



**Purdue Policy  
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**Policy Brief**

## Global Drivers of Land and Water Sustainability Stresses at Mid-century

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### Key Findings

Global population and income growth will continue to exert pressure on land and water resources in the coming decades with  $\frac{1}{4}$  of US cropland expansion due to demand growth in China and India

In the US, groundwater extraction in regions which are already unsustainable presents a considerable challenge at mid-century

Restricting future groundwater withdrawals to sustainable levels would result in a significant reallocation of global crop production overseas as well as within the US

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### Long Run Sustainability Challenge

The pressure on US farmers to produce more output has led to the unsustainable use of land and water resources in some locations. Groundwater withdrawals exceed recharge rates on fifteen percent of US lands and most of these withdrawals are for irrigated agriculture<sup>1</sup>. Recent droughts have exacerbated this problem in the Western US<sup>2</sup>. Groundwater levels in California’s Central Valley Aquifer, as well as in the High Plains Aquifer continue to decline<sup>3,4,5</sup>. Excessive pumping is the single largest cause of land subsidence leading to permanent setbacks in groundwater storage capacity through compaction of soils<sup>6,7</sup>. These reductions in groundwater storage could threaten the nation’s ability to meet future water needs<sup>8</sup>. The conversion of environmentally sensitive and erosive lands for farming also continues to be a concern, particularly in light of the 2006-2012 peak in commodity prices<sup>9</sup>. While the Conservation Reserve Program seeks to keep erosive land out of production in the United States, its effectiveness is circumscribed by commodity prices and land returns<sup>10</sup>.

### Global Drivers of US Agriculture

As we look forward to mid-century, continuing global population and income growth (Figure 1) will continue to boost the demand for agricultural products and therefore indirectly, for land and water resources. The demand for groundwater is likely to be particularly strong in the coming decades, as irrigation can offset some of the yield losses associated with a warming climate<sup>11</sup>. In the footrace

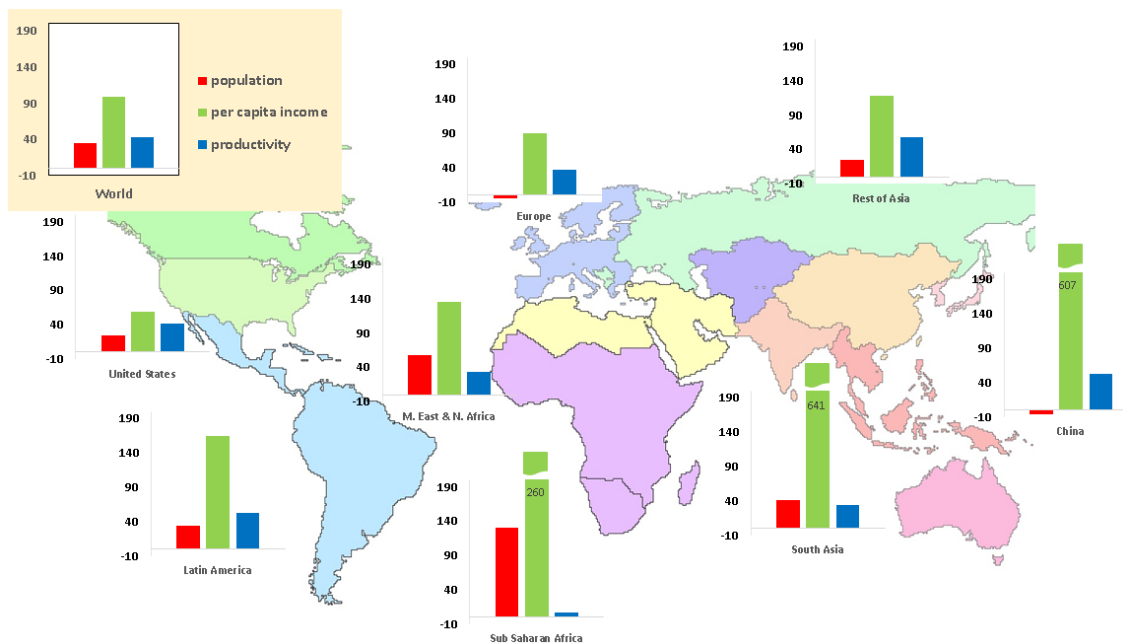
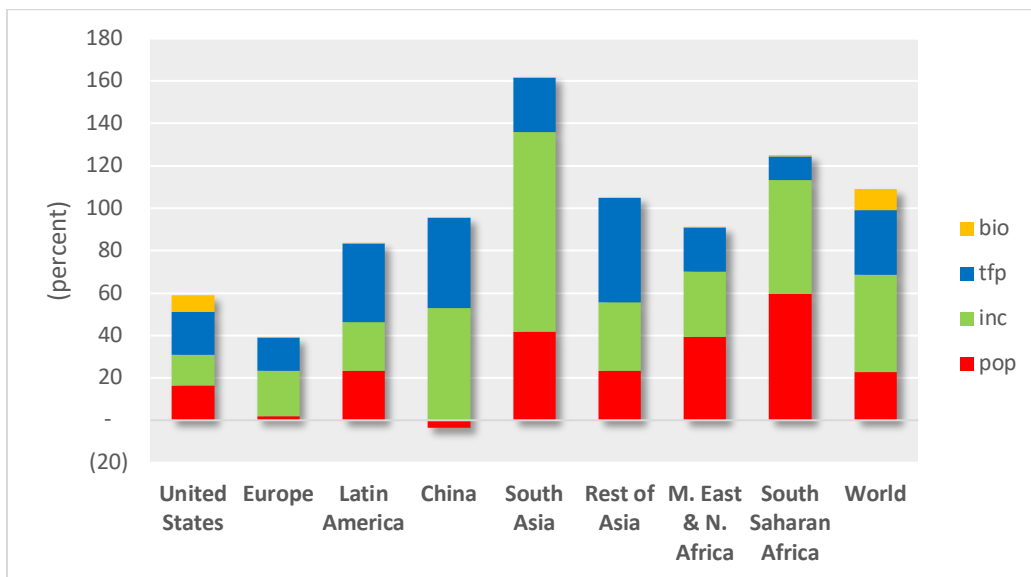




Figure 1. Percentage change in main drivers of crop production and land use from 2010 to 2050: population, per capita income and productivity. The latter is measured by growth in Total Factor Productivity (TFP).

between supply and demand, productivity growth is the key supply-side driver. We explore the linkages between these global drivers of agricultural production and potential sustainability challenges facing US agriculture using the SIMPLE modeling framework which has been widely used to explain historical changes in cropland extent, irrigation, prices and output at both global and regional scales<sup>\*,12,13</sup>. Results of these model projections are reported in the ensuing figures.

While crop output growth in each region is influenced first and foremost by the interplay between domestic supply and demand, developments in international markets also play an important role – particularly in those regions which are heavily reliant on crop exports or imports. Figure 2 explores the drivers of changes in aggregate regional crop output. In the US, production is expected to rise by nearly sixty percent or roughly one billion metric tons over this four-decade period.<sup>†</sup> The drivers of US crop output growth are fairly evenly divided between increases in population – both domestic and foreign (red bar), rising per capita incomes around the world (green bar), and improved productivity in global crop production (blue bar). We also include projected



\* SIMPLE stands for a Simplified International Model of Prices Land use and the Environment. For a detailed analysis of historical changes (1961-2006) as well as future projections (2006-2050) see Hertel and Baldos (2016). In this policy brief we employ the gridded version. The US version of SIMPLE-G measures the impacts on crop production, land use, groundwater and surface water withdrawal in ~75000 diverse grid cells in the US (each grid cell is around 10km x 10km) as well as in other regions of the world.

<sup>†</sup> Output is reported in corn-equivalent tons wherein each of the 175 crops in our data base is normalized by the individual crop price, divided by the price of corn, in our base year.

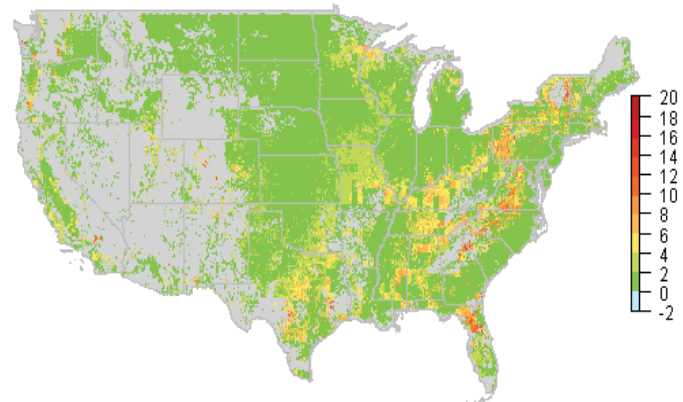


*Figure 2. Percent change in crop production from 2010 to 2050 due to the combined effect of changes in per capita income (inc), population (pop) and productivity (tfp), around the world, as well as growth in US biofuels (bio) demand. Growth in domestic and foreign population and incomes boosts demand, raises prices and output. Growth in productivity lowers costs, thereby depressing prices and encouraging consumption.*

growth of US biofuels as a driver of change which mainly influences US crop output. In Europe and China, regions with little projected population growth, income is the main driver of crop demand. Income growth is also a key driver of output growth in South Asia, whereas population growth is the most important food demand driver in Africa. Latin America and China are two regions where there have been significant investments in productivity-enhancing research and development in recent decades (see the companion Policy Brief: “Productivity Growth is Key to Achieving Long Run Agricultural Sustainability”) so improved crop productivity accounts for a larger share of their projected output growth.

## Projections of US Cropland Expansion

Although productivity growth leads to higher yields and therefore moderates the demand for land, the impact of population and income growth on land use is dominant in all regions except Europe. Sub-Saharan Africa (+155 Mha) and South Asia (+66Mha) are projected to have the largest increases in cropland due to strong demand growth in those two regions. Figure 3 shows the pattern of cropland expansion across the Continental US as a percent change from 2010. This is a better indicator of sustainability stress than the absolute changes, and it reveals that, absent any policy interventions, the greatest land use change stresses will arise in the marginal areas on the edges of the Corn Belt. These are precisely the areas where the largest land use stresses arose during the 2008-2012 period<sup>14</sup>. These changes can be explained statistically via both biophysical and economic variables<sup>15</sup>. Our analysis indicates that a quarter of the projected US cropland expansion is due to demand growth in South Asia and China.



*Figure 3. Projected percentage change in US cropland from 2010 to 2050 by 5 min grid cell*

## Groundwater Sustainability Stresses

We also examine likely changes in groundwater sustainability across the continental US. Figure 4a maps the degree of unsustainability in groundwater extraction in 2010 (ratio of annual withdrawal over annual recharge). The High Plains Aquifer, the Central Valley of California, the Snake River Basin and western Washington show dramatic levels of unsustainability (ratios much



greater than one). Figure 4b shows our projections of the change in this ratio due to increased production, if there are no new restrictions on withdrawals. Groundwater stress is projected to increase in these same areas. However, as costs rise due to the need for deeper wells, and efficiency improves, the rate at which groundwater withdrawals for irrigation in these regions are increasing is slowing.

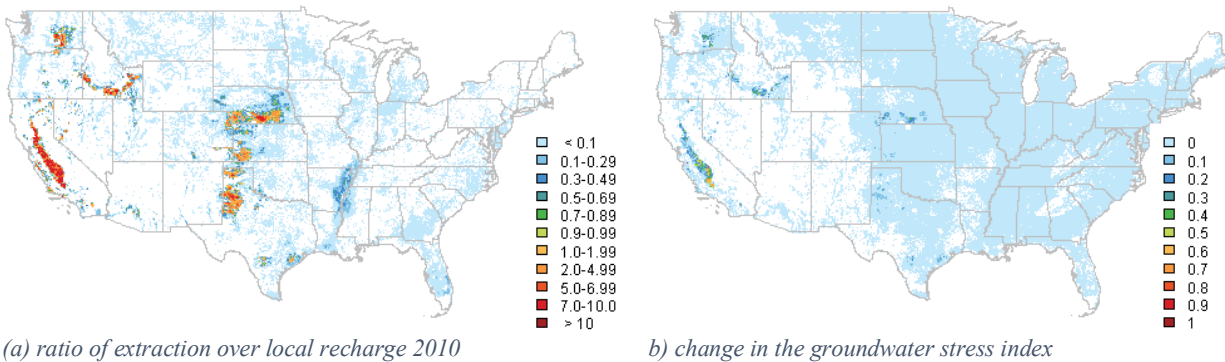


Figure 4. Groundwater sustainability by 5 arc minute grids: (a) The ratio of extraction over local recharge shows the degree of unsustainability in groundwater withdrawal (white color indicates very small groundwater withdrawal); (b) the change in the groundwater stress index from 2010 to 2050 (white color indicates no cropland).

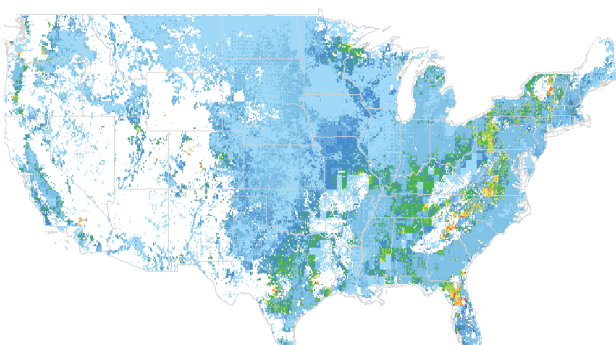


Figure 5. Percentage change in US groundwater withdrawal from 2010 to 2050 due to population, income and productivity growth.

Figure 5 reports the percentage increase in groundwater withdrawals from 2010-2050. Here, we clearly see that the fastest growth rates are expected to be in the Eastern US where physical and legal access to groundwater is easier.

## Consequences of Sustainability Policies

Any attempt to move to sustainable rates of groundwater withdrawals in 2050 will necessarily result in a reallocation of the pattern of crop production worldwide. The precise outcome will depend on the method used to limit abstractions, including pricing withdrawals in vulnerable regions, accelerated investments in irrigation efficiency, and institutional reforms designed to reallocate water to its highest value uses. We are not in a position to explore all of these reforms here, but we illustrate the potential reallocation of production via a simple ‘thought experiment’:



What if groundwater withdrawals in each US grid cell were limited to a sustainable level? We implement this by reducing future withdrawals to the rate of recharge. Figure 5 shows the resulting shift in production and land use worldwide. In those locations where rainfed production is possible, we predict that the irrigated land would be converted to dryland cropping. Furthermore, some crop production will shift overseas, while the ensuing rise in crop prices will also encourage increased production in other regions of the US – particularly in the more water-abundant Eastern US.

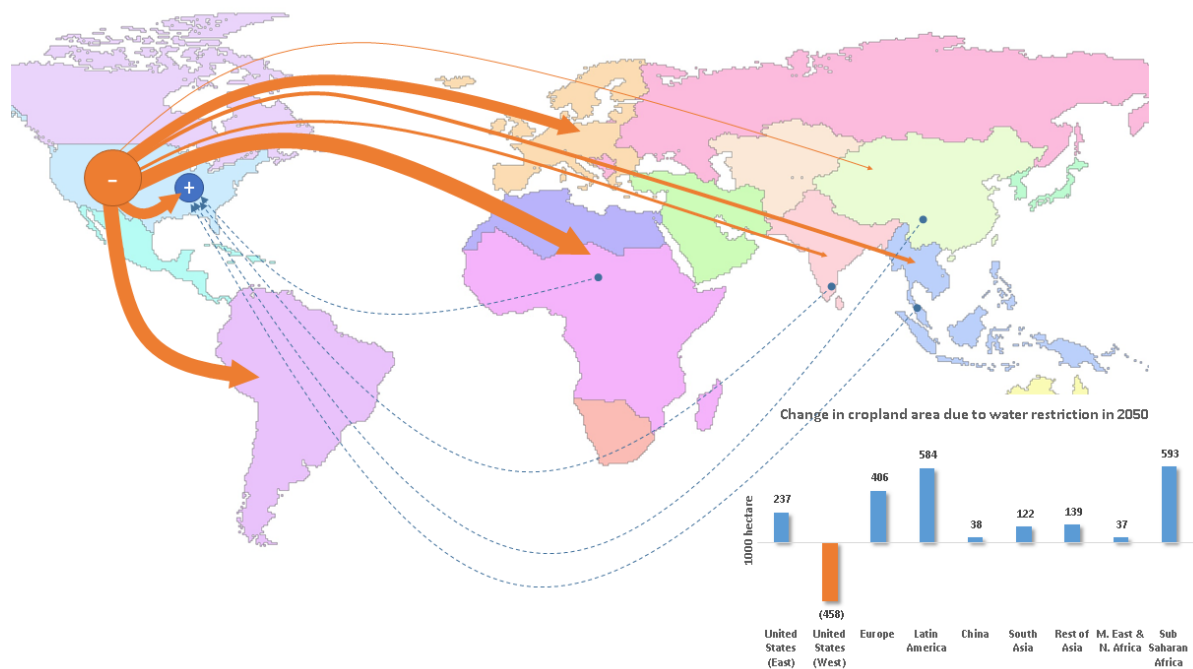


Figure 6. The impacts of imposing a US groundwater sustainability constraint in 2050 on cropland use around the world. Global crop markets will re-allocate cropland based on prices and economic returns to farming. Orange lines indicate the transfer of crop production from the western US to other locations, while blue lines show the growth of production in the eastern US at the expense of production elsewhere.

## Summary

In summary, increasing sustainability stresses are expected to emerge as a consequence of anticipated growth in crop output in the US. The underlying drivers of these stresses are global in nature, with demand growth in South Asia and China alone accounting for roughly one-quarter of US cropland expansion. We expect the land use stresses to be greatest in marginal areas where the current cropland base is modest. However, overall cropland expansion is modest in our baseline, and, while surface withdrawals increase, the emerging challenge would appear to be posed by unsustainable groundwater withdrawals. Pumping for irrigation and other uses now exceeds annual recharge rates by more than 10 times in the Central Valley of California, the High Plains Aquifer, and the Snake River Basin. Despite improvements in efficiency and higher pumping



costs, this figure is expected to further deteriorate in the absence of regulation. Furthermore, any attempt to restrict water for irrigation will result in the reallocation of cropping activity overseas, as well as to other regions of the country. And the longer sustainability regulations are delayed, the more difficult will be this adjustment. Dealing with this sustainability challenge will no doubt require multiple interventions as well as institutional reforms.

## Limitations

In closing, it is important to note some of the most significant limitations of our study. First of all, we have not considered the impact of future water scarcity on the crop composition within any given grid cell. Such changes could moderate the reallocation of crop production in the wake of sustainability constraints. A second limitation has to do with the treatment of the institutions governing water use and the reallocation of water rights. This is a complex subject which can only be dealt with in a relatively simple fashion in cross-scale economic models such as the one used here<sup>16</sup>. Finally, more historical validation is needed to assess the model's performance over recent decades. This work is currently underway at Purdue University.

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