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Biofuel Impacts on Water

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Abstract

Sandia National Laboratories and General Motors' Global Energy Systems team conducted a joint biofuels systems analysis project from March to November 2008. The purpose of this study was to assess the feasibility, implications, limitations, and enablers of large-scale production of biofuels. 90 billion gallons of ethanol (the energy equivalent of approximately 60 billion gallons of gasoline) per year by 2030 was chosen as the book-end target to understand an aggressive deployment. Since previous studies have addressed the potential of biomass but not the supply chain rollout needed to achieve large production targets, the focus of this study was on a comprehensive systems understanding the evolution of the full supply chain and key interdependencies over time. The supply chain components examined in this study included agricultural land use changes, production of biomass feedstocks, storage and transportation of these feedstocks, construction of conversion plants, conversion of feedstocks to ethanol at these plants, transportation of ethanol and blending with gasoline, and distribution to retail outlets. To support this analysis, we developed a 'Seed to Station' system dynamics model (Biofuels Deployment Model – BDM) to explore the feasibility of meeting specified ethanol production targets. The focus of this report is water and its linkage to broad scale biofuel deployment.

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Introduction

Water is a key input in the production of biofuels. Specifically, water is required for production of basic feedstocks from which biofuels are derived. Additionally, water is required in the processing and conversion of the raw feedstock to liquid fuel. To date, the potential impact of biofuel development on our nation's water resources has not received appropriate attention (National Research Council, 2008). Thus, the central question is to what extent is water use likely to change as the U.S. agricultural portfolio shifts to include more energy corps, as overall agricultural production potentially increases, and as new conversion plants draw on existing water supplies.

To help illuminate these issues the National Research Council held a colloquium on "Water Implications of Biofuel Production in the United States." Key findings of this effort include:

> "Water is an increasingly precious resource used for many purposes including drinking and other municipal uses, hydropower, cooling thermoelectric plants, manufacturing, recreation, habitat for fish and wildlife, and agriculture. The ways in which a shift to growing more energy crops will affect the availability and quality of water is a complex issue that is difficult to monitor and will vary greatly by region.
>
> In some areas of the country, water resources already are significantly stressed. For example, large portions of the Ogallala (or High Plains) aquifer, which extends from west Texas up into South Dakota and Wyoming, show water table declines of over 100 feet. Deterioration in water quality may further reduce available supplies. Increased biofuels production adds pressure to the water management challenges the nation already faces.
>
> Some of the water needed to grow biofuel crops will come from rainfall, but the rest will come from irrigation from groundwater or surface water sources. The primary concern with regard to water availability is how much irrigation will be required—either new or reallocated—that might compete with water used for other purposes. Irrigation accounts for the majority of the nation's 'consumptive use' of water—that is the water lost through evaporation and through plant leaves that does not become available for reuse.
>
> The question of whether more or less water will be applied to biofuel crops depends on what crop is being substituted and where it is being grown. For example, in much of the country, the crop substitution to produce biofuel will be from soybeans to corn. Corn generally uses less water than soybeans and cotton in the Pacific and Mountain regions, the reverse is true in the Northern and Southern Plains, and the crops use about the same amount of water in the North Central and Eastern regions.

> There are many uncertainties in estimating consumptive water use of the biofuel feedstocks of the future. Water data are less available for some of the proposed cellulosic feedstocks—for example, native grasses on marginal lands—than for widespread and common crops such as corn, soybeans, sorghum, and others. Neither the current consumptive water use of the marginal lands nor the potential water demand of the native grasses is well known. Further, while irrigation of native grass today would be unusual, this could easily change as production of cellulosic ethanol gets underway.
>
> In the next 5 to 10 years, increased agricultural production for biofuels will probably not alter the national-aggregate view of water use. However, there are likely to be significant regional and local impacts where water resources are already stressed." (National Research Council, 2008)

This report by the National Research Council provides the most comprehensive look at the nexus between water and biofuels to date. While the report provides a solid overview of the issues, there are a couple of important deficiencies. First, the report is not the product of a quantitative analysis; rather, findings are based on broad general trends. Second, the report is largely focused at the national level with limited reference made to regional details (with such regions representing the aggregate over 5-10 states). Finally, the report ignores water requirements associated with biofuel processing.

Objectives

The purpose of this effort is to provide a quantitative analysis of the nexus between water and biofuel production at the state level. Specific questions to be addressed by this analysis include:

- How much water is likely to be used by biofuel feedstock production and conversion?
- To what extent will the use of water in biofuels production (feedstock and processing) compete with traditional water uses?
- Where might we experience stress with expanded water use in biofuel production?
- To what extent will feedstock production be impacted by drought/climate change?
- Is the cost of water an important factor in biofuel production?

Methods

Data Acquisition

Two primary sources provided the bulk of the data used in this analysis, the U.S. Geological Survey (USGS) and the U.S. Department of Agriculture (USDA). USGS provided information in basic water use and water supply characteristics for the U.S., while USDA resources supported analyses involving irrigation, irrigation costs, and crop use.

Every five years since 1950 the nation's water-use data have been compiled and published by the USGS. The purpose of these reports is to provide a consistent and current water use picture for the U.S. The report describes water use in the U.S. by major water use category (e.g., municipal, industrial). For each category, water use is further disaggregated by source, use, and disposition (e.g., consumed, return flow). Collection of this data is a collaborative effort between the USGS and state and local water agencies and utilities. The level of detail that these data are reported varies greatly from year to year.

Data from the 1985, 1990, and 1995 campaigns provide the most comprehensive picture of water use in the U.S. For this reason, data from these three surveys form the basis of our analysis. For purposes of our modeling, water use was divided according to six different categories, municipal (including domestic, public supply, and commercial), industrial, thermoelectric power, mining, livestock, and irrigation. Each category was further disaggregated according to its source, surface water, groundwater, or other (e.g., saline, treated wastewater). Finally, the disposition of each water use is tracked as to whether it is consumed or returned to the environment.
Water use data according to use, source, and disposition were collected from the USGS's website "Water Use in the United States" (http://water.usgs.gov/watuse/). These data were acquired at the state level.

Some processing of the water use data was necessary. Specifically, data from 1985-1995 were used to estimate the rate of change of key water use variables. For example, the rate of change in livestock water use, or percent of water extracted from groundwater. These rates of change were calculated by simple linear regression. Each regression was visually inspected to assess the "goodness of fit". In roughly 25% of the cases the regression did not accurately represent the trends perceived from this limited set of data (i.e., data values for 1985, 1990, and 1995). In these cases the regressions were adjusted by hand to best fit the trend. Where we could argue that changes in water use were related to changes in local population, regressions involved water use vs. population (rather than time as above). Population data at the state level were available through the USGS website which reflected not only the bulk population but their association with a particular water source. Regressions were performed as discussed above. Where the data did not support a relation between use and population, the simple regressions with time were adopted. In the unique case of industrial water use, water use was found to be correlated with gross state product.

In contrast to water use data, information on water supply is largely lacking. To comprehensively compile such information is well beyond the scope of the current study. Rather, we have identified some basic stream flow and aquifer data that provide a rough indication of water supply. Specifically, the USGS has stream flow data at 23,000 gages in which the available sampling record has been statistically analyzed to give the min and max flows, long term average and key percentiles, and the base flow index. The average flow gives some insight into available surface water supply, while base flow is a measure of available groundwater. These data were again acquired from the USGS at (http://water.usgs.gov/GIS/metadata/usgswrd/XML/streamgages.xml#stdorder).

The USDA Census of Agriculture formed the primary source of data for irrigation related analyses. The Census of Agriculture, taken every five years, is a complete count of U.S. farms and ranches and the people who operate them. The Census looks at land use and ownership, operator characteristics, production practices, income and expenditures and many other areas.

These data are collected largely by survey of individual farmers. For purposes of this analysis, Census data was used to estimate irrigated acreage, the types of crops irrigated, irrigation demand by crop, crop yield, and irrigation costs. Data used in this analysis were taken directly from the 2002 survey (http://www.agcensus.usda.gov/Publications/2002/index.asp) at the state level.

Water Model

Below a general description of the water use model is given. The model is developed in a system dynamics framework disaggregated at the state level. Water supply is not calculated as a dynamic element in the model. Rather, the various water supply indicators noted above are included as base maps that can then be overlain with water demand.

The water use model is divided into six dynamic sectors including, municipal, industrial, thermoelectric power, mining, livestock, and irrigation. The basic causal and quantitative structures are very similar across the different sectors. Figure 1 shows this basic structure for the case of Municipal Water Use.

The model begins by reading in data from the Excel data base. Two types of information are handled, rates of change and initial condition data. The rate of change data (by time, population, or state gross product) was described above. Initial conditions for water use are taken as that reported in the 1995 water use survey.

Water use is simply calculated as the product of population and per capita water use. Per capita water use is allowed to change in time due to conservation, change in water use habits, etc. In this way, per capita water use, Q_{pc}, is calculated as

$$Q_{pc} = I_{pc} + \left(R_{qpc} * t_{elapsed}\right) \qquad 1$$

Where I_{pc} is the 1995 per capita water use, R_{qpc} is the rate of change, and $t_{elapsed}$ is the elapsed time since 1995. Recognizing that there is some limit to just how much the per capita water use can change, a limit is placed on this variable. Specifically, per capita water use is not allowed to increase or decrease by more than 20%. Once this maximum change is achieved it is held constant throughout the rest of the simulation. There is no quantitative basis for this limit, rather it is simply based on professional judgment.

Once water use is calculated the fraction consumed and discharged to the waste water treatment plant is determined. The consumed fraction is calculated as above using the 1995 per capita consumption rate, change in consumption, and the population. Waste water discharges are calculated as the difference between use and consumption.

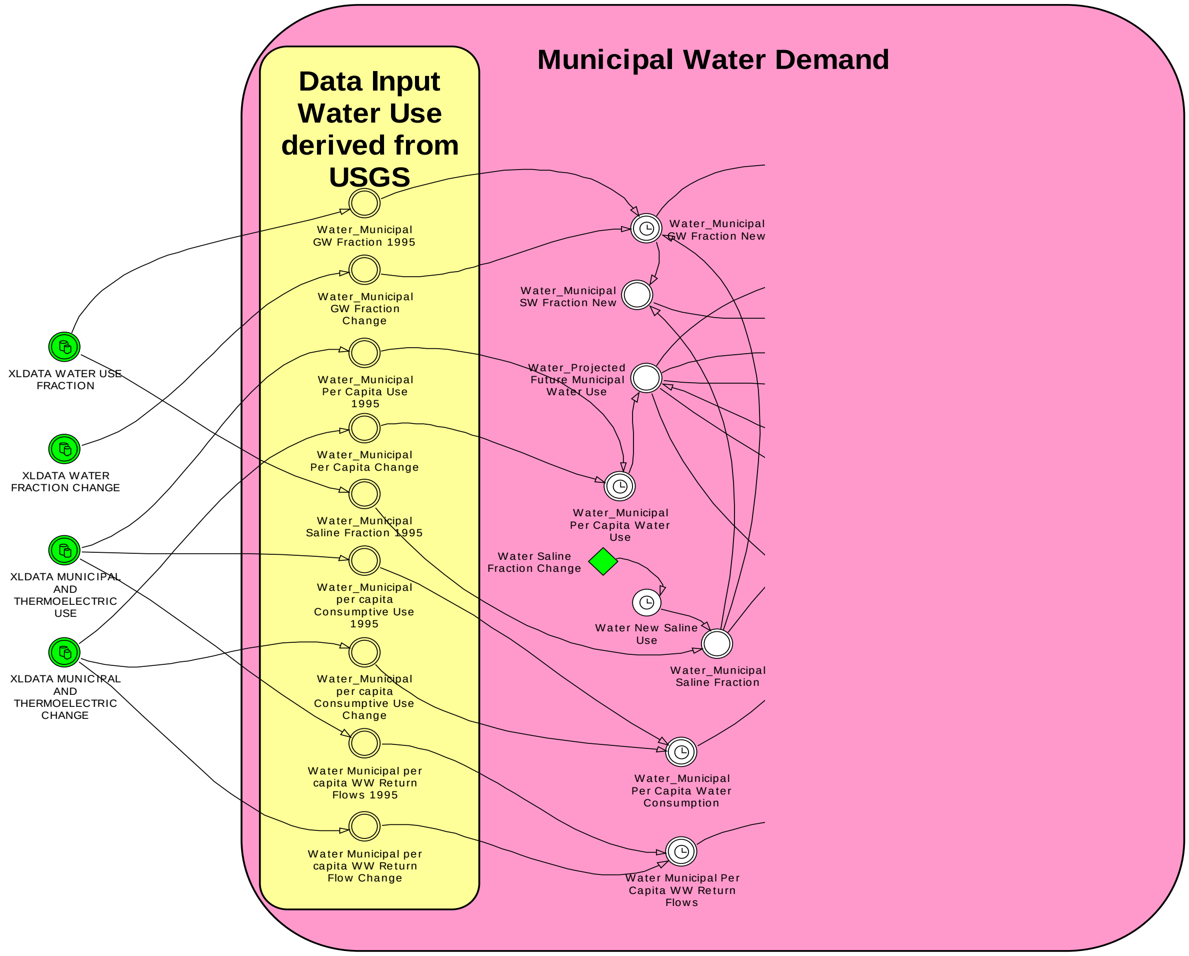


Figure 1. System dynamics model for water use in the municipal sector. Other model sectors follow a similar structure.

The source of the water is then calculated from knowledge of groundwater abstraction and non-traditional water use (saline, treated waste water). The dependence on groundwater is likely to change over time as such the fraction of supply from groundwater is treated as time dependent. The percent fraction from groundwater supply is calculated similarly to Equation 1 based on the 1995 fraction from groundwater supply and its rate of change (based on data from 1985-1995). Again a ±20% limit is placed on its change. Likewise the percent water coming from non-traditional sources is allowed to change, in this case according to user defined rate of change (set by a slider bar). The resulting supply taken from surface water is simply determined as that not taken from groundwater or non-traditional sources.

Water use for all other sectors, except irrigation, follows essentially the same structure. The few exceptions include the fact that industrial water use is driven by changing gross state product rather than population. Mining and livestock activity likewise are not driven by local population, as such changes in water use are based simply on historic trends. Also, a separate demand element for water use in biofuel conversion plant operation has been added to the industrial sector.

Water use for irrigated agriculture is ultimately driven by the number of acres under agricultural production. This defines a key feedback in the model in that the land use and feedstock sectors determine crop acreage and crop acreage determines water use in the irrigation sector. However, not all crop acreage is irrigated. Using information from the Agricultural Census (USDA, 2002) the percent irrigated acreage by crop and state was determined. This percent irrigated acreage is assumed to remain constant throughout the duration of the simulation. Also from the Census, relative estimates of irrigated water demand by crop and state were determined. Total irrigation water use, Q_i, is then determined by

$$Q_i = A_T * f * et \qquad 2$$

where A_T is the total crop acreage, f is the fraction irrigated, and et is the irrigation water demand for the crop. From here the total water use is distributed by source (groundwater, surface water, and other) and disposition (consumptive, return flow) according to the process described for the other water use sectors.

Data on water use and fraction irrigated are obviously lacking for new energy crops like switch grass and short rotation woody crops (SRWC). In the absence of such data, hay and small orchard crops were used as surrogates. Both are believed to provide conservative estimates of where and how much water is needed to grow the data limited energy crops.

Model output is ultimately preserved at its lowest level of analysis that is by sector, source, and disposition. However, data have been aggregated at a variety of levels to aid in analysis. For example, data have been aggregated by total water use by sector, total water use by source, and water use aggregated at the national level. Data is presented both as total water use, change in water use and percent change in water use (relative to 1995).

Results

Below, modeling results are reviewed according to the five questions raised above. But first in efforts to verify our results, model output is compared against other studies aimed at projecting future water demand.

Model Verification

Efforts have been made to verify the water use projections produced by the model. To do this, comparisons have been drawn with other water use studies published in the open literature. Comparisons are drawn with three different studies each exploring the sustainability of our nation's water supply (Guldin 1989, Brown 1999, Roy et al., 2005). Each study utilized the USGS water use studies to establish initial water use figures. The Guldin and Brown studies then projected future use at the national level, while the Roy et al. studies approached future water use projections from a more regionalized view. Results from the three studies are provided in Table 1. Model results are also given in terms of total freshwater withdrawals.

Most notable in this data is the relatively large spread in results. As such, this highlights the difficulty in exactly forecasting future water use. Nevertheless, the modeled results are seen to fall nicely in between the various other projections. This is particularly evident considering our numbers consider roughly 12BGD for energy crop production and conversion not considered in these other reports.

Table 1. Comparison of water use projections with those documented in other studies (BGD).

Year	Guldin, 1989	Brown, 1999	Roy et al., 2005	Model
2020	461	349	-	454
2025	-	-	451	469
2030	495	356	-	482

How much water is likely to be used by biofuel feedstock production and conversion?

The demand for water within the biofuels industry arises through feedstock irrigation and through the conversion of that feedstock into ethanol or other liquid fuel. Model estimates of biofuel water use in 2006 include 5616 MGD for irrigation and 94 MGD for conversion. This represents 1.3% of total withdrawals in the United States. Water use is entirely for the irrigation of corn and its conversion to ethanol. As such, water use is most intensely focused in the High-Plains (Nebraska, Kansas, and Colorado) where corn yields are significantly enhanced by irrigation. Likewise, corn ethanol conversion plants have been sited where supply is most plentiful.

Water use by biofuels is projected to increase through 2030 (Figure 2). Growth does not follow a simple linear trend; rather, there is a slight decrease in demand through 2017 due to improving corn and conversion yields. After this date water demand accelerates due to expanding use of cellulosic feedstocks (and corresponding increase in overall biofuel production). Overall biofuel water use in 2030 is projected to be 12,018 MGD with 11,548 MGD for feedstock irrigation and 470 MGD for biomass conversion. These data are further disaggregated by water use, water consumption, as well as by feedstock type in Table 2.

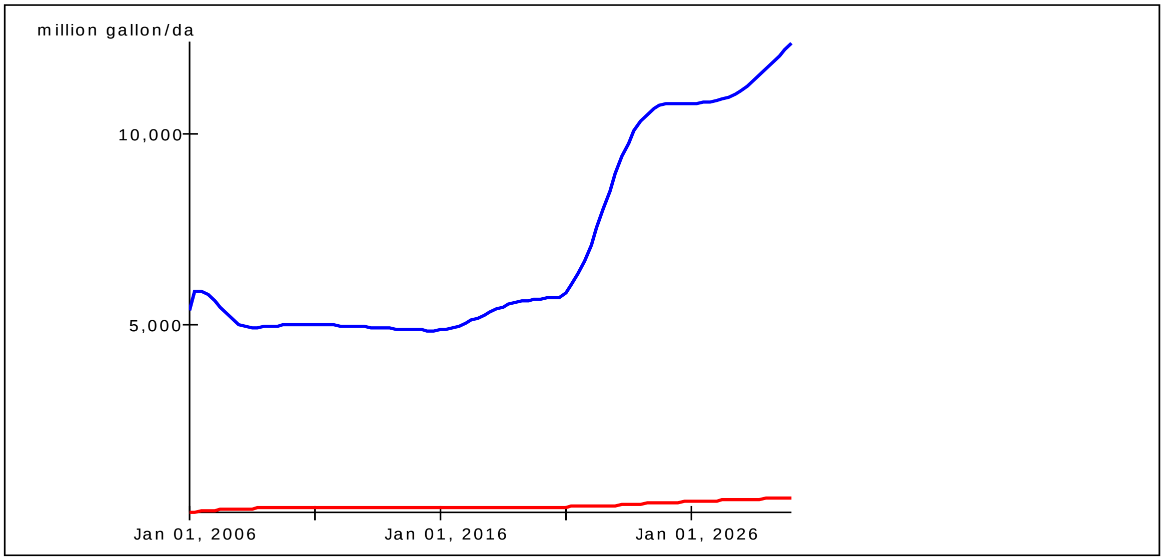


Figure 1. Biomass water demand for feedstock irrigation and conversion aggregated for the entire United States.

Table 2. Water use and consumption by feedstock type.

Category	Water Use 2006	Water Consumption 2006	Water Use 2030	Water Consumption 2030
Corn Biomass Irrigation	5616	4804	4649	3977
Switchgrass Biomass Irrigation	0	0	4077	3488
SRWC Biomass Irrigation	0	0	2822	2414
Corn Biomass Conversion	94	70	219	164
Cellulosic Biomass Conversion	0	0	251	188

Irrigation practices, climate conditions, cropping patterns, transportation fuels demand, etc. differ considerably across the United States. Likewise the demand for water to support biofuel production varies regionally. In efforts to capture this spatial variability, biofuel water demand is investigated at the state level. Figure 3 shows the total planted acres and total irrigated acres for corn, switchgrass, and SRWC by state (corn irrigation shown is only for that portion used for energy purposes). Table 3 provides total planted acres, irrigated acres, and irrigation demand for corn, switchgrass and SRWC at the national level.

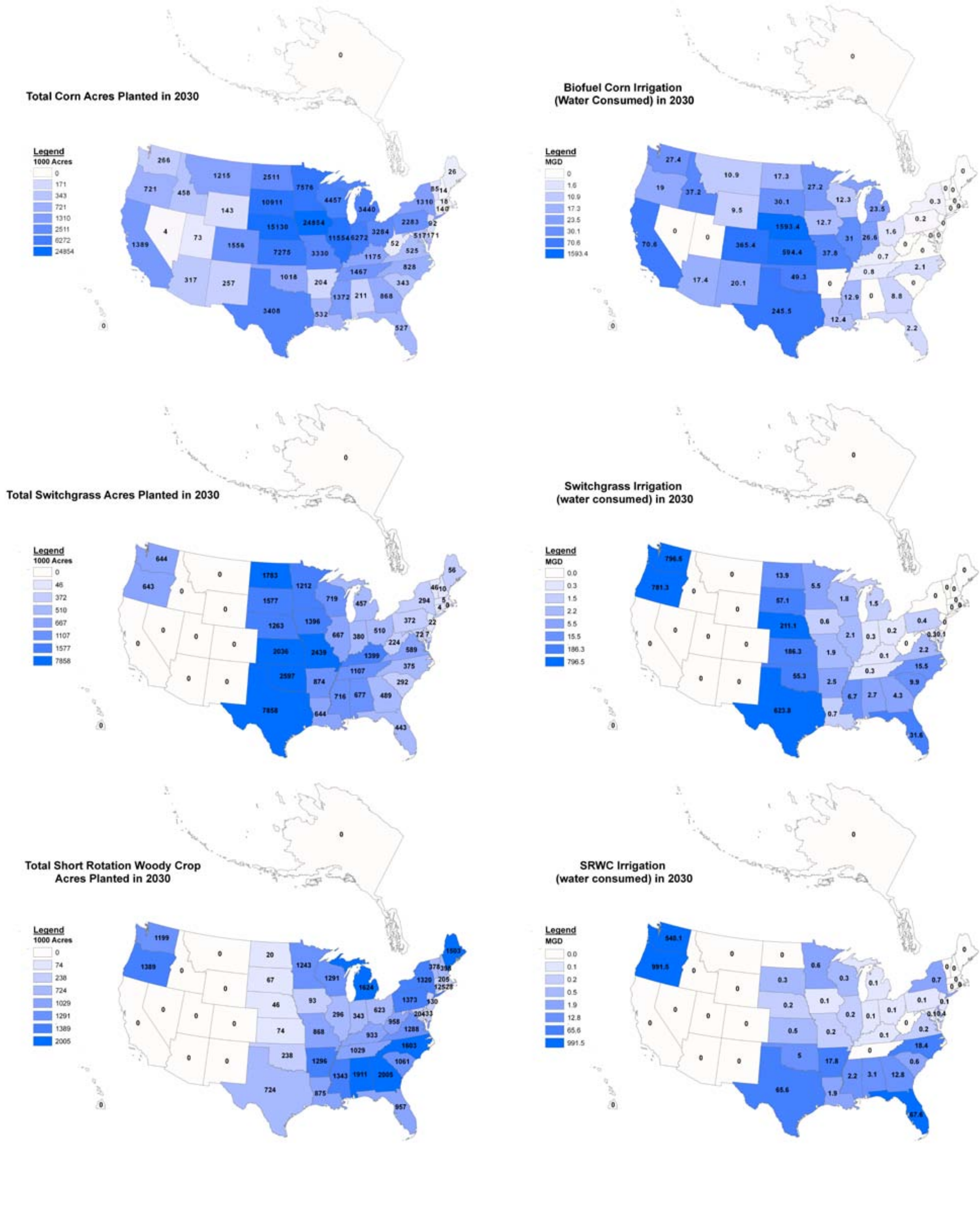


Figure 2. Planted acres and irrigation water consumption by state for corn, switchgrass and SRWC.

Table 3. Land use and irrigation characteristics in 2030 by feedstock type.

Feedstock	Cultivated Land	Irrigated Land	Total Irrigation
	M Acres	M Acres	MGD
Corn	19.9	2.9	4649
Switchgrass	34.9	2.2	4077
SRWC	31.1	1.0	2822

Irrigation patterns differ across the three feedstock types. Corn irrigation is focused in the High-Plains region and West Coast, switchgrass irrigation largely occurs in the Central and Southeastern states, while SRWC irrigation is largely focused in the Northwest. These projections suggest no cultivation of switchgrass and SRWC (except Washington and Oregon) in western states. This behavior reflects assumptions that these energy crops would not be grown in areas requiring significant irrigation.

One important fact to consider is that corn irrigation in 2006 and out to 2030 does not represent a new burden to the system. These acres have historically been devoted to corn or other feed crop and are likely to remain so regardless of what happens with biofuels.

Figure 4 shows water use for biofuel conversion by state. Conversion demand appears closely related to feedstock production. Demands are highest in the Mid-West and the Southeast. Nevertheless, conversion demands are broadly distributed across the entire nation with every state having some biomass conversion capacity.

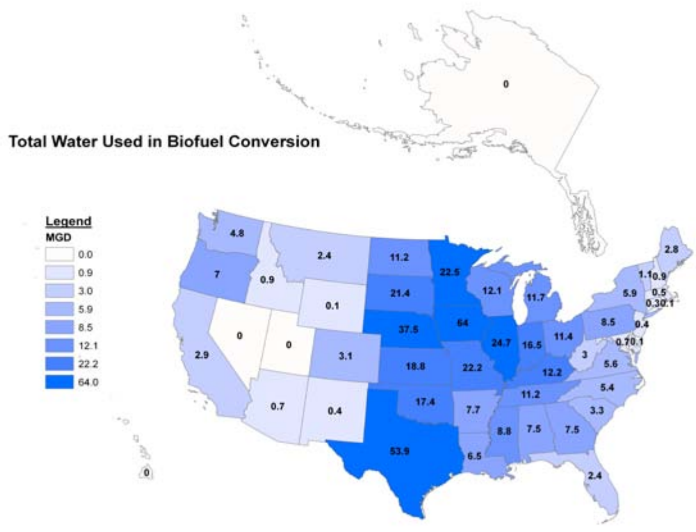


Figure 3. Biomass water demand for feedstock conversion by state.

How Will Biofuel Water Use Compete with Traditional Demand Sectors?

Total water withdrawals, including fresh and saline, in the United States for 2006 amounted to 432 BGD of which 1.3% was due to biofuel production. Of this use approximately 46% was for thermoelectric power generation, 28% for irrigated agriculture, 15% for municipal, 8% industrial, and 1% each for mining and livestock (Figure 5). Water use in 2030 is projected to grow by almost 12% to 483 BGD with biofuel use representing 2.5% of total use. This growth is largely realized in the municipal and industrial sectors (Figure 5), while minimal growth occurs in the thermoelectric and irrigation sectors.

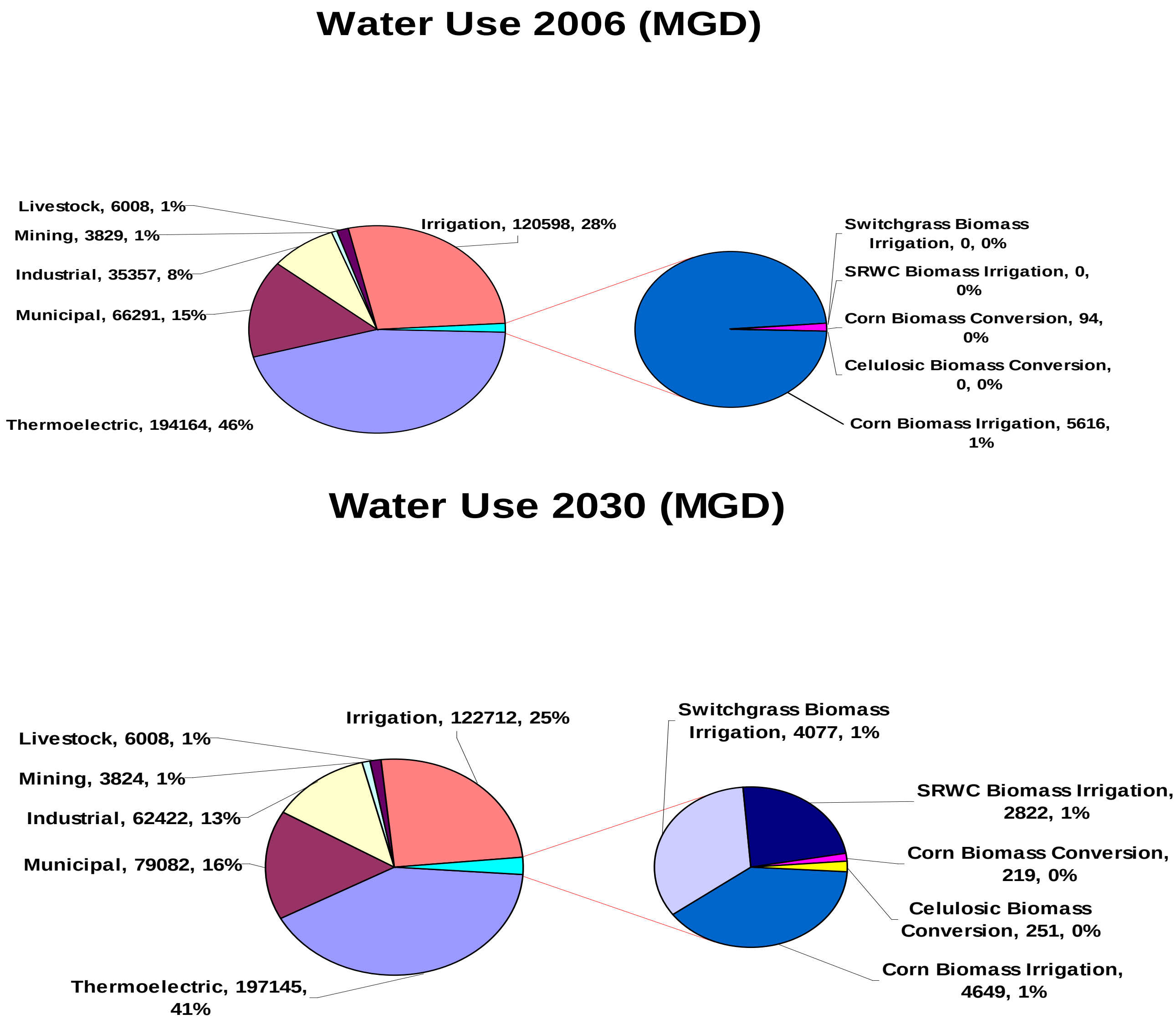
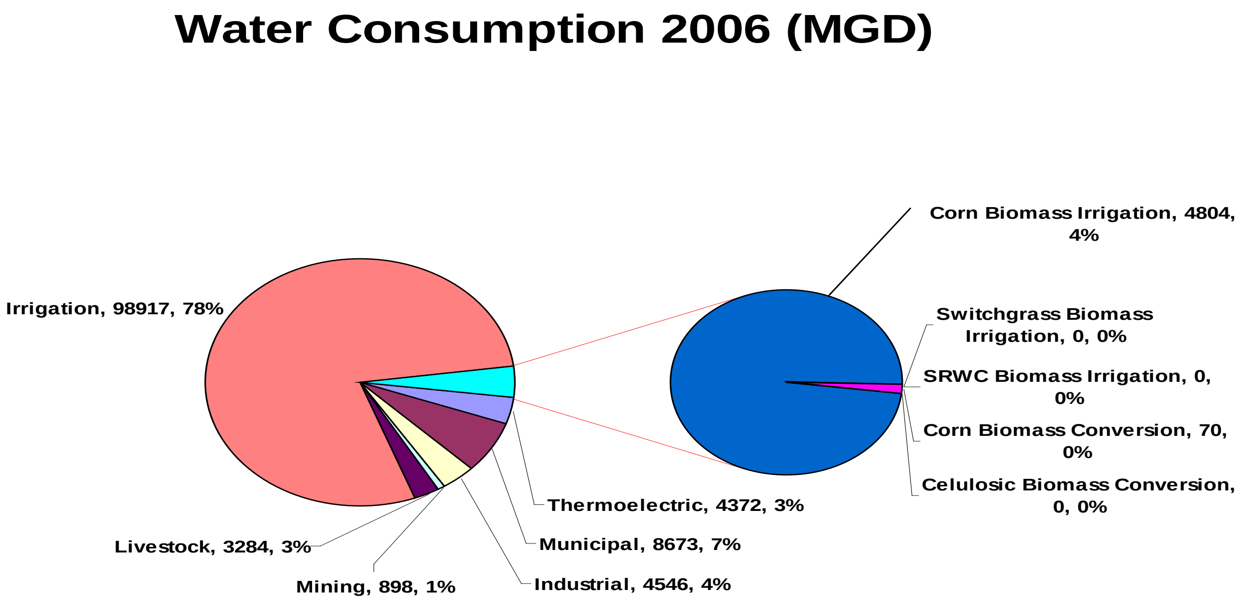


Figure 4. Fresh and saline water withdrawals by use sector in 2006 and 2030.

There are significant differences between water use and consumption. Namely, consumption in 2006 accounted for only 126 BGD. The distribution is also very different with most consumption resulting from irrigated agriculture at 78%, with municipal (7%), industrial (4%), thermoelectric (3%), livestock (3%), biofuels (4%), and mining (1%) combining for the remaining 22%. In 2030, water consumption is projected to grow to 141 BGD, a 13% increase. Growth in consumption is largely realized in the municipal, industrial, and thermoelectric sectors (Figure 6).



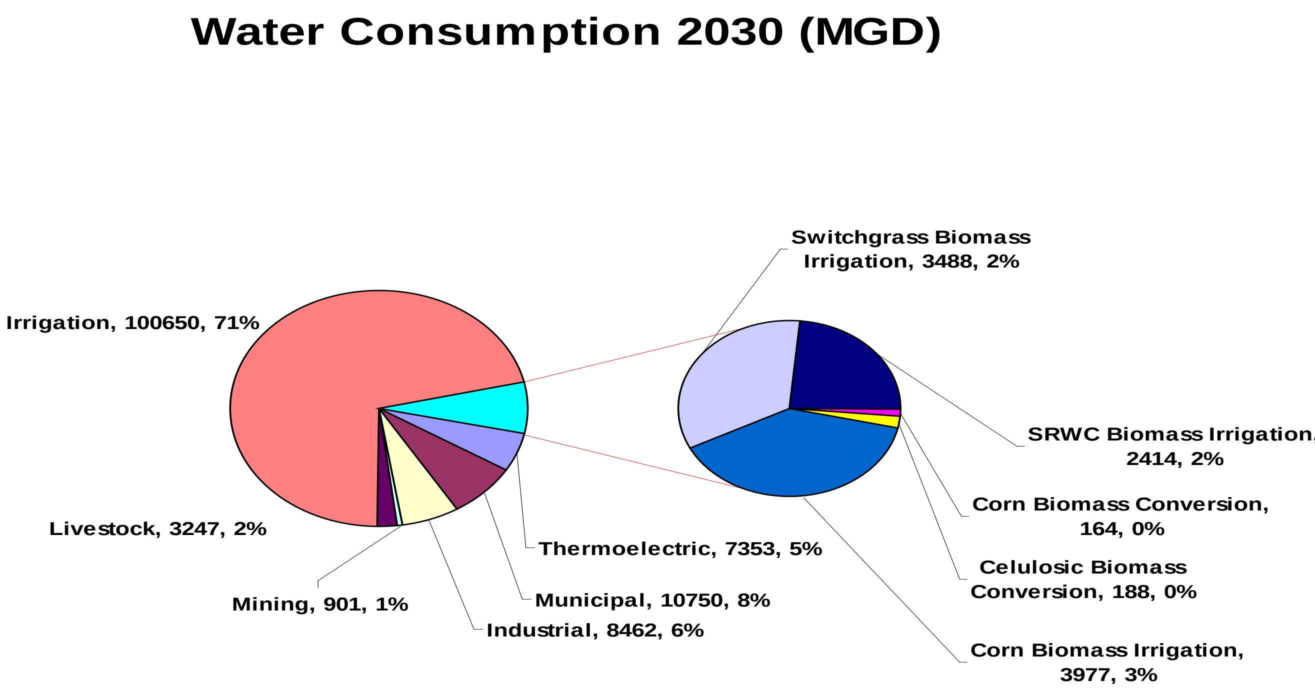


Figure 5. Fresh and saline water consumption by use sector in 2006 and 2030.

Water withdrawals vary regionally across the United States (Figure 7). States with the largest demand correspond to those states with the largest population (e.g., New York, Illinois, California, Texas). This correlation is driven by high thermoelectric power generation capacity servicing municipal and industrial needs. States with high irrigation demands are evident in the High-Plains and several of the Western states. Also shown in Figure 7 is the percent change in demand from 2006 to 2030. Highest growth is projected for Hawaii, Texas, and the Gulf-southern Atlantic Coastal area. Nevertheless, all but 6 states are projected for double digit growth. Some of the smallest growth rates are associated with states in the interior west, while Michigan is projected for negative growth.

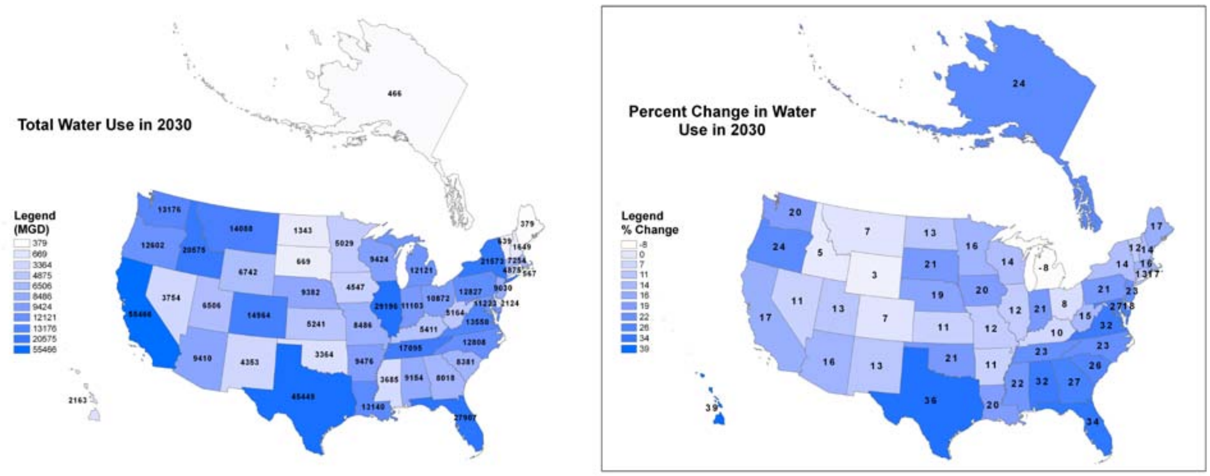
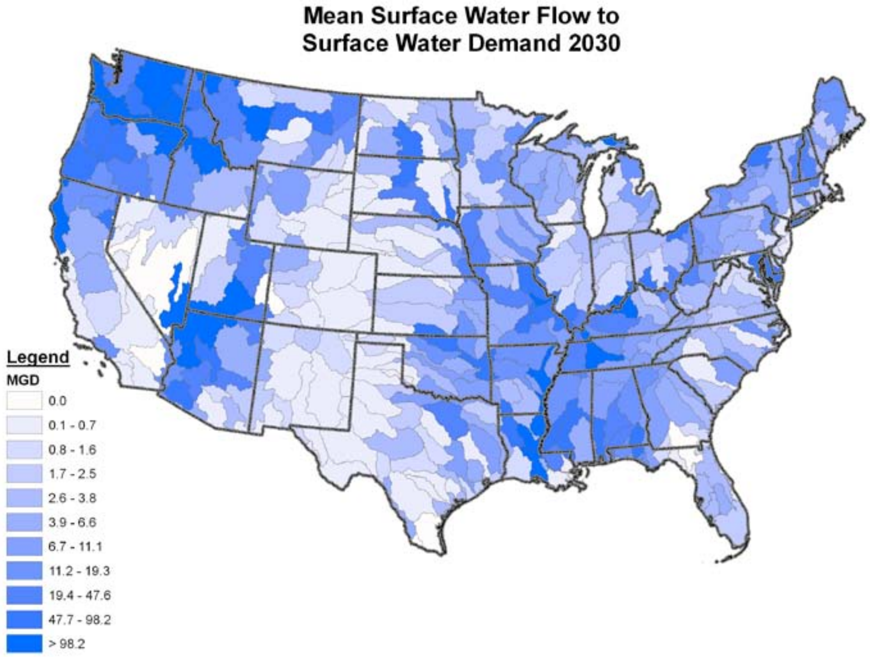


Figure 6. Total water use and percent change in water use (2006-2030) by state.

Where Will Biofuels Production Compete for Water?

To help address this issue maps were produced that relate water supply to water demand (for 2030) for both surface water and groundwater resources (Figure 8). These maps are prepared on a watershed basis, rather than state, as the watershed is the natural bounds that constrain water supply. Stress would be expected any place where supply is only one or two times the projected demand. As noted earlier, detailed data on water supply is not available and thus we are limited to use of general proxies to actual water supply. For surface water supply mean stream flow (generally based on over 20 years of gauge data) is used, while average base flow is used as a surrogate for sustainable groundwater recharge. The main limitations of these proxies are the lack of consideration of interbasin transfers and water allocation regulations. This limitation is evident in the southern Colorado River basin (along the California-Arizona border) where conditions look good within the basin; however, much of this water is transferred out of the basin to demands in southern California and central Arizona.



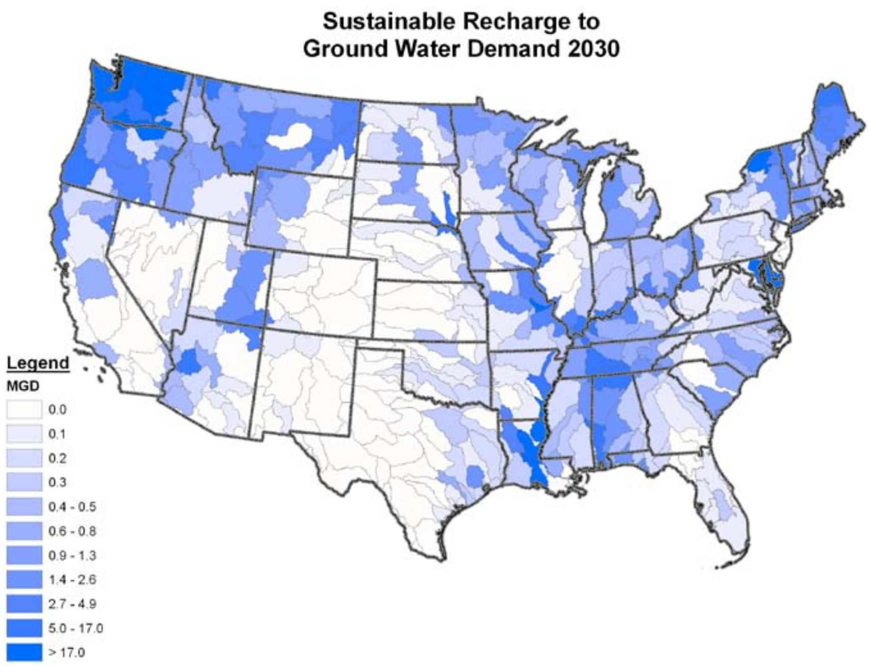


Figure 7. Areas potentially facing water stress in 2030. Maps show the ratio between mean surface water flow and surface water demand (top) and sustainable groundwater recharge to groundwater demand (bottom).

From these maps several areas of concern are evident; in fact, most of these areas are already experiencing water related stress. In terms of surface water resources much of the central U.S., Nevada, and southern California are at particular risk. Concerns related to groundwater resources are evident throughout most of the Southwest and Central United States.

Comparison of water demand for biofuels conversion (Figure 4) and the maps in Figure 8 suggest locations where the acquisition of water may be problematic. In general, demands by biofuels conversion are small relative to the growing demands for water in other water use sectors (e.g., municipal and industrial). However, when considered at the scale of a single plant the water demand is not insignificant. Thus, permitting for water withdrawals and environmental discharges are likely to be challenged anywhere in the U.S. The greatest scrutiny will still occur in areas where water supplies are under the most stress (e.g., Texas, Kansas, Nebraska).

Competition over water for feedstock irrigation has increased potential for stress given that more water is at stake. Figure 9 shows the total irrigation demand by biofuels feedstocks and the percent biofuels feedstock irrigation to all irrigation by state. Remember that most of the projected irrigation of energy related corn does not represent a new demand but rather has historically been irrigated. Thus, irrigation related stress is most likely to be forced by the emergence of new energy crops, switchgrass and SRWC. Fortunately, these crops are likely to be grown largely in the East where they are unlikely to require substantial irrigation. The only real concerns will be for crops grown in Nebraska, Kansas, Colorado and Texas (and possibly the Dakotas and western Washington and Oregon).

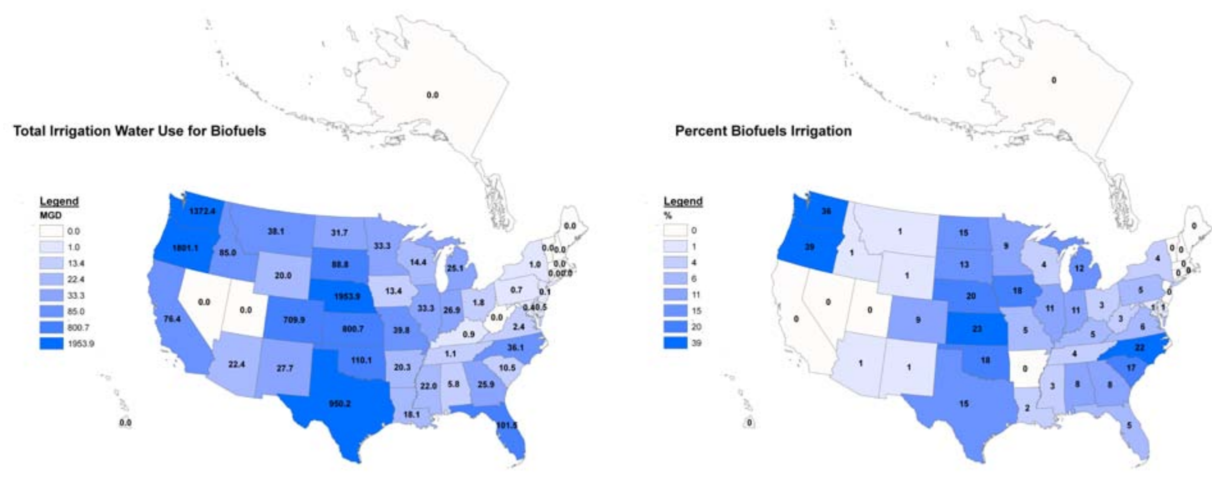


Figure 8. Biomass feedstock irrigation requirements by state (left) and the percent biomass irrigation to total irrigation (right).

One additional concern is the sustainability of historical irrigation practices in areas experiencing groundwater overdraft (Figure 10). Of particular concern is the Ogallala Aquifer of the High-Plains. As overdraft continues, water levels will decline making the pumping of water uneconomical. This could reduce yields by a factor of 4 or more in these regions and/or drive farmers completely out of business.

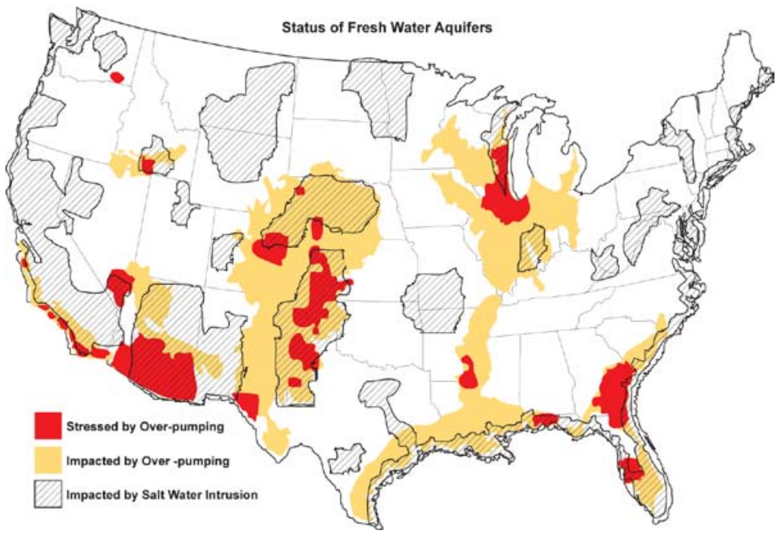


Figure 9. Groundwater aquifers experiencing overdraft and/or salt water intrusion difficulties (from Shannon, 2006).

What is the Susceptibility of Feedstock Production to Drought and Climate Change?

Drought, disease, pest infestation, flooding, and markets have significant impact on crop production. Figure 11 shows annual corn production from 1930 to present and annual alfalfa production (best available proxy for switchgrass) from 1928 to present. In both time series significant variability is evident as is the strong influence of growing yields due to the green revolution. Variability is also noticeable greater in the case of corn relative to alfalfa. To explore this variability closer the yearly deviation in yield from the 10 year running average was calculated (Figure 11). In the case of corn yields fell by 15% or more 17 times over the 79 year record. Alfalfa recorded deviations of -15% three times over its 81 year record. This level of variability is also noted to be pretty uniform, at least since the 1970s.

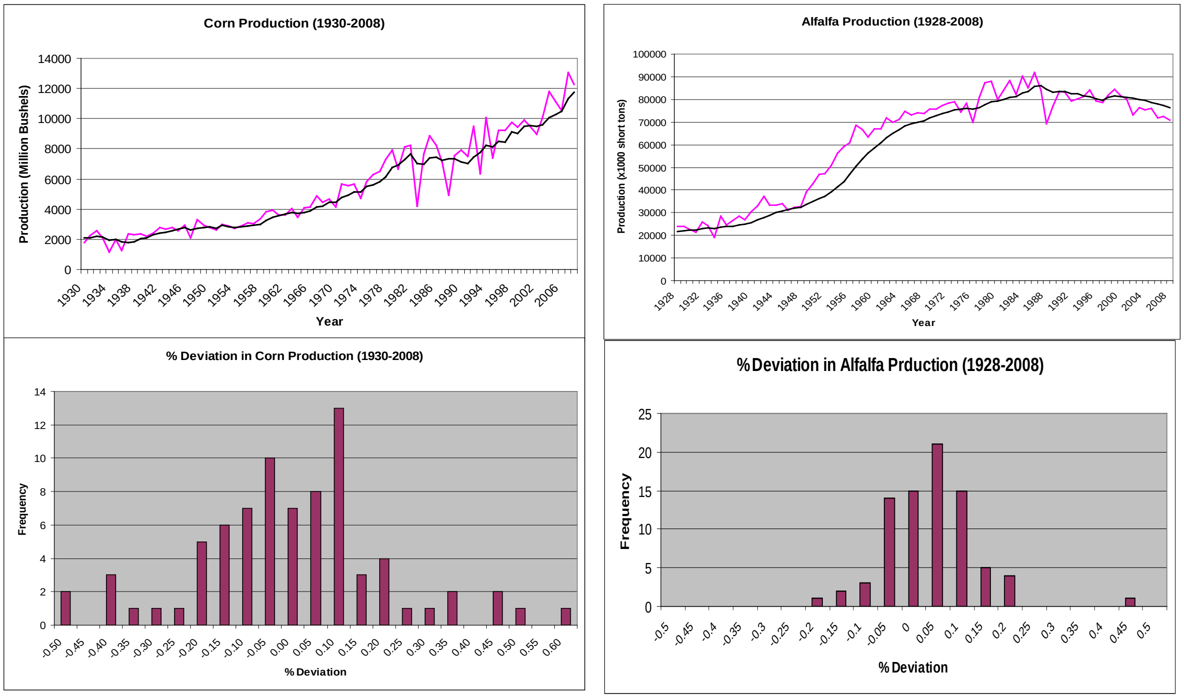


Figure 10. Yearly production of corn (left) and alfalfa (right) at the national scale. Histogram of deviation in production from the 10-year running average (bottom).

Even greater variability can be expected at the county level. Kucharik and Ramankutty (2005) investigated corn yields at the county level from 1930 to present for the Mid-West region of the U.S. Over this period of time they found corn yields to vary by as much as 30-40%. Additionally, these authors estimate that significant deviations in yield (>20%) can be expected once every 10 years.

The past is currently the best indicator of future variability in production. The variability noted in Figures 11 and 12 is not limited to drought but is the result of a variety of environmental and market driven factors. Impacts of climate change on temperature and precipitation are not projected to be significant over the planning horizon of this model. The most likely measureable influence of climate change will be in the severity of drought and flooding cycles.

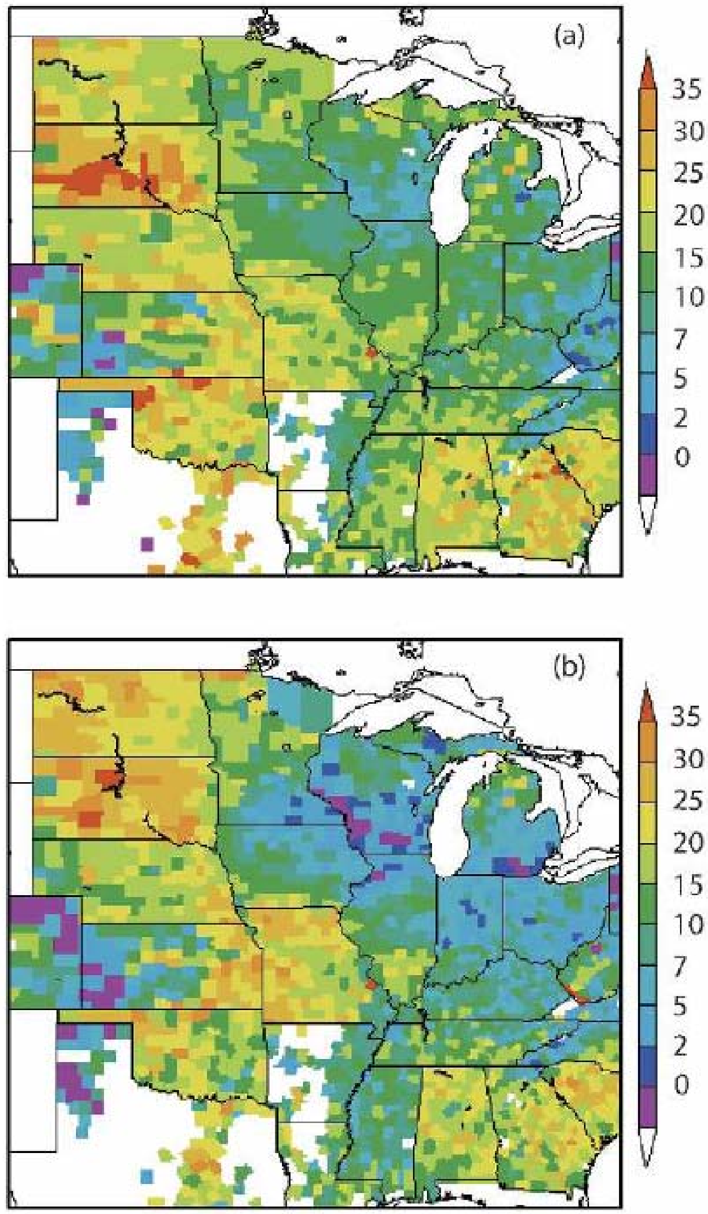


Figure 11. Percentage of years between 1930 and present that a county had corn yields that were less than -20% (top) and greater than 20% (bottom) (from Kucharik and Ramankutty, 2005).

Is the Cost of Water an Important Factor in Biofuel Production?

Irrigation expenses are tracked by the USDA as part of their Agricultural Census Program (http://www.agcensus.usda.gov/Publications/2002/index.asp). Average costs in 2003 were $92 per acre with roughly half going to capital expenditures and the other half to maintenance and operation (largely fuel/electricity to lift and move water). Expenses vary widely across the U.S. as shown at a statewide level in Figure 13. Variations in expenses are even more dramatic at the individual farmer level where costs can be negligible where irrigation is by gravity fed flood or furrow methods.

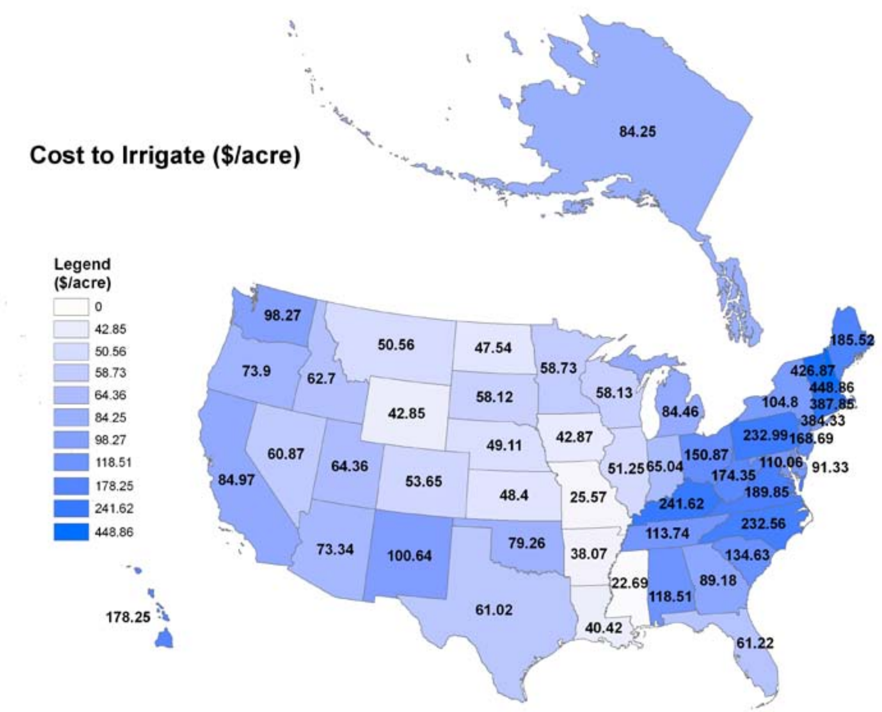


Figure 12. Average expenses to irrigate an acre of crop land.

As $92 per acre for irrigation is roughly equivalent to all other costs for the production of cellulosic feedstock materials, irrigation is unlikely to be economically viable (except where the infrastructure already exists, is simple, and is gravity fed). Alternatively, irrigation costs are only about 20% of the total production costs for corn. In the case of corn, irrigation is viable, particularly, where irrigation makes dramatic differences in yield. As such, pressure for expansion of irrigation for energy related crops will be strongest for corn grown in the High-Plains region where yields are increased by 75-90%.

In contrast, the cost of water is not expected to play a major role in the siting of feedstock conversion plants. Throughout most of the east, water acquisition will just be a matter of obtaining a permit. In the western states abstraction of water to satisfy new demands will require the purchase and transfer of a water right from some other use (usually farming). Historically, the average purchase price of an acre-foot of water has been roughly $2500. At these rates, the cost of water amounts to less than one cent per gallon of ethanol.

Summary

The following are the key findings concerning potential impacts of biofuel production on the water sector:

- Overall biofuel water use in 2030 is projected to be 12,018 MGD with 11,548 MGD for feedstock irrigation and 470 MGD for biomass conversion. Of this approximately 10,231 MGD will be consumed.
- Water for biomass conversion is broadly scattered across the United States while irrigation demand is focused in the High-Plains and the Northwest.
- Between 2006 to 2030 water use is projected to increase by 51 BGD nationwide. Over this same period of time biofuel demand will increase by roughly 6.3 BGD thus accounting for 12% of the total growth.
- Between 2006 and 2030 water consumption due to biofuel production will increase by 5.3 BGD. This increase in consumption is larger than any other single sector (2.1 BGD for municipal, 3.9 BGD for industrial, 3.0 BGD for thermoelectric). However, recall that over half of this water is for the irrigation of corn which is currently irrigated and thus does not represent a new burden on the system.
- Based on limited water supply information, competition between water for biofuels and other demand sectors is most likely to be realized in the High-Plains region.
- Based on historical trends of corn and alfalfa (rough proxy for switchgrass) variations in feedstock production are likely to exceed -15% over the next 25 years. Factors driving such variation include drought, flood, disease, infestation, and market fluctuations.
- In most circumstances irrigation of cellulosic energy crops is not economically viable; however, the cost margin is better for corn, particularly where strong improvements in yield are realized. Expenses to acquire water for feedstock conversion are small, generally much less than one cent per gallon of ethanol.

One final point is that water use can be reduced by carefully considering where the feedstock is produced. Figure 14 presents the cumulative water use vs. cumulative ethanol produced by state (i.e., states ranked according to increasing water use). This graph clearly shows that a majority of the water use is concentrated in a few states which in turn generate relatively little feedstock and ethanol. Specifically, feedstock production in states requiring significant irrigation should be avoided (e.g., Kansas, Nebraska, Texas, Colorado, Oregon and Washington).

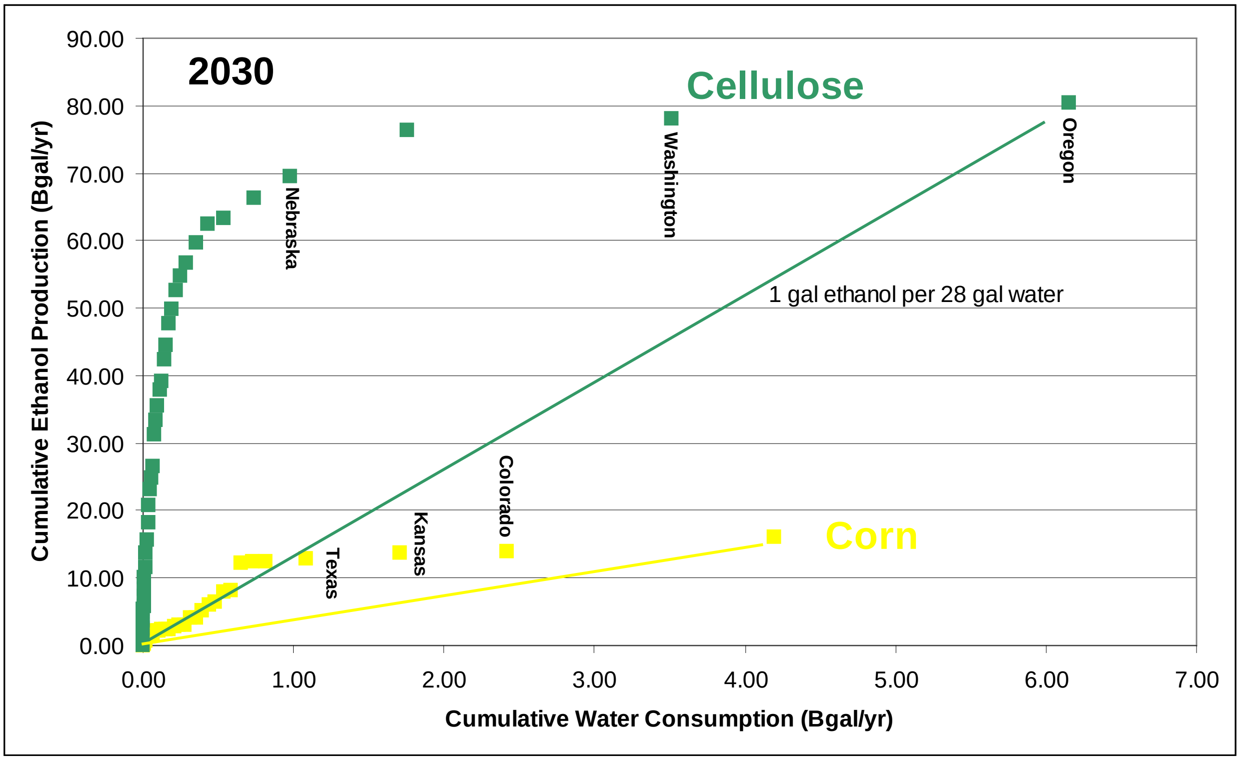


Figure 13. Cumulative water use vs. cumulative ethanol production by state (states are ranked according to increasing water use).

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