonal shifts in the annual hydrograph are most pronounced under the warmer and wetter HadCM2 scenario for 2095. Conditions are projected to be more favorable for irrigated agriculture over much of the country in 2030 and 2095. A notable exception is the Great Plains, a major agricultural region, where irrigation demands may not be met by available water supply under climate change.

5. REFERENCES

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Baseline



2030



2095



Figure 1. Temperature at baseline and change under 2 HADCM2 scenarios.

Baseline



2030



2095



Figure 2. Precipitation at baseline and under two HADCM2 scenarios.

| | | DJF | | | МАМ | | | JJA | | SON | | | | |
|----------|----------|------|--------|----------|------|------|----------|------|------|----------|------|------|--|--|
| MWRR | Baseline | 2030 | 2095 | Baseline | 2030 | 2095 | Baseline | 2030 | 2095 | Baseline | 2030 | 2095 | | |
| | mm | % | , 0 | mm%% | | mm | 9 | 6 | mm | | -% | | | |
| 1 (NE) | 246 | 10 | 41 | 263 | 5 | 7 | 284 | 23 | 33 | 289 | 8 | 25 | | |
| 2 (MA) | 218 | 9 | 30 | 267 | 9 | 21 | 295 | 17 | 28 | 263 | 5 | 25 | | |
| 3 (SAG) | 323 | 5 | 8 | 333 | -8 | 10 | 408 | -6 | 18 | 275 | 16 | 23 | | |
| 4 (GL) | 143 | -4 | 26 | 204 | 10 | 10 | 257 | 24 | 45 | 235 | 14 | 39 | | |
| 5 (OH) | 232 | 13 | 14 | 312 | 11 | 28 | 309 | 8 | 32 | 252 | 2 | 32 | | |
| 6 (TN) | 348 | 17 | 11 | 382 | 1 | 25 | 323 | 4 | 48 | 298 | 10 | 36 | | |
| 7 (UMS) | 100 | 2 | 16 | 230 | 11 | 22 | 297 | 12 | 31 | 214 | 9 | 32 | | |
| 8 (LMS) | 365 | 4 | -3 | 389 | -5 | 15 | 327 | -13 | 26 | 318 | 3 | 28 | | |
| 9 (SRR) | 46 | -13 | 18 | 127 | -4 | 10 | 237 | 10 | 16 | 121 | -4 | 42 | | |
| 10 (MO) | 48 | 13 | 35 | 156 | 14 | 23 | 190 | 5 | 4 | 108 | 5 | 25 | | |
| 11 (ARK) | 112 | 15 | 16 | 226 | -1 | 24 | 233 | -4 | 17 | 198 | 4 | 19 | | |
| 12 (TG) | 146 | 4 | -24 | 207 | -2 | 4 | 212 | 1 | 24 | 235 | -5 | 12 | | |
| 13 (RG) | 45 | 56 | 37 | 55 | 19 | 24 | 141 | -11 | 0 | 106 | -15 | 11 | | |
| 14 (UCO) | 61 | 45 | 92 | 71 | 37 | 52 | 78 | -6 | -12 | 81 | 7 | 60 | | |
| 15 (LCO) | 79 | 67 | 82 | 50 | 4 | 76 | 98 | -39 | -37 | 80 | -31 | 41 | | |
| 16 (GB) | 65 | 39 | 110 | 74 | 39 | 58 | 58 | -16 | -26 | 67 | 21 | 58 | | |
| 17 (PNW) | 255 | 25 | 40 | 160 | 33 | 37 | 85 | 16 | 6 | 177 | 59 | 44 | | |
| 18 (CA) | 259 | 16 | 68 | 130 | 36 | 54 | 22 | -1 | 17 | 127 | 7 | 35 | | |

Table 1. Seasonal mean precipitation totals aggregated from the 8-digit HUAs to the MWRR level for baseline climate and percentage deviations from baseline for the HadCM2 scenarios of 2030 and 2095 by MWRR.

Baseline

2030

2095



Figure 3. Water Yield simulated at baseline and change under climate change



Figure 4. Percentage change in water supply and use variables for selected MWRRs.

| Scenario | Baseline | | | Baseline | | | Baseline | | | Baseline | | |
|-----------------------|----------|------------|-----|----------|------------------|-----|----------|-----|-----|----------|----------|-----|
| CO ₂ (ppm) | 365 | 365 | 560 | 365 | 365 | 560 | 365 | 365 | 560 | 365 | 365 | 560 |
| | ET | Δ I | ET | PET | PET Δ PET | | Q | Δ | Q | WY | Δ | WY |
| MWRR | | | | | | m | nm | | | | | |
| 1 (NE) | 399 | 45 | 13 | 804 | 101 | 87 | 360 | 45 | 61 | 598 | 62 | 90 |
| 2 (MA) | 425 | 36 | 16 | 982 | 94 | 92 | 275 | 51 | 60 | 520 | 60 | 75 |
| 3 (SAG) | 564 | -2 | -34 | 1313 | 91 | 82 | 279 | 37 | 47 | 607 | 18 | 41 |
| 4 (GL) | 498 | 40 | 26 | 989 | 62 | 60 | 199 | 25 | 32 | 330 | 32 | 45 |
| 5 (OH) | 539 | 41 | 22 | 1080 | 104 | 104 | 358 | 66 | 76 | 525 | 53 | 69 |
| 6 (TN) | 543 | 23 | -2 | 1085 | 86 | 84 | 315 | 69 | 76 | 759 | 82 | 104 |
| 7 (UMS) | 512 | 41 | 26 | 1076 | 115 | 114 | 237 | 40 | 51 | 313 | 35 | 50 |
| 8 (LMS) | 656 | 12 | -27 | 1271 | 111 | 102 | 373 | -5 | 14 | 586 | -31 | 2 |
| 9 (SRR) | 449 | 24 | 17 | 1130 | 130 | 128 | 62 | -18 | -13 | 82 | -19 | -11 |
| 10 (MO) | 406 | 34 | 27 | 1306 | 155 | 154 | 68 | 5 | 10 | 94 | 8 | 14 |
| 11 (ARK) | 544 | 9 | -6 | 1700 | 139 | 136 | 150 | 11 | 21 | 211 | 5 | 19 |
| 12 (TG) | 577 | 9 | -9 | 1881 | 71 | 67 | 121 | -6 | 4 | 196 | -14 | 3 |
| 13 (RG) | 318 | -3 | -6 | 1731 | 158 | 158 | 10 | 4 | 5 | 29 | 5 | 7 |
| 14 (UCO) | 237 | 20 | 17 | 1215 | 112 | 109 | 25 | 13 | 13 | 53 | 32 | 34 |
| 15 (LCO) | 260 | -29 | -30 | 1748 | 138 | 136 | 12 | 11 | 11 | 46 | 18 | 19 |
| 16 (GB) | 217 | 34 | 32 | 1308 | 125 | 125 | 28 | 7 | 8 | 48 | 23 | 25 |
| 17 (PNW) | 235 | 74 | 60 | 1000 | 70 | 44 | 192 | 87 | 92 | 400 | 139 | 153 |
| 18 (CA) | 217 | 29 | 24 | 1394 | 44 | 41 | 119 | 29 | 31 | 290 | 54 | 59 |

Table 2. Simulated evapotranspiration (ET), potential evapotranspiration (PET), surface runoff (Q) and water yield (WY) for the major water resource regions under baseline climate and under climate change in 2030 projected by the HadCM2 model, with and without 'CO₂-fertilization'

| Scenario | Baseline | | | Baseline | | | Baseline | | | Baseline | | |
|-----------------------|----------|----------|-----|----------|------------|-----|----------|-----|-----|----------|------------|-----|
| CO ₂ (ppm) | 365 | 365 | 560 | 365 | 365 | 560 | 365 | 365 | 560 | 365 | 365 | 560 |
| | ET | Δ | ET | PET | Δ F | PET | Q | Δ | Q | WY | Δ V | WY |
| MWRR | | | | | | mr | n | | | | | |
| 1 (NE) | 399 | 66 | 32 | 804 | 158 | 145 | 360 | 117 | 134 | 598 | 185 | 214 |
| 2 (MA) | 425 | 56 | 36 | 982 | 147 | 144 | 275 | 119 | 127 | 520 | 168 | 183 |
| 3 (SAG) | 564 | 23 | -9 | 1313 | 136 | 128 | 279 | 118 | 128 | 607 | 149 | 172 |
| 4 (GL) | 498 | 65 | 52 | 989 | 112 | 110 | 199 | 83 | 90 | 330 | 138 | 151 |
| 5 (OH) | 539 | 70 | 53 | 1080 | 144 | 143 | 358 | 181 | 190 | 525 | 206 | 220 |
| 6 (TN) | 543 | 55 | 33 | 1085 | 115 | 114 | 315 | 199 | 206 | 759 | 321 | 342 |
| 7 (UMS) | 512 | 68 | 54 | 1076 | 162 | 161 | 237 | 127 | 138 | 313 | 151 | 166 |
| 8 (LMS) | 656 | 54 | 14 | 1271 | 156 | 142 | 373 | 133 | 153 | 586 | 149 | 183 |
| 9 (SRR) | 449 | 76 | 66 | 1130 | 182 | 180 | 62 | 9 | 15 | 82 | 22 | 31 |
| 10 (MO) | 406 | 55 | 48 | 1306 | 240 | 239 | 68 | 24 | 29 | 94 | 31 | 37 |
| 11 (ARK) | 544 | 56 | 38 | 1700 | 214 | 211 | 150 | 77 | 88 | 211 | 87 | 103 |
| 12 (TG) | 577 | 24 | 4 | 1881 | 172 | 167 | 121 | 27 | 39 | 196 | 25 | 44 |
| 13 (RG) | 318 | 10 | 7 | 1731 | 265 | 264 | 10 | 12 | 13 | 29 | 25 | 28 |
| 14 (UCO) | 237 | 41 | 37 | 1215 | 210 | 206 | 25 | 32 | 33 | 53 | 83 | 86 |
| 15 (LCO) | 260 | 9 | 7 | 1748 | 225 | 224 | 12 | 34 | 34 | 46 | 81 | 83 |
| 16 (GB) | 217 | 62 | 60 | 1308 | 219 | 219 | 28 | 28 | 30 | 48 | 70 | 73 |
| 17 (PNW) | 235 | 87 | 74 | 1000 | 157 | 144 | 192 | 85 | 89 | 400 | 138 | 149 |
| 18 (CA) | 217 | 62 | 55 | 1394 | 125 | 122 | 119 | 98 | 100 | 290 | 199 | 204 |

Table 3. Simulated evapotranspiration (ET), potential evapotranspiration (PET), surface runoff (Q) and water yield (WY) for the major water resource regions under baseline climate and under climate change in 2095 projected by the HadCM2 model, with and without 'CO₂-fertilization'

| CO ₂ / | | | | | | | | | | | Region | | | | | | | | | |
|-------------------|-------|-----|-------|------|--------|-----|--------|-----|------|-------|-----------|------|-------|----|-------|------|--------|--------|--------|------|
| Scenario | Paci | fic | Mount | tain | N. Pla | ins | S. Pla | ins | Lake | s | Corn | Belt | Delta | a | North | east | Appala | achian | Southe | east |
| | | | | | | | | | | | Mg ha⁻¹ ⋅ | | | | | | | | | |
| | | | | | | | | | | Dry | yland Co | orn | | | | | | | | |
| B-365 | 1.38 | а | 0.98 | bc | 4.6 | ba | 5.55 | b | 4.57 | d | 6.05 | С | 6.26 | ba | 4.16 | d | 6.13 | bc | 5.76 | ba |
| H1-365 | 1.08 | а | 0.51 | d | 3.11 | d | 4.33 | с | 5.3 | с | 6.31 | cb | 5.84 | b | 4.7 | bdc | 5.94 | С | 5.34 | ba |
| H1-560 | 1.42 | а | 0.8 | dc | 4.2 | bc | 5.7 | ba | 5.94 | b | 6.98 | а | 6.74 | а | 5.24 | ba | 6.7 | ba | 6.13 | ba |
| H2-365 | 1.71 | а | 0.76 | dc | 3.48 | dc | 4.2 | с | 6.04 | b | 6.53 | b | 5.84 | b | 4.81 | bac | 6.27 | bac | 5.04 | b |
| H2-560 | 2.15 | а | 1.18 | ba | 4.51 | b | 5.23 | bc | 6.69 | а | 7.09 | а | 6.32 | ba | 5.35 | а | 6.95 | а | 5.76 | ba |
| | | | | | | | | | | Irri | gated Co | orn | | | | | | | | |
| B-365 | 5.39 | b | 4.47 | с | 5.66 | d | 7.7 | bc | 4.65 | d | 6.15 | С | 6.14 | b | 4.24 | С | 6.32 | b | 5.8 | а |
| H1-365 | 5.53 | ba | 5.53 | b | 6.52 | b | 7.81 | bc | 5.82 | с | 6.69 | b | 6.84 | ba | 5.02 | ba | 6.57 | ba | 5.82 | а |
| H1-560 | 6.01 | ba | 6 | ba | 7.02 | а | 8.41 | а | 6.24 | cb | 7.2 | а | 7.28 | а | 5.44 | а | 7.17 | а | 6.48 | а |
| H2-365 | 6.48 | ba | 5.67 | ba | 6.24 | с | 6.72 | d | 6.42 | b | 6.68 | b | 6.03 | b | 5.08 | ba | 6.52 | ba | 5.42 | а |
| H2-560 | 7.02 | а | 6.17 | а | 6.72 | b | 7.27 | dc | 6.89 | а | 7.17 | а | 6.38 | ba | 5.5 | а | 7.11 | ba | 6.06 | а |
| | | | | | | | | | | Dry | land Alf | alfa | | | | | | | | |
| B-365 | 4.34 | b | 3.08 | с | 5.57 | bc | 6.85 | с | | | 7.66 | С | | | | | | | | |
| H1-365 | 4.51 | ba | 3.09 | с | 4.68 | с | 7.76 | b | | | 8.64 | b | | | | | | | | |
| H1-560 | 5.81 | ba | 4.05 | ba | 6.16 | ba | 9.53 | а | | | 10.44 | а | | | | | | | | |
| H2-365 | 5.15 | ba | 3.6 | bc | 5.17 | с | 8.27 | b | | | 9.23 | b | | | | | | | | |
| H2-560 | 6.68 | а | 4.69 | а | 6.81 | а | 10.03 | а | | | 10.97 | а | | | | | | | | |
| | | | | | | | | | | Irrig | ated Alf | alfa | | | | | | | | |
| B-365 | 10.7 | d | 9.21 | С | 7.71 | с | 7.17 | d | | | 7.99 | С | | | | | | | | |
| H1-365 | 11.92 | dc | 10.9 | b | 9.35 | b | 9.07 | cb | | | 9.58 | b | | | | | | | | |
| H1-560 | 14.08 | ba | 12.8 | а | 10.98 | а | 10.59 | а | | | 11.17 | а | | | | | | | | |
| H2-365 | 12.11 | dc | 10.94 | b | 9.69 | b | 9.23 | b | | | 9.72 | b | | | | | | | | |
| H2-560 | 14.37 | а | 12.87 | а | 11.41 | а | 10.77 | а | | | 11.31 | а | | | | | | | | |

Table 4. Simulated yields of corn and alfalfa under baseline climate (B) and the HadCM2 projections in 2030 (H1) and 2095 (H2), each at two CO₂ concentration levels (365 and 560 ppm) under dryland and irrigated conditions.

[†] Means within a column and section followed by the same letter are not significantly different at the 10% level of probability.

| Scenario | | Basel | line | | HadCN | /12 2030 | | HadCM2 2095 | | | | |
|-----------------------|-------|-------------|------------|--------|----------|----------|--------|-------------|----------|--------|--------|--|
| Variable | | Water Yield | Irrigation | ∆ Wate | er Yield | ∆ Irrig | gation | Δ Wate | er Yield | ∆ Irri | gation | |
| CO ₂ (ppm) | | | | 365 | 560 | 365 | 560 | 365 | 560 | 365 | 560 | |
| MWRR | HUA 4 | | | | | Co | orn | | | | | |
| New Eng. | 107 | 584 | 46 | 42 | 56 | 54 | 31 | 139 | 154 | 57 | 37 | |
| Mid-Atl. | 205 | 518 | 69 | 74 | 89 | 61 | 17 | 196 | 211 | 54 | 19 | |
| S.AtlGulf | 305 | 526 | 13 | 39 | 55 | 50 | 31 | 187 | 204 | 17 | 11 | |
| Great Lakes | 408 | 302 | 107 | 61 | 74 | 74 | 31 | 160 | 173 | 85 | 46 | |
| Ohio | 512 | 455 | 102 | 63 | 78 | 87 | 46 | 211 | 226 | 57 | 13 | |
| Tenn. | 603 | 804 | 111 | 55 | 72 | 154 | 115 | 310 | 328 | 67 | 30 | |
| U. Miss. | 708 | 296 | 80 | 51 | 65 | 106 | 63 | 186 | 199 | 78 | 41 | |
| L. Miss. | 805 | 604 | 52 | -8 | 4 | 235 | 174 | 198 | 212 | 107 | 44 | |
| Souris-RR | 902 | 56 | 102 | -18 | -13 | 133 | 85 | 13 | 21 | 119 | 69 | |
| Missouri | 1012 | 33 | 206 | -9 | -7 | 119 | 52 | -10 | -9 | 104 | 37 | |
| Ark-WR. | 1103 | 81 | 228 | 8 | 14 | 144 | 72 | 25 | 33 | 98 | 33 | |
| TX Gulf | 1209 | 151 | 300 | -2 | 10 | 119 | 61 | 17 | 32 | 98 | 22 | |
| Rio Grande | 1306 | 18 | 278 | -11 | -11 | 237 | 146 | -2 | 0 | 237 | 159 | |
| U. Colorado | 1406 | 29 | 313 | 9 | 11 | 183 | 109 | 50 | 53 | 163 | 91 | |
| L. Colorado | 1507 | 32 | 593 | 18 | 20 | -7 | -96 | 89 | 90 | -81 | -148 | |
| Great Basin | 1604 | 42 | 492 | 22 | 23 | 67 | -17 | 42 | 43 | 31 | -51 | |
| Pacific NW | 1702 | 186 | 380 | 106 | 112 | 174 | 70 | 54 | 59 | 163 | 70 | |
| California | 1804 | 398 | 267 | 21 | 23 | 406 | 304 | 150 | 153 | 352 | 258 | |
| MWRR | HUA 4 | | | | | Al | falfa | | | | | |
| Great Lakes | 408 | 302 | 181 | 61 | 74 | 133 | 59 | 160 | 173 | 148 | 70 | |
| Ohio | 512 | 455 | 154 | 63 | 78 | 94 | 37 | 211 | 226 | 83 | 26 | |
| U. Miss. | 708 | 296 | 154 | 51 | 65 | 196 | 143 | 186 | 199 | 163 | 74 | |
| Souris-RR. | 902 | 56 | 204 | -18 | -13 | 313 | 228 | 13 | 21 | 319 | 226 | |
| Missouri | 1012 | 33 | 289 | -9 | -7 | 226 | 150 | -10 | -9 | 300 | 206 | |
| ArkWR. | 1103 | 81 | 578 | 8 | 14 | 407 | 250 | 25 | 33 | 433 | 294 | |
| Rio Grande | 1306 | 18 | 804 | -11 | -11 | 550 | 367 | -2 | 0 | 719 | 528 | |
| U. Colorado | 1406 | 29 | 567 | 9 | 11 | 280 | 178 | 50 | 53 | 341 | 222 | |
| L. Colorado | 1507 | 32 | 1613 | 18 | 20 | 185 | 0 | 89 | 90 | 19 | -181 | |
| Great Basin | 1604 | 42 | 759 | 22 | 23 | 113 | -22 | 42 | 43 | 261 | 106 | |
| Pacific NW | 1702 | 186 | 622 | 106 | 112 | 393 | 246 | 54 | 59 | 531 | 369 | |
| California | 1804 | 398 | 498 | 21 | 23 | 361 | 252 | 150 | 153 | 431 | 31 | |

Table 5. Water yield and irrigation requirement (mm) for corn and alfalfa under baseline, climate change, and CO₂-fertilization scenarios



CO2 = 365





2030



Figure 5. Difference in water supply and demand simulated with the HUMUS and EPIC models, respectively, under baseline climate conditions for irrigated corn



2030

CO2 = 560



CO2 = 365



Figure 6. Difference in water supply and demand simulated with the HUMUS and EPIC models, respectively, under baseline climate conditions for irrigated alfalfa