Part A NSF Food Energy Workshop Summary

Migration of Agriculture as a Path to the Geographical Sustainability of Agriculture Considering Production, Energy and Water Constraints

Boulder, Colorado October 21-23, 2015

Workshop Summary

In the last century the geography of the Nation's agricultural production changed dramatically as food and fiber production shifted from the East to the arid West under irrigated agriculture. Similarly, as transportation improved corn and grain production migrated to deep water holding soils in a small area of the upper Midwest. As a result agriculture in the East dropped precipitously. In a positive sense, this migration of agriculture produced a bountiful fare of food at a price afforded by ordinary Americans. However, the present drought in the West and the 2012 Midwest drought perhaps expose the vulnerability of the new geography of U.S. agriculture. Additionally, the shift in agriculture brought about adverse impacts on river ecosystems in the West and the concentration of nutrient export to the Mississippi River. This leads to several strategic questions. Is the geography that evolved in the last century, due to immediate market forces and government investments, sustainable and reliable for the future? Will the geography of agriculture continue to evolve and, if so, can information be developed that can guide future migrations of agriculture. The East lost its agriculture in large part because of drought losses so bringing agriculture back to the East will require expanded irrigation. Can some portion of the production in the West now under water stress due to increasing demand from population growth and potential reduction in supply from climate change be migrated back to the East or Northwest under irrigation? Can grain production be more geographically distributed to avoid the environmental issues (e.g. nutrient run-off) and vulnerability to small regional droughts that the present concentration of grain production in such a small area entails? This new geography of agricultural production has also changed energy consumption through electrical energy used to move water surface water in the West and to pump water in the High Plains. It has created the need for transportation energy to move refrigerated food from the West to the East and grains from the Midwest to the Southeast for consumption by poultry and swine. While transportation energy is generally a small part of total energy in food production it can, however, have large impacts on final profit. A new migration of agriculture back to the Southeast may see competition for water for cooling in thermoelectric generation and hydroelectric losses. Thus, the sustainable geography for U.S. agricultural production is at the nexus of food energy and water interactions.

An NSF Workshop was convened in Boulder, Colorado October 21-23, 2015 that brought together hydrologists, agronomists, economists, engineers, climatologists, ecologists, energy experts, data scientists and water resource planners to discuss the vulnerabilities of the present geography of agriculture. The workshop discussed whether information might be developed to assess the geography of economic and agricultural sustainability in the future that might guide private sector investments and government policy as needed to sustain production in the coming century. Data mining and cyber infrastructure components such as software tools and models were introduced by Graves at the beginning of the workshop as critical parts needed to meet information gathering needs for informed decisions. The workshop began the process of determining how the geography of sustainable production might be defined in terms of food, energy, and water metrics. This Part A summarizes the background on the geography of production and discussions at the workshop. Part B describes research challenges for an NSF FEW Program that outlines the major science questions and paths to develop metrics and components to define geographical sustainability.

The workshop participants concluded that the migration of agriculture as one path to a more sustainable, secure, US food production system was an idea that should be explored further. Feedbacks on the major research questions associated with food, energy and water (FEW), including multifaceted or nexus issues among FEW were identified. The challenges ahead are to secure funding to begin to address these critical research questions and produce map products with metrics to guide policy makers in determining the appropriate locations for discrete crops to migrate.

1. Introduction

While many have voiced concerns about vulnerabilities of agriculture to future climate change (Schneider 1989, CCSP, 2008, Mearns et al 1999), less has been discussed about geographical changes in U.S. agriculture in the last century that has made it more vulnerable to climate. Also, these geographical changes may be more vulnerable to competing demands on water resources and the energy required for effective distribution of food to population centers.

Sustaining the country's extraordinary agricultural production in the face of population growth, water use, environmental, energy and climate challenges will be difficult in the 21st Century. There have been at least 4 major climate adaptation paths proposed for sustaining food supply in the U.S:

1. Water conservation (e.g. reduction in flood irrigation, use of conservation tillage, low pressure nozzles, improved scheduling (O'Neill and Dobrowolski, 2005))
2. Additional large water projects to store or deliver water to agriculture (e.g. projects proposed in California (Bureau of Reclamation 2014) or moving water vast distances from the Northwest or the East).
3. New drought, heat and salt tolerant hybrids through genetics.
4. The Genesis Strategy - Food storage- (Schneider 1976)

Given the remarkably rapid geographical shift in agriculture in the last century, it seems that a discussion of a fifth strategy - a planned positioning or migration of agriculture to provide a more sustainable U.S. food production system might be in order. The migration that occurred in the last century was largely unplanned and primarily forced by immediate market forces driving production to the locations that could provide the best quality and lowest costs of production. Non-market driven forces such as the environmental costs, or the real costs of water or the sustainability of production, or future energy costs were not fully considered in this geographical shift.

It was the first purpose of this workshop to evaluate whether migration should be one of the strategies that the Nation should consider as it plans for agricultural production in the next century. Participants explored whether or not the U.S. can plan and foster its geographical production so that it is more sustainable for the future in terms of production efficiency, energy costs and environmental impact. The workshop addressed whether metrics can be developed to guide the most sustainable distribution of production and how these metrics might be used by the private sector and policy makers. Figure 1 gives the organizing committee and distribution of participants in the workshop. In the appendix, the agenda is provided (A.1), links to the presentations (A.2), and the attendee list with links to names from the body of the document.

Figure 1 Organizing Committee (left) and participant distribution (right) for NSF FEW Workshop.

2. The Current Geography of U.S. Agricultural Production:

At the start of the workshop, background on the geographical shift that occurred in the last century and its potential vulnerability were provided by McNider and Jones. Jones noted that at a point in time agricultural production can be in equilibrium, but perturbations can alter this equilibrium. Agricultural production systems evolve and adapt to climate, soil, markets, economics of production, industry, technology, social, political, and ecological conditions where they occur. However, internal, external, natural and manmade disruptions can occur too. These can be climate change, soil degradation, changes in policies or regulations, pests and disease, increases in populations, changes in diet, changes in product or input prices, and change in water supply/drought or conflicts. The dramatic shift in agricultural production geography in the past century was the result of disruptions such as improvements in transportation, irrigation technology, drought and public policy.

In the last century a significant amount of the Nation's food and fiber production shifted from the East to the arid West due to the establishment of irrigation infrastructure (Efland, 2000, Gardner 2002) and improved transportation. Similarly, with transportation improvements corn and grain production became concentrated in deep water holding soils in the upper Midwest that avoided drought losses occurring in the shallow poor water holding soils in much of the East (Meyer 1987, Gardner 2002, McNider et al. 2005, McNider and Christy 2007).

A similar shift occurred with cotton, vegetables, and potatoes as irrigated production became concentrated in the river basins of the arid West. The East and especially the Southeast lost a large portion of its row crop agriculture due to poor water holding soils and short-term droughts. Rain-fed corn farmers in the East could not compete with farmers cultivating in the high water holding capacity soils of the Midwest or irrigated cotton in the West (Arax and Wartzman 2003, Effland 2000). The shift in production was accelerated by drought conditions in the 1950's that forced corn and cotton farmers out of business.

In 1939 Maine, New York and Pennsylvania led the nation in potato production. By the 1950's, Maine, New York and Pennsylvania lost their historical top rankings in potato production to Idaho and Washington as irrigation projects on the Snake River began operating. The Middle Atlantic lost vegetable production to California and Arizona. Potato farmers in the Northeast and vegetable farmers throughout the East went out of business.

At present California accounts for approximately 25% of the nation's vegetable production including potatoes. If potatoes are excluded California accounts for probably more than 50% of the nation's vegetable production. McNider noted at the workshop that Wysong et al. (1984) showed that in 1950 the Northeast produced nearly the same amount of vegetables as California does now (21%). However, by 1980 this had dropped to less than 7%.

Figure 2 shows one measure of this shift by changes in crop land from 1910 -1997. While other factors noted by Jones such as pests (boll weevil), climate variability (1930's and 1950's drought), and government policies (Bureau of Reclamation) played some role, the overall drivers were the consistent production that was provided by irrigated agriculture in the West and deep water holding soils in the upper Midwest and improved transportation. In a positive sense, this migration of agriculture produced a King's fare of food at a price afforded by ordinary Americans. Remarkable results in grain production allowed prime cuts of poultry, pork and beef to be a mainstay of America's diet. Fresh perfect fruits, vegetables and nuts grown almost year around in deserts displaced locally grown seasonal vegetables and canned goods. However, the immediate market economic efficiencies provided by consistent production that drove the shift in agriculture in the last century did not fully account for the environmental externalities, the future competition for water supply or the adverse societal impacts of abandoned agricultural land.

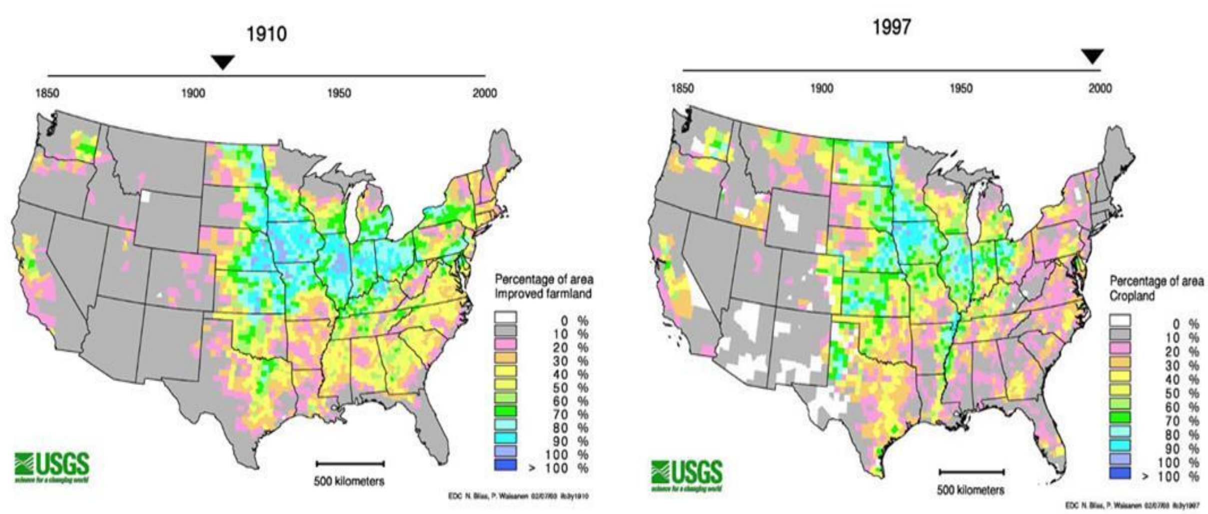


Figure 2 Maps showing changes in row crop area from 1910 -1997. Note expansion of potato production in the Snake River Valley, gradually westward movement in the High Plains, expansion of production in California and the loss of agriculture in the East.

On a smaller scale Jones described a migration of the dairy industry in Florida from the south to the north due to water withdrawals and water quality concerns. This was in large part a planned migration with incentives and buy-outs provided by the state and local water districts used to encourage movement. Zorn noted an unplanned migration of peanuts from Southeast Alabama due to government changes in peanut allotments and better soils.

2.1 Role of Energy in the Current Geography of Production

Relatively inexpensive transportation energy was also a key underpinning of the geographic shift in the last century. It allowed potatoes and vegetables to be shipped to the population in the East and Midwest grains to be shipped to the Southeast for consumption by poultry and swine. As will be discussed further below, while transportation energy is normally a small part of the total energy used in the agricultural production, it can be a major factor in the net profit of production.

While gravity played a dominant role in the near term movement of water for projects in the West, in many places electrical energy was critical to be able to move and pump water for agriculture. The California State Water Project is the largest single user of energy in the state (CEC 2014) and most of the water is used for irrigation. In the High Plains, rural electrification and inexpensive fuel allowed for pumping from the Ogallala aquifer. As aquifer water levels drop the energy costs of pumping ground water may be a limiting factor in economic viability.

In the East many reservoirs were built for hydroelectric production and for thermo-electric withdrawal. Easements owned by power companies coupled with the riparian rights policy discouraged the adaptation of irrigation. There was perhaps also implicit concern by power companies on the impact to hydroelectric and cooling water withdrawals that further dissuaded irrigation from these power reservoirs (Union of Concerned Scientists 2013). As discussed further below, the expansion of irrigation in the East will need to assess the competition between irrigation withdrawals for agriculture, hydroelectric energy generation and cooling water withdrawals for nuclear energy production and industrial needs.

2.2 Societal Impacts of the Shift in Agriculture

The migration of agriculture in the last century also had large attendant social costs. The old abandoned agricultural areas in the South have high rates of poverty as the economic engine of agriculture was removed. See figure 3. The extreme poverty on which the press reported during President Obama's visit to Selma for the 50th anniversary of the Selma to Montgomery March had its origins in the collapse of Southern agriculture. Andrew Young commented - "The farmers who let us stay in their homes, who bonded us out of jail, are old guys now. They still own land but they can't make a living on the land." While other parts of the country also suffered economic losses with the loss of agriculture, the old agricultural areas in the South have had particular difficulty adjusting to new economic realities and are now among the poorest regions in the U.S. (Lee and Sumners, 2003).

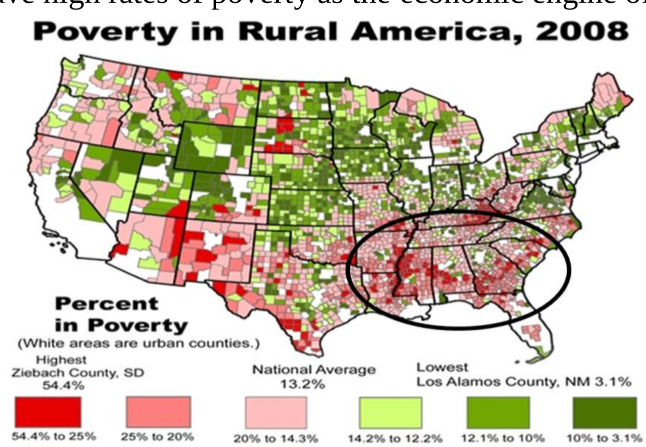


Figure 3 Rural poverty in America from USDA. Note swath of poverty in abandoned agricultural lands in the Southeast.

Increases in rural poverty are likely to occur in the West if agriculture contracts. Including the social costs for the abandonment of agriculture should be part of the cost equation for migration of agriculture to promote a more sustainable U.S. food supply.

2.3 Vulnerability of the Present Geography

The West: Christy, Tootle and Udall presented information on climate change and paleo-climate that may make the water future different in the West. The present drought in the West, the 2012 Midwest drought, and the 2005-07 drought in the Southeast underscore the vulnerability of the present geography of U.S. agriculture. In the West, burgeoning population growth and environmental restoration are competing with farmers for water supply (Reisner 1986, Postel, 1992; Rosegrant et al., 2002; Gleick et al, 1995). At the workshop speakers Christy and Tootle provided background on the historical climate of the West and East with special attention to the paleo-climate record. The last 100 years in which western irrigated agriculture evolved was likely the wettest in the last 500 years in the Colorado Basin – see figure 4 (Pechoita et al. 2004 – co-author Tootle). The paleo-climate record shows historical multi-year and decadal droughts in the West far exceeding those in the recent past (Cook et al. 2015). Further, future climate change scenarios generally show drying in the Southwest U.S. and increased risks of decadal and multidecadal droughts, but little change or an increase in precipitation in much of the East and South (Melillo et al 2014; Cook et al 2015). At the workshop, Udall began by showing that many parts of the West are facing water conflicts due to population growth and oversubscription of water supplies even without consideration of climate change or a return to drier paleo-climates. He showed that under climate change scenarios the Southwest is likely to become drier (figure 5) and that higher temperatures with increased evaporation will likely exacerbate precipitation deficits. Christy, however, showed that climate change model performance against past data did not give confidence in future scenarios and that observed warming in California temperatures (Christy et al. 2006) were largely due to increases in minimum temperatures that would not increase evaporation.

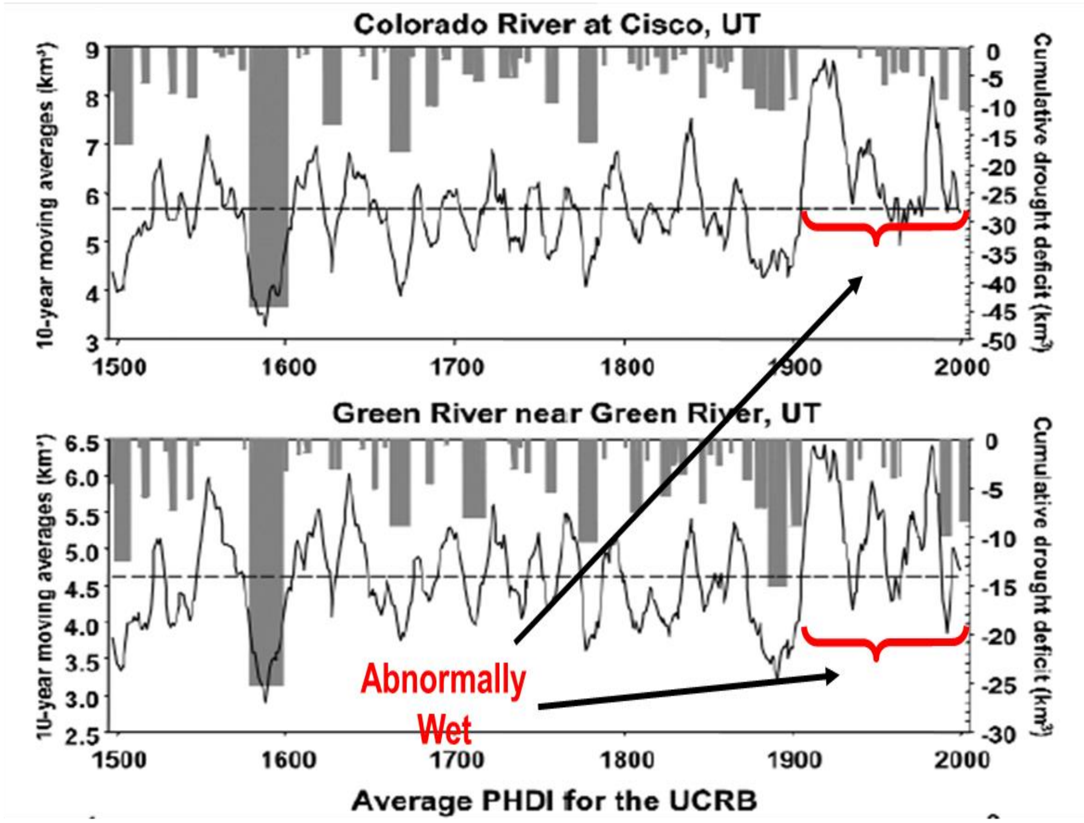


Figure 4 Palmer Hydrologic Drought Index (PHDI) for the Upper Colorado River Basin (UCRB). From Piechota, T., J. Timilena, G. Tootle and H. Hidalgo, 2004 EOS.

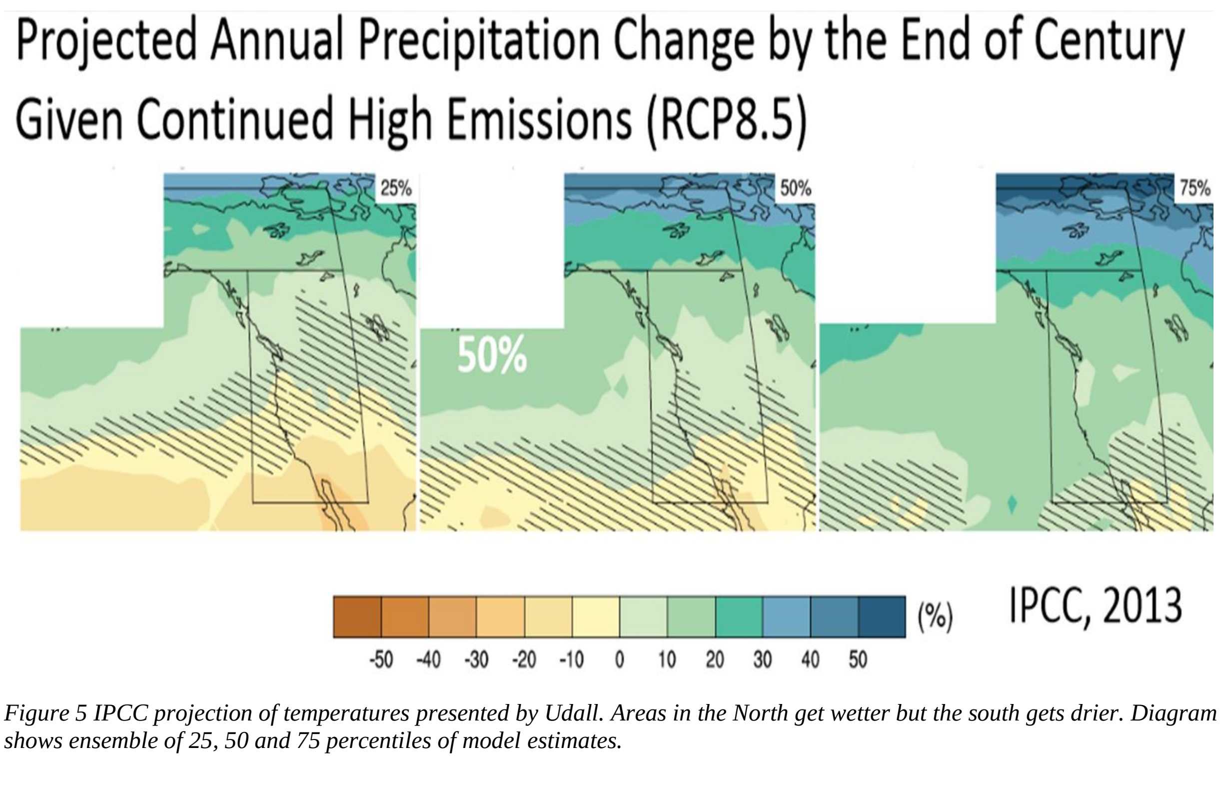


Figure 5 IPCC projection of temperatures presented by Udall. Areas in the North get wetter but the south gets drier. Diagram shows ensemble of 25, 50 and 75 percentiles of model estimates.

The Midwest: The 2012 Midwest drought shows the danger of concentrating so much of the Nation's grain production in such a small geographical area (see figure 6). While climate change scenarios are not as strong in terms of drying in the Upper Midwest as in the Southwest, models do indicate drying in the western part of the corn belt. This is an area that has seen westward expansion of corn production to the Dakotas as corn prices increased in recent periods. However, the historical instrumental climate has droughts exceeding the 2012 Midwest drought in terms of intensity and placement in the grain producing areas. The concern is that back to back drought (drought coupled with floods in the Upper Midwest) would wreak havoc on corn and soybean production in the U.S.

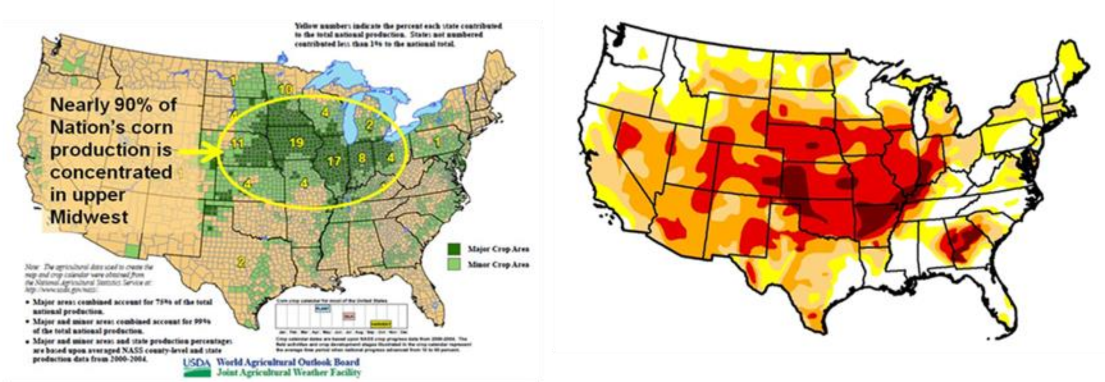


Figure 6 Left shows concentration of corn production. Right shows 2012 drought monitor map indicating a regional drought that doubled the price of corn with several weeks despite the fact that the core of production was spared in this particular drought.

In addition to the regional drought, the concentration of production in the upper Midwest has overwhelmed the assimilative capacity of the watersheds leading to nutrient export into the Gulf of Mexico resulting in a large area of hypoxia waters (Rabalais et al. 2001). See figure 7. Cruise and Arritt noted recent EPA policy panels set significant reduction targets for nutrient export to alleviate nutrient loading (Rabalais 2011). While Arritt pointed out agricultural methods that are being evaluated to reduce export, lawsuits by municipalities to force clean water may constrain Midwest agricultural production in the future and/or increase costs.

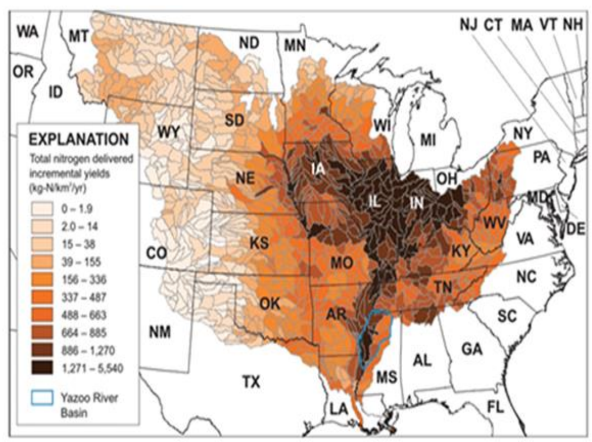


Figure 7 Nutrient loading in the Mississippi Basin due to concentration of grain production in upper Midwest.

World Wide Vulnerability: While the focus of the Workshop was on migration of agriculture as a path to maintain sustainable production in the U.S., presentations by Brown and Kramer pointed out that U.S. agriculture cannot be viewed in isolation. Brown noted that many parts of the world currently face a calorie deficit (see figure 8). Thus, a

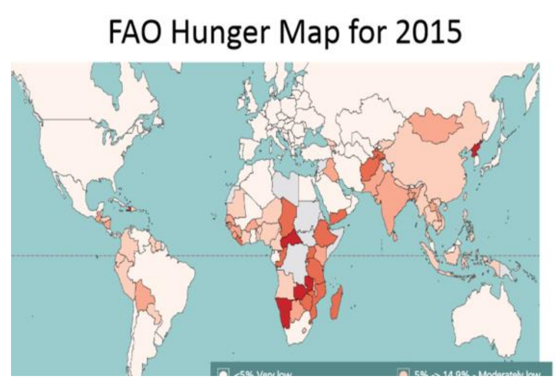


Figure 8 Estimate of World Hunger from Food and Agriculture Organization presented by Brown.

contraction in U.S. agriculture could have an impact on world food availability. The U.S. is an important source of technological advancement across many elements of the food production system. How U.S. agriculture responds to these challenges makes a difference for global food security. While one aspect of migration was seen as protecting U.S. production, Kramer pointed out that U.S. agricultural consumption also depends on imports of food from around the world (see figure 9). Both Kramer and Brown noted that any consideration of migration of agriculture should consider these external imports and exports impacting supply/prices, which could grow or shrink depending on climate and economic conditions.

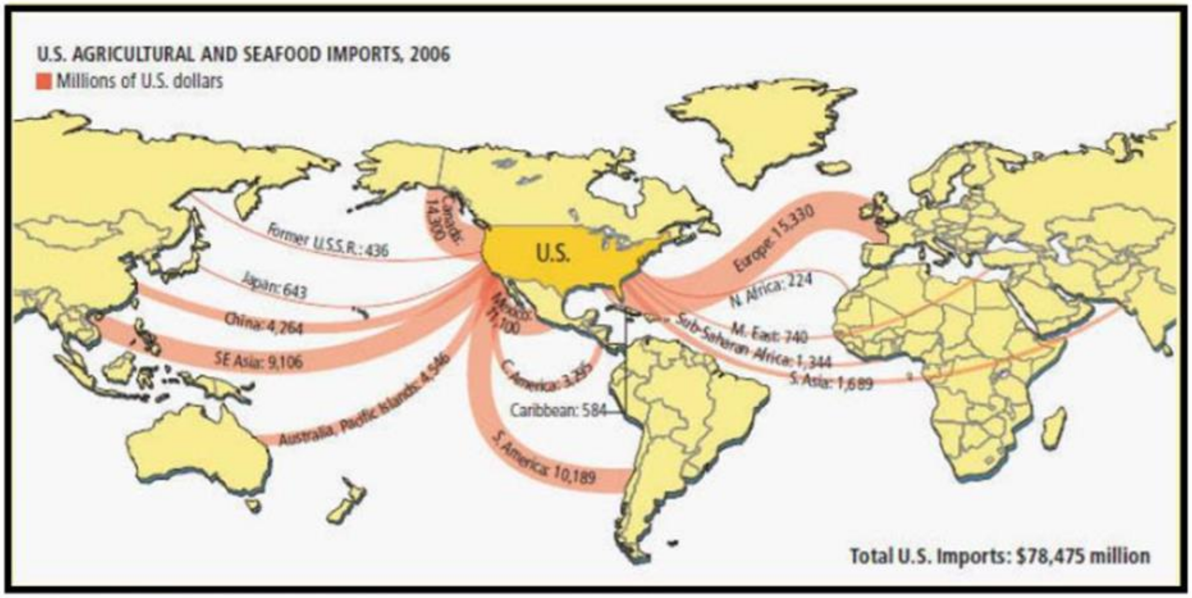


FIGURE WO-2 U.S. agricultural and seafood imports (millions of U.S. dollars).
SOURCE: George Retseck and Lucy Reading-Ikkanda for *Scientific American* magazine in Fischetti (2007).

Figure 9 Illustration of U.S agricultural and seafood imports presented by Kramer.

The Current Western Drought:

Several talks discussed the current western drought. Gunasekara and Medellin-Azuara reported on the reductions in surface water and actions taken by farmers in the past four years. This is also provided in reports to the California Department of Agriculture by Howitt et al. (2014) and Howitt et al. (2015). Both emphasized the amazing short-term resilience of California agriculture in the face of the substantial short-fall in surface water. However, as they noted and reported in Howitt et al. (2015), the short-fall in surface water (8 .6 million acre-ft.) was largely made up from

Description	Impact	Base year levels	Percent change
Surface water shortage (million acre-ft)	8.7	18.0	-48%
Groundwater replacement (million acre-ft)	6.0	8.4	72%
Net water shortage (million acre-ft)	2.7	26.4	-10%
Drought-related idle land (acres)	540,000	1.2 million*	45%
Crop revenue losses ($)	$900 million	$35 billion	2.6%
Dairy and livestock revenue losses ($)	$350 million	$12.4 billion	2.8%
Costs of additional pumping ($)	$590 million	$780 million	75.5%
Direct costs ($)	$1.8 billion	NA	NA
Total economic impact ($)	**$2.7 billion**	NA	NA
Direct job losses (farm seasonal)	10,100	200,000#	5.1%
Total job losses	**21,000**	NA	NA

* NASA-ARC estimate of normal Central Valley idle land.
# Total agriculture employment is about 412,000, of which 200,000 is farm production.

Table 1 Impact on water and agriculture in California. From Howitt et al. 2015 presented by Medellin-Azuara.

increased ground water pumping (6 million acre-ft.) (see Table 1). While Gunasekara indicated ground water was not being depleted in most areas at an unsustainable rate, others such as Minton, Udall, McNider and Hightower reported concerns with ground water depletion in California and throughout the West. Previous studies such as Famileghetti et al. (2011) report serious long term declines (see figure 10). Howitt et al. (2015) see ground water as a key factor in resilience to drought but state "Increased groundwater overdraft during drought will slowly deplete groundwater reserves at an incremental cost. New groundwater regulations could eventually reverse this trend and force groundwater basins towards sustainable yields. The transition will cause some increased fallowing or longer crop rotations, but will preserve California's ability to support more profitable permanent and vegetable crops through drought."

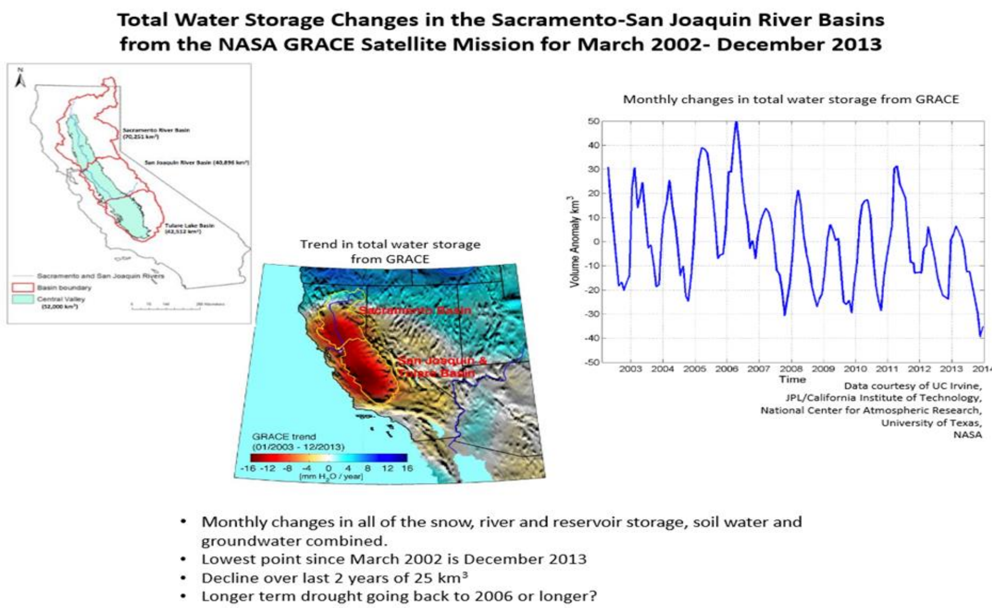


Figure 10 Illustration of large scale ground water depletion. However, as noted by Gunasekara not all areas are being depleted at the same rate.

As discussed in Howitt et al. (2015) and Howitt et al. (2014), most of the fallowing of crops due to surface water shortages was in lower value crops- cotton, rice, forage etc. Water markets appear to be working to some extent. It was noted that average water costs in districts in 2015 were around $650 per acre. This is greater than the return on crops such as cotton and rice. While farmers were reluctant to make large permanent transfers; rice and cotton farmers did sell water and fallowed lands. The switch to orchard crops such as almonds and walnuts, while market driven rather than drought driven, may change some of the dynamics in dealing with drought. Though immature orchards consume less water than row crops, the demand increases over time and cannot be fallowed in dealing with short-term drought like row crops.

Larger Scale Western Drought:
While the recent California Drought has garnered significant attention, it is set against the backdrop of a longer term western drought. Several speakers- Udall, Christy, Tootle and Hightower talked about these longer wider spread droughts. The paleo-record indicates that mega-droughts existed throughout the last 500-1000 years. Udall especially mentioned the

backdrop of these mega-droughts and impact on the Colorado Basin. The mega-droughts coupled with warming temperatures and dust loading on snowpack may combine to produce extraordinary low flows on the Colorado River (Vano et al. 2014). Hightower, in his energy-water talk also discussed the current widespread drought that the West is experiencing. As noted by Udall, lake levels on the Colorado at Lakes Powell and Mead have declined since 2000 and are back near historic lows (figure 11)

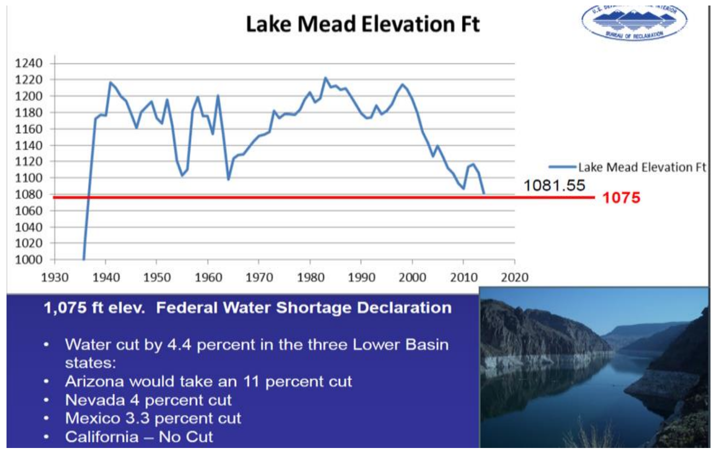


Figure 11 Long-term elevation levels for Lake Mead. Red line points provides level at which mandatory reductions would go into effect. From Bureau of Reclamation.

McNider pointed out that these long-term droughts, coupled with the current California drought, climate change and the continuing population growth in the region constitute an almost "Perfect Storm" that may drastically impact agriculture (figure 12). Under the present drought California continues to get its full Colorado allotment. However, should lake level continue to drop mandatory reductions in allotments may be put in place with the first curtailments to Arizona, Nevada and Mexico. Should the next phase of reductions be required this might have strong negative impacts on California agriculture since local agricultural water might have to be directed to municipal supply.

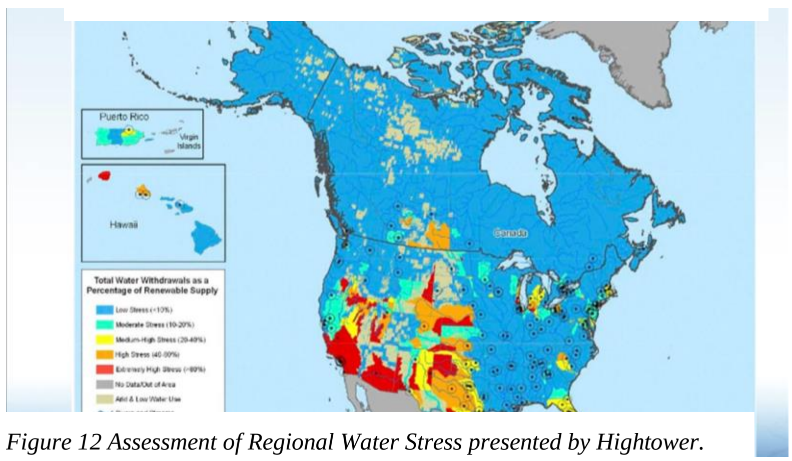


Figure 12 Assessment of Regional Water Stress presented by Hightower.

Agriculture is not the only segment impacted by the long-term droughts. Hightower reported on large scale water availability and the Southwest U.S. was shown to be the areas with the largest current stress. There are existing and potential conflicts between energy use, irrigation and public water supply. This is consistent with maps of existing and potential conflicts developed by the Bureau of Reclamation and presented by Udall (see figure 13).

3. Role of Migration in Reducing Vulnerabilities of Current Geography of Agricultural Production

Giving the vulnerability of the current geographical agricultural production system, sustaining the country's extraordinary agricultural production in the face of population, water use, environmental and climate challenges will be difficult in the 21st century. In the West, the silo approach (e.g., engineers talking to engineers, economists to economists, etc.), has proven to be unsustainable. Going forward it is imperative that agricultural interests work collaborative with

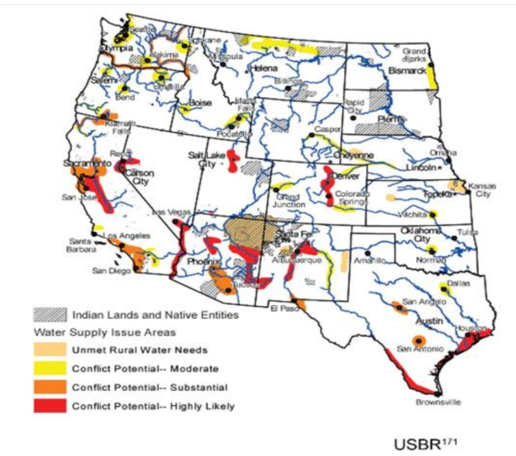


Figure 13 Areas of existing and potential water conflicts expected under current climate conditions from Bureau of Reclamation presented by Udall.

environmental interests to develop sustainable agricultural systems that function in healthy sustainable ecological environments as suggested by Reid and Minton. As mentioned in the introduction, several strategies have been developed to sustain production in the face of such challenges; these include conservation, construction of additional water projects to store and move water as well as the development of new drought and salt resistant hybrids. Here we explore whether changes in geography of production may also help meet these challenges.

3.1 Geography of Water Availability

Given the climate of North America there is a huge variation in available water for consumption. Figure 14 provides a map of water demand to water supply shown by Cruise. It shows that many areas of the west currently are consuming large fractions of the available water. In fact, Sabo et al. (2010) calculate that humans now appropriate the equivalent of 76% of the West's streamflow for agriculture, domestic use, and other purposes. On the other hand, in the East in most watersheds only a small fraction of the water is actually consumed. Yet, the schematic in figure 15 shows that in the past 80 years we have migrated agriculture away from water.

Perhaps of more concern from the discussions above is that both climate change scenarios and paleo-climate data indicate that the West is likely to experience greater reductions in available supply. Figure 16 from Cruise's presentation shows that climate change is likely to further exacerbate the existing difference in water supply with the West becoming drier and the East in large part showing no change or an increase in water supply. Can western agriculture be sustained with substantially less water likely in the future?

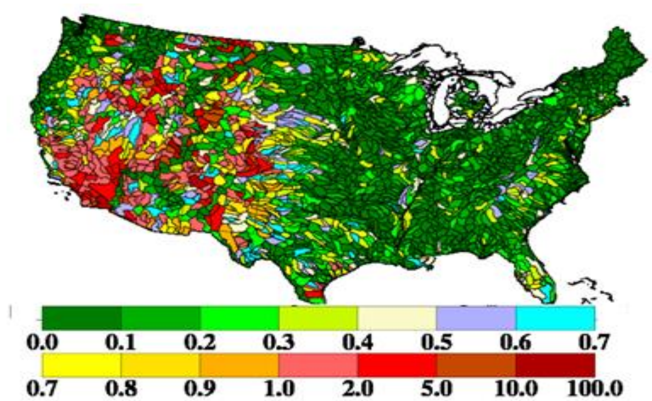


Figure 14 Depiction of national water stress by basin. The index is the Water Stress Supply Index (WaSSI) which depicts the ratio of water demand (consumption) to available supply. Produced by UAH in conjunction with the U.S. Forest Service.

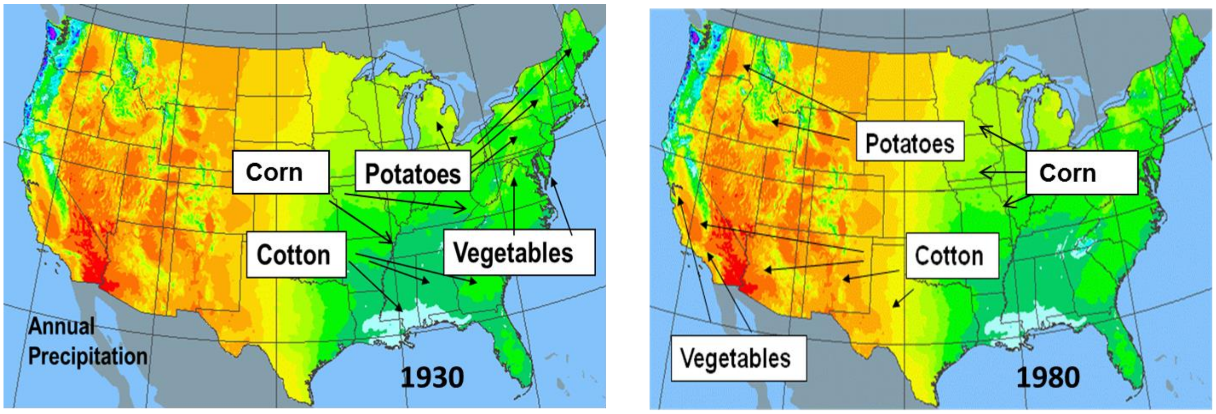


Figure 15 Schematic of geographical shifts in agriculture in the last century. Background map is precipitation.

3.2 Western Agricultural Response to Reduced Water Supply

Given, the information above about current water stress in the West and potential future drying, how will agriculture be impacted? Investigators at UC Davis have looked at the response of California agriculture to potential water reductions. Figure 17 from Medellin-Azuara (2012) shows the modeled response of California agriculture by area and crop to a 30% reduction in water supply. This was carried out by optimizing profit through the inclusion of water as a cost. It shows that lower value crops such as cotton and grains are fallowed preferentially rather than higher valued crops such as vegetables, nuts and grapes. Also, there are different responses by areas based on where crops are grown and water availability.

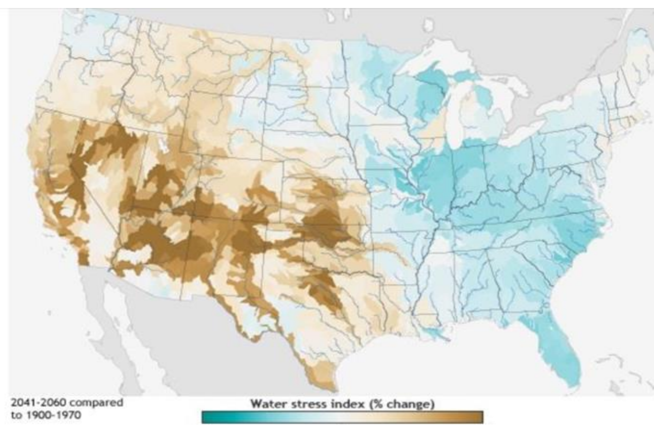


Figure 16 Expected changes in Water Stress Supply Index (WaSSI) due to climate change. Thus, water stress in the Southwest in the past century (see figure 15) might be expected to worsen.

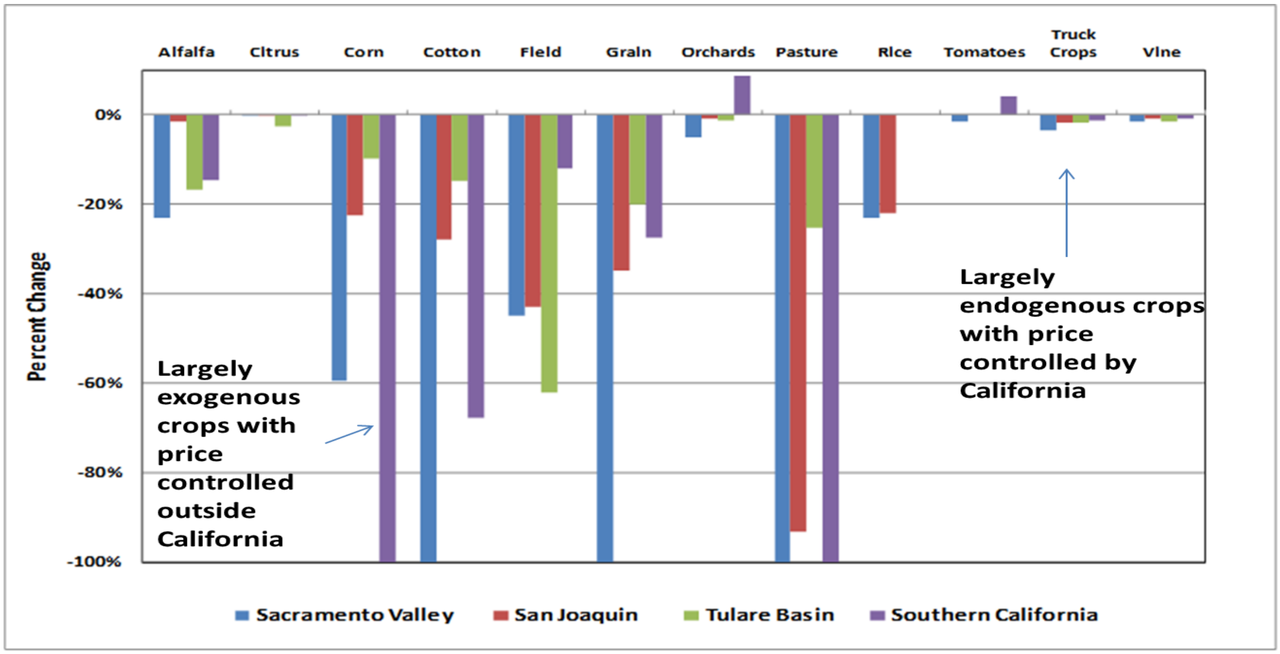


Figure 17 Modeled response of California agriculture to a 30% reduction in water supply. Note that lower value crops for which prices are controlled outside of California whereas vegetable are not reduced as much but perhaps raising prices of vegetables (from Medellin-Azuara 2012).

Of particular interest to food security is that fruits and vegetables are protected by their value. Their value, in part, is determined by the fact that prices for these crops are endogenous; that is in large part prices controlled by local production. If the production cost increases then prices increase. Prices for crops such as cotton and grains are exogenous and controlled by production costs outside of California - thus production is reduced.

This raises two factors relative to the need for geographical shifts in agriculture. Where can the production of fallowed crops be replaced? Second, while the value (profits) of the fruits and vegetables are maintained, this may come at the expense of the amount of fruit and vegetables produced or by a higher price of fruit and vegetables to consumers across the U.S. Both of these are threats to nutrition for the country.

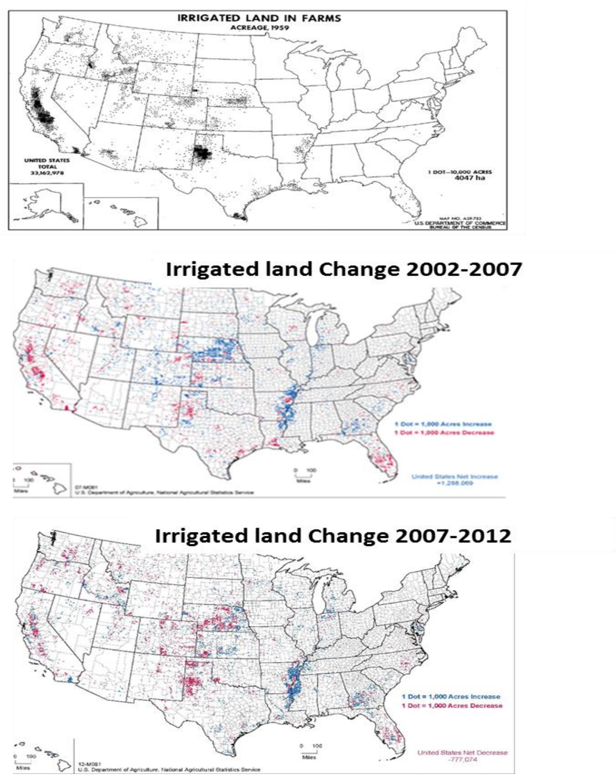


Figure 18 (top) Irrigated land in the U.S. in 1959. Middle change in irrigated land 2002-2007(bottom) change in irrigated land 2007-2012. Presented by Evett.

On a larger scale, Evett made a presentation on irrigation trends for the U.S. as a whole. It began by showing that a significant part of the growth in agricultural productivity in the U.S. was due to blue technology (irrigation) in addition to green technology (genetics and nutrient management). In 1959 almost all irrigated agriculture was in the West (see figure 18). However, since then there has been a steady migration of irrigation to the East and a corresponding decrease in the West (see figure 19). While the Eastern expansion was driven by the improved production efficiency, at least part of the reduction in irrigated acreage in the West was due to decreased water supply, especially in the Ogallala area of the High Plains.

Evett also mentioned the reduced use of water due to increased efficiency of pressurized systems rather than older flood irrigation. Thus, water use per acre has decreased over the last thirty years. Gollehon (2012), however, pointed out that a substantial part of the national statistics of the reduction in water applied per acre is tied to the Eastern migration of irrigation into regions where irrigation demand per acre is much reduced due to natural rainfall. Thus, in a holistic sense migration of agriculture and irrigation to the East provides a net national savings of water.

3.3 Response to Grain Concentration in the Upper Midwest

As noted above, the concentration of grains in the upper Midwest may be an issue in terms of long-term sustainability. Threats to the current geography come from regional drought, westward expansion of rain-fed corn and soybean production into traditional wheat areas (Pryor 2013) where precipitation in the long-term may not support such production and its accompanying basin wide nutrient loading due to the concentrated production. There has not been as much national attention to this problem as with western water issues. There are several questions that need to be answered. Will the frequency of Midwest drought (especially runs of drought/floods) be such that production will be impacted to the point that it is a threat to food/ethanol security? While the U.S. has had droughts that have been national in scope, the typical regional drought is often tied to synoptic scale weather patterns. Figure 19 shows that if the Midwest is in drought the Southeast may not be and vice versa. This argues for a more distributed system of production.

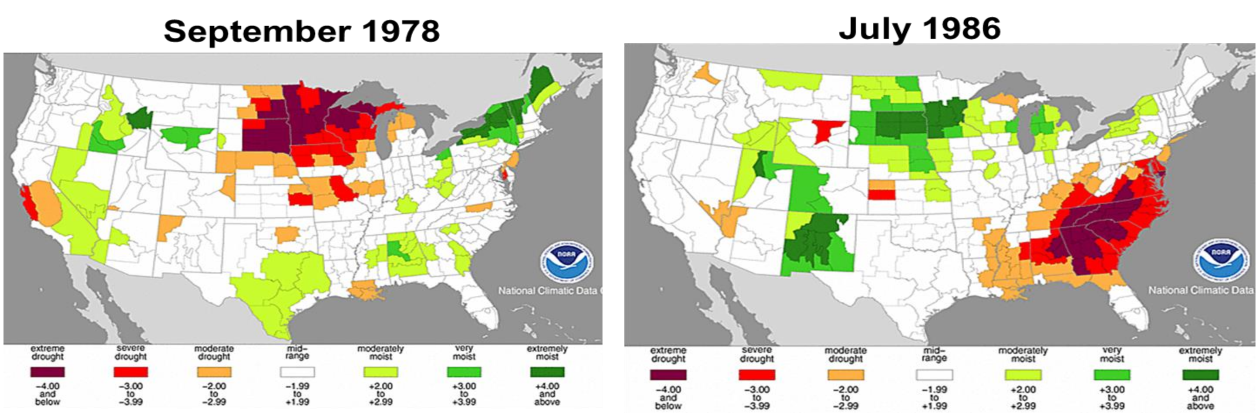


Figure 19 Typical drought pattern when controlled by synoptic weather scales. Droughts are normally defined by persistent high pressure systems that inhibit precipitation. These have scales of order a 1000 km so that many are regional in scope. This argues for a more distributed production system across synoptic scales.

As mentioned above ecologists and the EPA have determined that nutrient export has become a major problem in the Midwest. Will environmental regulations to control nutrient export be a threat to current levels of production or needs for expanded production?. Would a more distributed system of grain production back to other parts of the East, which are not in the

Mississippi Basin, be a better geography of production? Is such a distribution economically and environmentally viable?

4. Free Market Migration of Agriculture

The above discussions point to a clear picture that if water resources continue to come under pressure in the West, that western agriculture will likely contract though most likely maintaining higher value crops. As water becomes more expensive, it would seem (if water is the limiting constraint), then shifts in agriculture will inevitably be drawn back to water. Trends shown by Evett appear to indicate that this is occurring.

Along a similar line, if the costs of implementing nutrient control in the Midwest decrease profits will this drive production out of the Midwest? If droughts in the Midwest drive down supply and increase costs will farmers outside the Midwest take advantage of this profit opportunity and naturally increase production outside the Midwest?

Thus, a valid question is - will free market economics simply drive the migration of irrigated agriculture back to the East and reduce the concentration of grain in the Midwest? Will the market evolve to a new equilibrium production system as defined by Jones in the discussion of the historical geographic distribution of agricultural production at the beginning of the workshop? Will this new free market equilibrium provide the food and energy production the U.S. and the World needs?

There is evidence, in the shift of agriculture in the last century, that short-term market forces do not always foresee the environmental, societal and water resource issues that are important to sustainability. There are also other barriers that may restrict migration – some are economic, legal and environmental. The workshop addressed some of these externalities and barriers which are addressed in the next section.

5. Barriers to Migration of Agriculture

The example in section 3.2 above, of the response of California agriculture to reduced water supply, is an example of the response to a perturbation and the evolution to a new but profitable equilibrium for California. However, this new equilibrium gives up some production (cotton, grains, rice etc.) for the U.S. and world. What might inhibit a free market evolution to replace this agriculture in the East or Northwest? What might inhibit Southeastern farmers from replacing Midwest grain if nutrient or drought impacts Midwest production?

5.1 Pests, Disease and Appropriate Cultivars

As noted by Evett, there are other factors besides water which may inhibit the migration of agriculture. In the Eastern climate, pests and disease may reduce yield and quality. Aside from environmental impacts, if more pesticides and fungicides are used, then the economic costs of these inputs may offset the economic advantage of cheaper water in the East. Economic analyses are needed to assess these competing costs and their impact on profit. Cultivars developed in the arid west or for the Midwest may not do well in the East. The Eastern Broccoli Project was developed precisely to develop cultivars suited for the East.

5.2 Legal Issues – Water Access and Water Markets

Huffaker gave a presentation on legal issues that may be barriers to market forces evolving agriculture to a new sustained production equilibrium. The Riparian Rights legal system that governs water use in most of the East may limit the ability of the East to expand irrigated agriculture (Dellapenna 2004). Under the riparian system it is illegal for surface water to be transferred from riparian land to non-riparian land. Thus, almost all the irrigated land in the East has been irrigated using local surface sources or ground water which avoids this transfer. This has led to ground water depletion and has impacted stream flows that need the ground water to maintain base flows (Konikow 2013). An example is the depletion of the Mississippi Alluvial Aquifer in the Delta Region of Arkansas, Mississippi and Louisiana (see figure 20). This is a case where greater use of surface water from large rivers might be a better strategy than taking large fractions of the aquifer and impacting smaller streams. Less than 3% of the flow of the Mississippi could service all the irrigated land in the Delta. Evett pointed out that Arkansas has already moved down this path by developing irrigation districts using water from the White river. States will have to change the riparian restrictions on water movement via irrigation districts to open up this renewable source of water. However, access to this water will also require coupled demand/hydrologic studies to ensure that limits on surface withdrawals are established to avoid the oversubscription that has occurred in the West. The actions in Arkansas may be a model for the rest of the Delta and the East in general. But, limits on surface withdrawal would have to be put in place. It is also preferable to take small fractions from big rivers rather than large fractions of small streams.

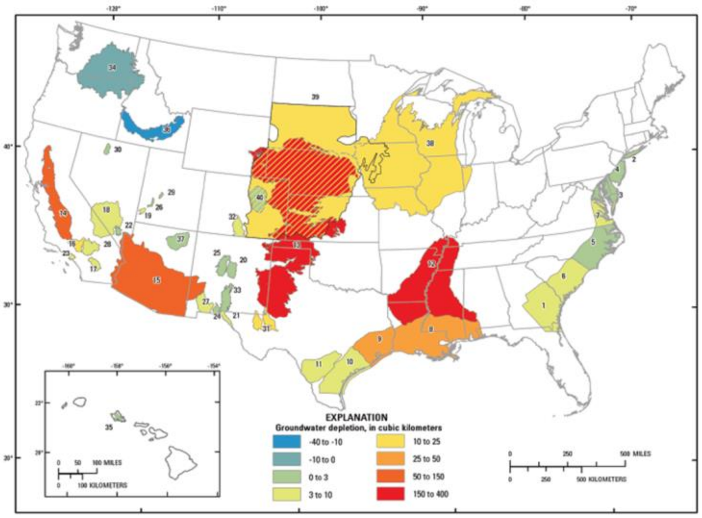


Figure 20 Depiction of ground water withdrawal from Konikow-USGS. Shows that depletion in the Midsouth may be nearly as bad or worse than in parts of the West.

In the West issues with the Water Doctrine of Prior Appropriation and water contracts in the West may inhibit the functioning of water markets. Some prior appropriations are conditioned on use and place. Cotton framers are not likely to become tomato farmers, so it is essential that the water be transferred either in place or at a distance. This will require transparent water markets without constraints. The orderly movement of water to higher value crops discussed above in section 3.2 depends on these functioning water markets.

5.3 Land Availability

Old abandoned row crop land in the East has been converted to forests, pasture and to urban/suburban uses (Ellenburg et al 2015). Some areas have been put in conservation reserve programs (NRCS –CRP) too. It is usually not economically feasible to return urbanized land to production. Batchelor and Walter noted clearing forest land is of order 1000 to 1500 dollars per acre which is feasible, but increases the cost of land. As Kramer noted, taking land out of forests may have implications for levels of carbon sequestration that have been expected.

There is, however, some low hanging fruit. In many parts of the Southeast remnant rain-fed row crop farmers try to hang on through extraordinarily low cost operations and government supported crop insurance. Irrigating this land would expand production and reduce government insurance rates.

5.4 Age of Farmers, Leased Land, Lack of Capital and other Factors

Batchelor provided a comprehensive discussion on barriers to expanded irrigated agriculture in the Southeast. The first of these is the level of rented/leased land. As farmers went out of business the land was often left in estates. Non-operating owners may be reluctant to make investments since land in the family for generations may be at risk. There needs to be attention to model leases so that both owners and operators share in the risk/reward. Good forward looking economic analyses may help spur investments.

Existing rain-fed farmers operating in a marginal business often do not have the capital to make irrigation investments. The age of farmers is also a consideration. Young farmers may have the time horizon to profit from investment, but they are often the ones with the least credit to make investments. Government insured low cost loans may be one solution. There is also a significant need for minority farmers in these old agricultural areas.

Melvin and LaRue, representing irrigation equipment suppliers, provided a fairly consistent picture of impediments to Eastern expansion which will have to be addressed through, policy, capital and education (table 2). LaRue noted that there are some areas of high intensity irrigated development in the East which are under water pressure – e.g. the Flint River and Suwannee River.

Impediments to Expansion in the East

- Irrigation may not pay every year on many crops in the east where it rains more
- Water supply-wells or surface water development will be required
- Field size, shape, and terrain
- Land ownership - who pays for development
- Irrigation equipment dealerships
- Climate- days of full sun, temperature, humidity level
- Farmer skill set
- Farmer's current equipment set
- Infrastructure and equipment
- Farmers and others in the local ag industry willingness to change
- Competition getting farmers in west to stop producing
- Labor
- Access to markets
- Processing plants
- Financing- bankers without experience with the new crops

Table 2 Impediments to Expansion of Irrigation in the East – Presented by Melvin.

5.5 Investment in Eastern Water Infrastructure

Another key obstacle to whether the East may be able to expand irrigation is investment in Eastern water infrastructure. Analyses need to be carried out to determine if the East perhaps should move away from non-sustainable (in some areas) ground water withdrawals and take greater advantage of the surface water resources. Rivers in the East are huge compared to Western Rivers. For example, Cruise stated that the Mississippi at Memphis is about 40 times the flow of the Colorado as it enters Arizona (see figure 21). The Alabama and Tombigbee separately are about twice the size of the Colorado River.. Thus, given the modest irrigation requirements in the East, irrigation withdrawals are on average only a small fraction of total flow.

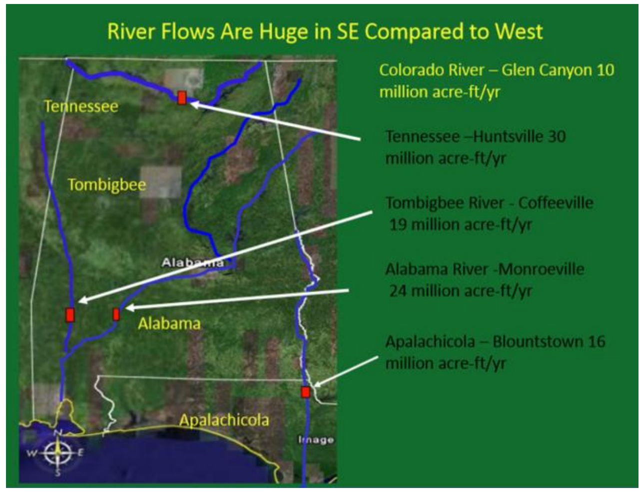


Figure 21 Depiction of the size of rivers in the Southeast compared to Colorado flow into Arizona. The natural flow of the Colorado is about 17 million acre-ft.

However, while annual average stream flows are large and precipitation is fairly uniform over the year, as noted by Cruise, the large deciduous biomass in the East increases ET to the point that stream flows decrease substantially during the growing season (May-October).

Figure 22 gives an example of the annual cycle in the Alabama River. Thus, it is better to avoid making withdrawals when the river has the least to give. A model has been developed for this type of withdrawal. As will be discussed in the energy section below this winter/spring withdrawal also avoids competition between thermo-nuclear withdrawals and irrigation withdrawals when the thermal dilution capacity of the rivers decrease during the summer. Thus, for low impact irrigation withdrawal it is likely investment in infrastructure such as in figure 23 will be required.

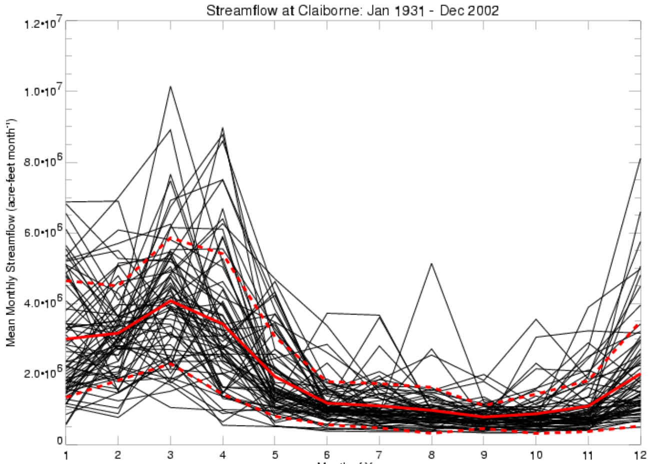


Figure 22 The black lines show the individual flow years from 1931 to 2002 and the red lines average flow, and dashed red lines standard deviation of the average flows. The key point is that while large flows occur during the cool season during the growing season flows are much reduced due to ET losses. Presented by Srivastava.

The Workshop was fortunate to have several attendees from the Bureau of Reclamation. While the Bureau has often been the subject of criticism on environmental issues and water subsidies, it is clear that people in the Bureau have a sense of their mission provided by Congress. In listening to the Bureau they understand they were there to help agriculture be successful in the West. They acknowledged that the type of planning, investment and construction would have been difficult through the action of farmers alone. Thus, they were sympathetic to even modest irrigation investments in the East.

While on-farm reservoirs may be simpler and cheaper, they recognized that the capital and time horizon for recouping the investment may be beyond most farmers ability. They mentioned that throughout the Bureaus history, water fees, repayments etc. were structured so that farmers could be successful. The East may need something like the Bureau to ensure that Eastern farmers have a similar chance at success.

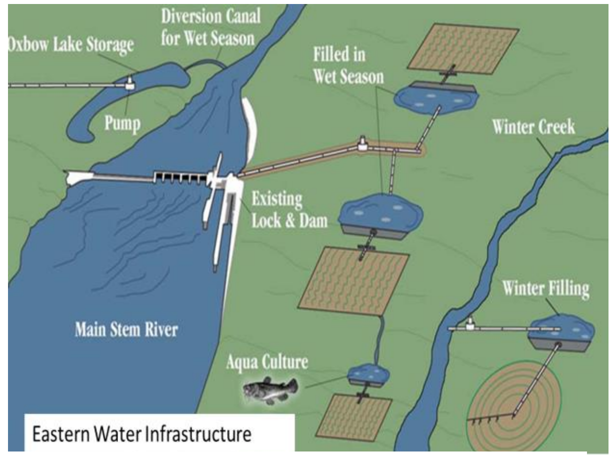


Figure 23 On farm pond withdrawal schematic.

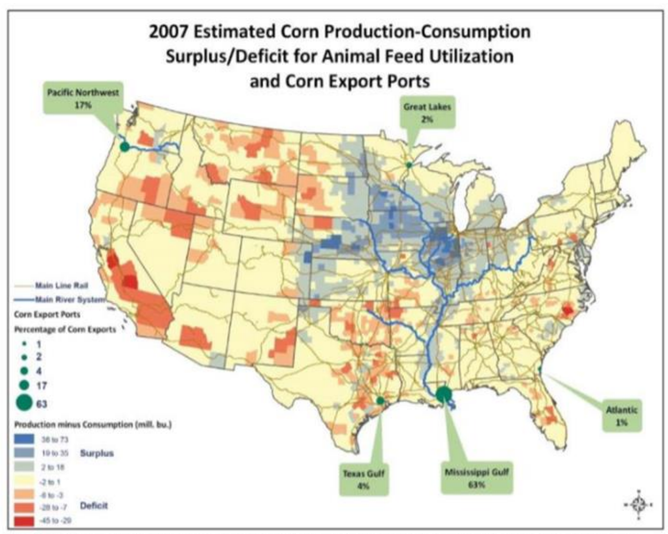
While the Bureau has been a major part of the success of western agriculture, there is concern that with limits on available water that any additional water construction projects to support agriculture in the West may be too expensive compared to the equivalent production and investment in the East. It was noted by Bureau participants that due to current Bureau geographical limits in its charter Eastern analyses may not be possible. [Cruise](#) noted that the National Resources Conservation Service (NRCS) has taken up some of the slack, albeit on a smaller scale. Consideration should be given to developing review policies, perhaps by the Corp of Engineers, which would allow agricultural water projects in the west to be independently evaluated to determine the East versus West return on investments.

6. Energy Aspects to Migration

There were several aspects of the relation to energy discussed at the workshop. These are categorized below.

6.1 Transportation Energy

As noted above, transportation was a critical factor that garnered most of the attention in the shift in agriculture in the last century. It allowed fruits and vegetables to be shipped refrigerated across the country and allowed Midwest grain farmers to ship and sell grains throughout the Southeast and West. For example figure 24 presented by [Batchelor](#) shows the transportation path of grains exported from the upper Midwest to other parts of the country. The Southeast imports grain for poultry and swine and the West imports grains for beef and dairy.



Source: Census of Agriculture, 2007 and Economic Research Service, USDA. Surplus-deficit estimate is based on county-level production, U.S. feed use, and county-level animal inventories (summed based on Grain Consuming Animal Unit factors). U.S. Waterborne Exports and Imports from the Port Import Export Reporting Service (PIERS).

Figure 24 Map of import and export areas for corn production and consumption. Blue areas indicate export (production) and Orange areas indicate consumption areas. Presented by Batchelor.

The ability of transportation system to move these large amounts of grain to the Southeast was in significant part due to the energy efficiencies gained in water transport from the upper Midwest to ports of delivery or railheads. The water transport was largely subsidized by lock and dam construction on the Upper Mississippi and Missouri Rivers. However, the cost of energy (diesel fuel) also played a role in that this efficiency.

Similarly, in the West Interstate highways and relatively fast rails provided a reliable pathway to ship fresh fruits and vegetables refrigerated or ice packed across the country.

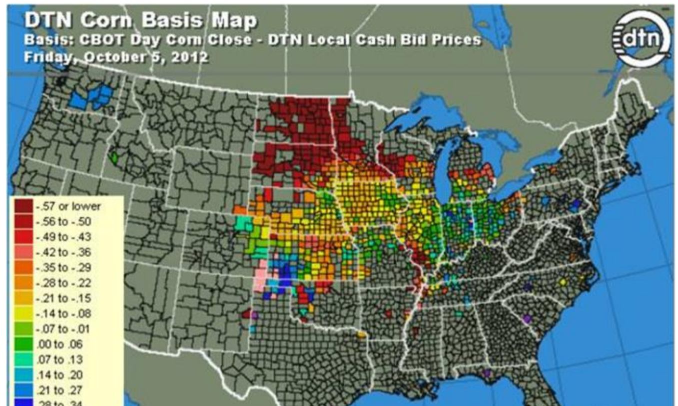


Figure 25 National map of corn basis price (the reduction or increase above the Chicago Board of Trade Price). Note that farmers in the major corn production area get less for their corn than those in consumption areas. The basis price is largely dependent on the transportation cost to ship grain to the consumer.

Transportation energy has often been downplayed because it is usually a small fraction of the total energy involved in the production of food (Heller and Keoleian 2003). Energy for fertilizer production, operational fuel consumption, and for water pumping may all have a greater share of the energy costs. However, since some of these energy input costs are geographically inelastic such as fertilizer, the final transportation costs can make a substantial difference to the net profit of a producer (see Heller Dairy example in Chapter 7).

This was discussed in Wysong et al (1984) for NE vegetable production, but, it also can be illustrated for grains. Figure 25 shows a map of the national corn basis price. Note that farmers in the major corn production area such as Iowa get less for their corn than those in consumption areas. The basis price is largely dependent on the transportation cost to ship grain to the consumer which depends on distance to railhead or barge dock.

Figure 26 presented by McNider shows the difference in profit this basis difference can make for a Midwest rain-fed farmer versus a Southeast irrigating farmer. While the Southeast farmer makes less profit due to irrigation expenses at a constant corn price, when the higher price that the Southeast farmer receives is used, then the Southeast farmer actually makes a greater profit. Thus, in this case transportation energy/costs would make a dramatic difference in maps of corn profit.

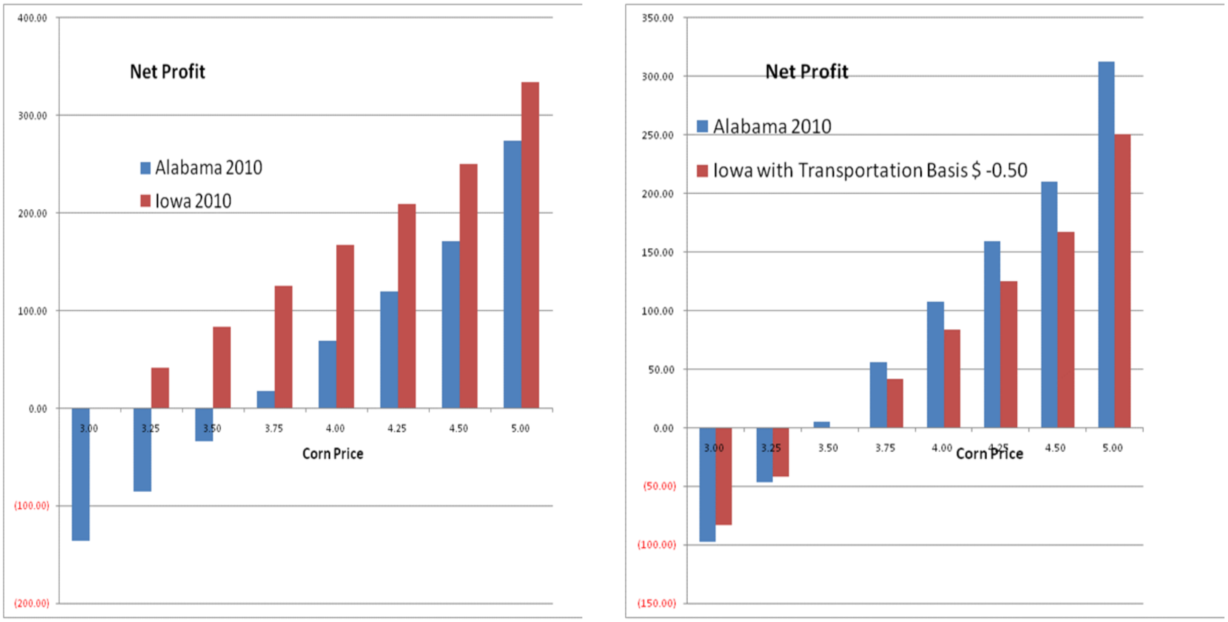


Figure 26 Depiction of net profit for an Alabama irrigating farmer versus arain-fed Iowa farmer. On the left if both the Iowa farmer and Alabama farmer receive the same price then the Iowa farm has a greater profit without the irrigation costs so is more competitive. However, if the difference transportation cost is included then the Alabama farmer becomes more competitive.

6.2 Competition between Energy and Agriculture for Cooling

Hightower presented maps of power plants nationally and where power plants may be vulnerable to changes in water supply (precipitation based flows) or increased demand for water due to energy demand or cooling requirements (figure 27). Water is a critical, often overlooked, component of thermo-electric power generation. Many power plants in the Southeast use closed cycle once through cooling as the means to condense steam. While once-through cooling was once the accepted operating design for thermoelectric plants, in recent years the volume of flow removed from the stream has made once-through cooling the target of environmental regulation because of impacts on aquatic ecosystems. Also, EPA's recent 316b rule on cooling water withdrawal addressing these concerns may have a major impact on use of once through cooling.

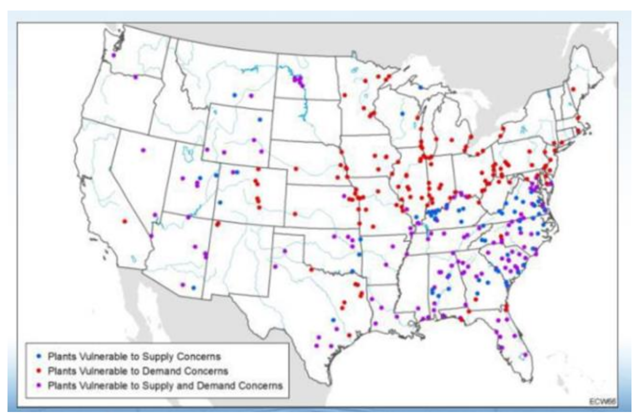


Figure 27 Depiction of power plants vulnerable to supply and demand. Presented by Hightower.

If irrigation is expanded in the East this withdrawn water may be considered as a threat to cooling supply for these plants. Thus, any analysis of water used for irrigation/food production and the timing of its withdrawal would need to include the thermo-electric demand.

There, however, may be some innovative solutions to this problem. As mentioned, once through cooling withdraws a tremendous volume of water from a river and returns the water at a higher temperature. Cooling ponds/closed loop systems would reduce the withdrawal and reuse the cooled water in the thermal plant. However, cooling ponds have to be large and take valuable land. One alternative presented by Cruise is that strings of on-farm reservoirs could be used as cooling ponds (figure 28). This would also avoid the water consumption and energy for closed loop cooling tower systems. The water consumed by the crops in the irrigation would provide the additional benefit of food/fiber production.

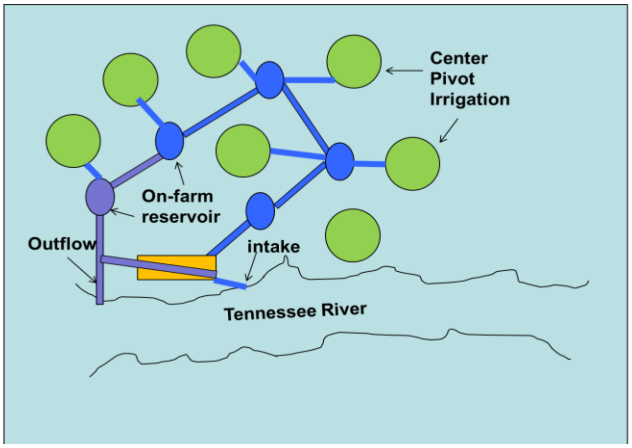


Figure 28 Schematic of on-farm reservoirs as option to once through cooling. Presented by Cruise.

6.3 Hydroelectric Competition with Irrigation Water

Cruise noted that on most of the major river systems in the East there are hydroelectric facilities operated by the Army Corp of Engineers or public utilities. In the SE and other parts of the nation, water used by farmers for irrigation can limit the water available for hydroelectric generation. Thus, one has to evaluate the value of an acre-ft. of water for electric generation compared to the value it gives to food production. Under a current NSF-USDA study initial calculations have made been made of the hydroelectric value of water on the Tennessee River and found that the average wholesale value for power is substantially less than the value this water provides in irrigation. These analyses need to be refined and done for the nation as a whole using the actual variable value of the electricity during peak demand times rather than an average rate. In other parts of the country there is perhaps less competition between hydroelectric production and irrigation. In the Plains states there is little hydroelectric power generation even though large amounts of water are used for irrigation.

6.4 Impact of Midwest Drought on Ethanol Production/Soy Diesel

Several speakers (e.g., Cruise, Evett, etc.) discussed the ethanol issue as related to corn production. As ethanol mandates in gasoline from Congress have come into play ethanol has become a significant factor in gasoline. While debates may continue on its place as a net energy source, it currently has a critical role in gasoline blends in the U.S. It not only serves as energy but perhaps as importantly as the octane booster of choice. As refineries set up their seasonal blends having ethanol available is critical. If the Midwest went through back to back drought or flood/drought at the heart of the corn belt (see above discussion in section 3.3), it could have devastating impacts on having enough ethanol for refinery blends. The abruptness of the impact of drought may not allow enough time to find replacement blends. If so, then food supply would be threatened as corn for food would be diverted to ethanol. Soy diesel is also heavily dependent on the Midwest, but is probably not as critical as ethanol.

6.5 Energy Constraints on Agricultural Production and Transportation

Schramski made a presentation on the large scale uses of energy in the past 500 years ending with the current exponential increase in the last century (figure 29). The point made was that the extraordinary energy that drove the blue (water) and green (fertilizer) development may not be sustainable. This may be especially true if the transportation energy cost that has made the movement of food and grain possible at extremely low rates is not sustainable.

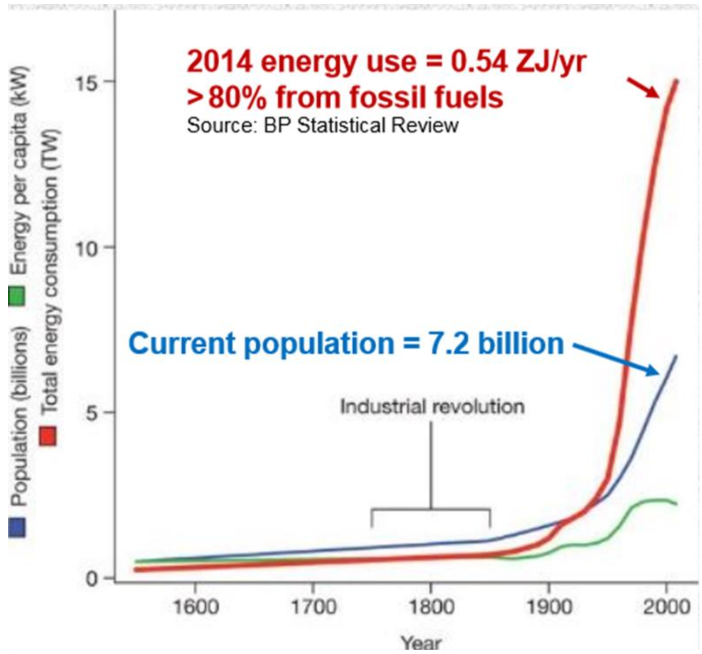


Figure 29 Plot of energy use over time. Presented by Paul Schramski. .Current energy use trends may not be sustainable. Reduction in energy availability may impact transportation, pumping and fertilizer costs which have spurred productivity and defined agricultural geography.

6.6 Energy for water pumping and transfer

Water for irrigation in many areas is tied to energy required for pumping. The geography of available energy may not be in synch with the agricultural water needs. The California State Water Project is the largest single user of energy in the state (CEC 2014) and most of the water is used for irrigation. California, however, is an electricity-deficit state, importing 60k GW-hrs., or 23 percent of consumption (compare with Alabama, for example, which exports 67k GW-hrs., EIA 2014, CEC 2014). Further difficulty comes during droughts as low-cost hydroelectric power is reduced as seen in 2013 production (24.2k GW-hrs.) being 70 percent of the 2003-2012 average (34.5k GW-hrs., CEC 2014) and 2014 will likely finish at about 50 percent of that – a stark water-energy nexus. The electricity deficit in California is demonstrated in that rate-payers incur some of the highest rates in the U.S. ($0.17 kW-hr, vs. less than $0.10 in the Southeast, EIA 2014). Energy for electric irrigation in the Southeast is much more available and cheaper than in parts of the Western U.S. However, as noted above, the production of this energy requires water, and hydro-electric and hydro-thermal withdrawals account for approximately 80% of the total withdrawals in the Southeast. Thus, this potential conflict must be considered.

7. Maps of Geographical Sustainability

It is the hypothesis of this workshop that national maps of agricultural production and environmental metrics that relate to production efficiency, transportation to consumption, available water, and nutrient export can be developed to understand geographical sustainability. Perhaps such maps, can guide private sector investment and public policy to sustain agricultural production, while avoiding some of the oversubscription of water resources, environmental impact and negative societal impacts associated with the change in geography of production in the last century. As an example, suppose that yield per acre of rain-fed corn was a metric. Then the deep water holding soils of the Midwest would show its watersheds having the greatest yields and a high positive metric. Thus, this would validate the market driven migration that concentrated corn in the upper Midwest in the last century. However, if maps of nutrient export by watershed were computed then the Midwest would perhaps show a negative production metric. If transportation distance (or energy) to where corn was consumed were mapped then the Midwest may show up as a negative attribute but for the Southeast, where corn is consumed in the poultry and swine industries, then energy /distance might show up as a positive attribute. Similarly, cotton in California may show positive attributes in terms of yield and quality, but negative attributes in costs for water and fraction of available water consumed. Potatoes may show a high level of yield in the Snake River Valley but might show a negative transportation metric to ship the potatoes for consumption or a negative in terms of the water resource used and future water availability.

7.1 Geographical Metrics

McNider on the last day of the workshop provided a strawman list of the type of metrics that might be useful. It was suggested that the details of the metrics and their development would be part of a research FEW effort on Geographical Sustainability.

Economic Metrics: The first order geographic metrics would be economic maps that relate to yield, cost of production and net profit. In the optimization of California agriculture carried out by investigators at UC Davis (see Medellin-Azuara 2012) , net profit is seen as the metric to be optimized. In some sense this follows the decision making made by the producer to maximize profit for the given costs and available price. In this case comparative maps of production costs of crops in different geographical regions can be developed. Costs which vary across regions such as water costs, transportation costs, energy costs, and labor costs can be included in the net profit. Because of the structure of economic analyses at Land Grant institutions in association with USDA Economic Research Service (ERS), there are generally good cost input data on most major crops. There is also a relatively common structure (Enterprise Budgets) for delivering this information to producers and economists.

Environmental Metrics: As noted above, in the migration of agriculture in the last century there was little attention given to environmental externalities or consideration of the long-term sustainability of a resource such as water with new competing demands. While economic analysis is perhaps easier because of a common unit such as dollars, metrics that can be calculated to provide maps of resource constraints or impacts will not be as uniform. Perhaps, the first example is the water availability map which was provided above (see figure 14). Here, ratios of water demand (anthropogenic uses) to water supply (run-off) are geographically mapped. In the early days of western agriculture, in most of the West this water supply stress index would have been green like the East is today (although volume of water would be much greater in the East). There would have been little irrigation and no competing uses of water by power or for public water supply. However, if there had been the ability to look forward to the current century where supplies have dropped (the 1920's were extraordinarily wet – see figure 4.), populations have increased and irrigation expanded; it might have changed the trajectory of public and private investment.

Figures 30 and 31 show examples of environmental, resource and societal metrics that might be developed.

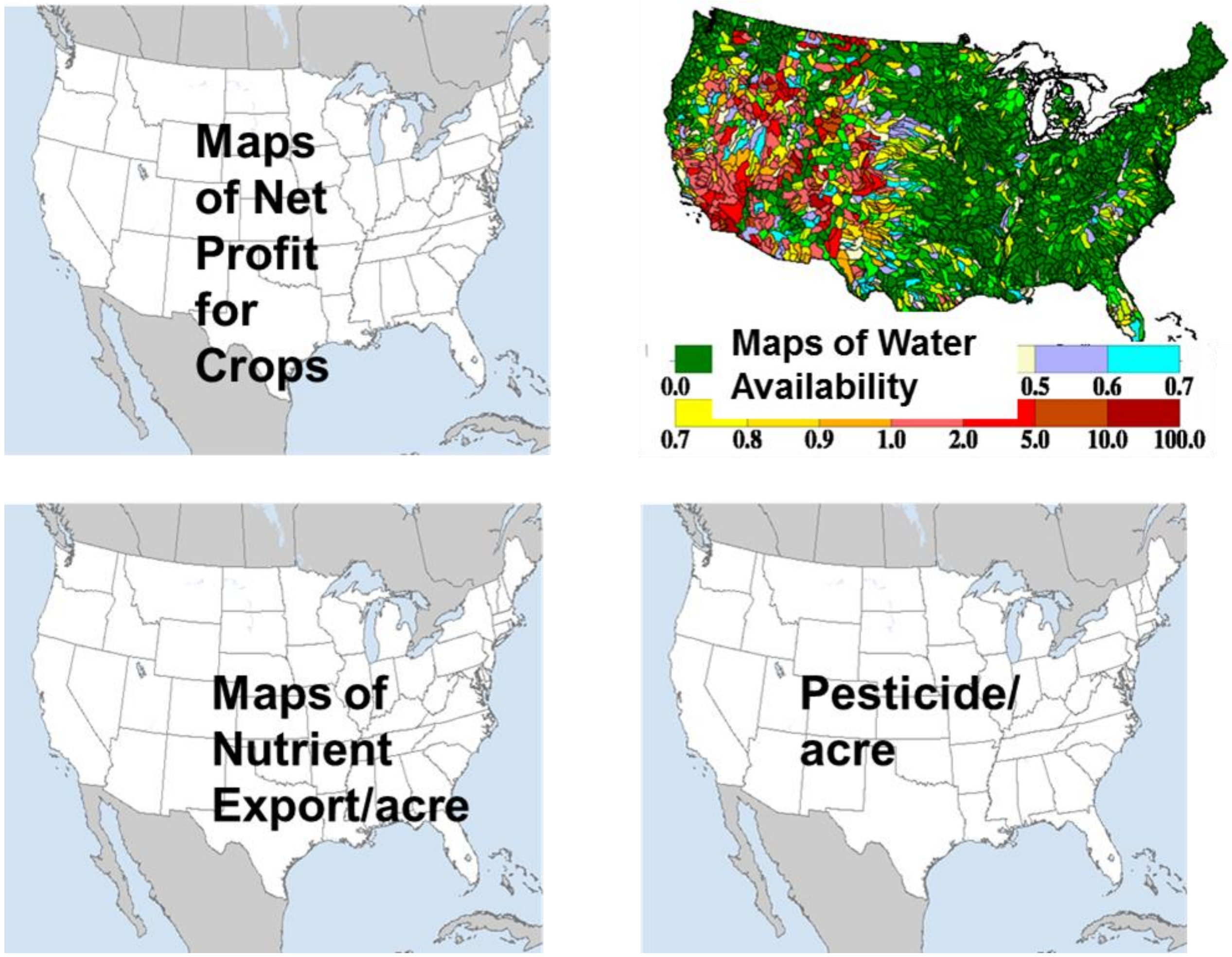


Figure 30 Examples of maps of metrics that might be mapped for geographical sustainability. The image in the top left is a water availability image but illustrates hydrologic basins as a background.

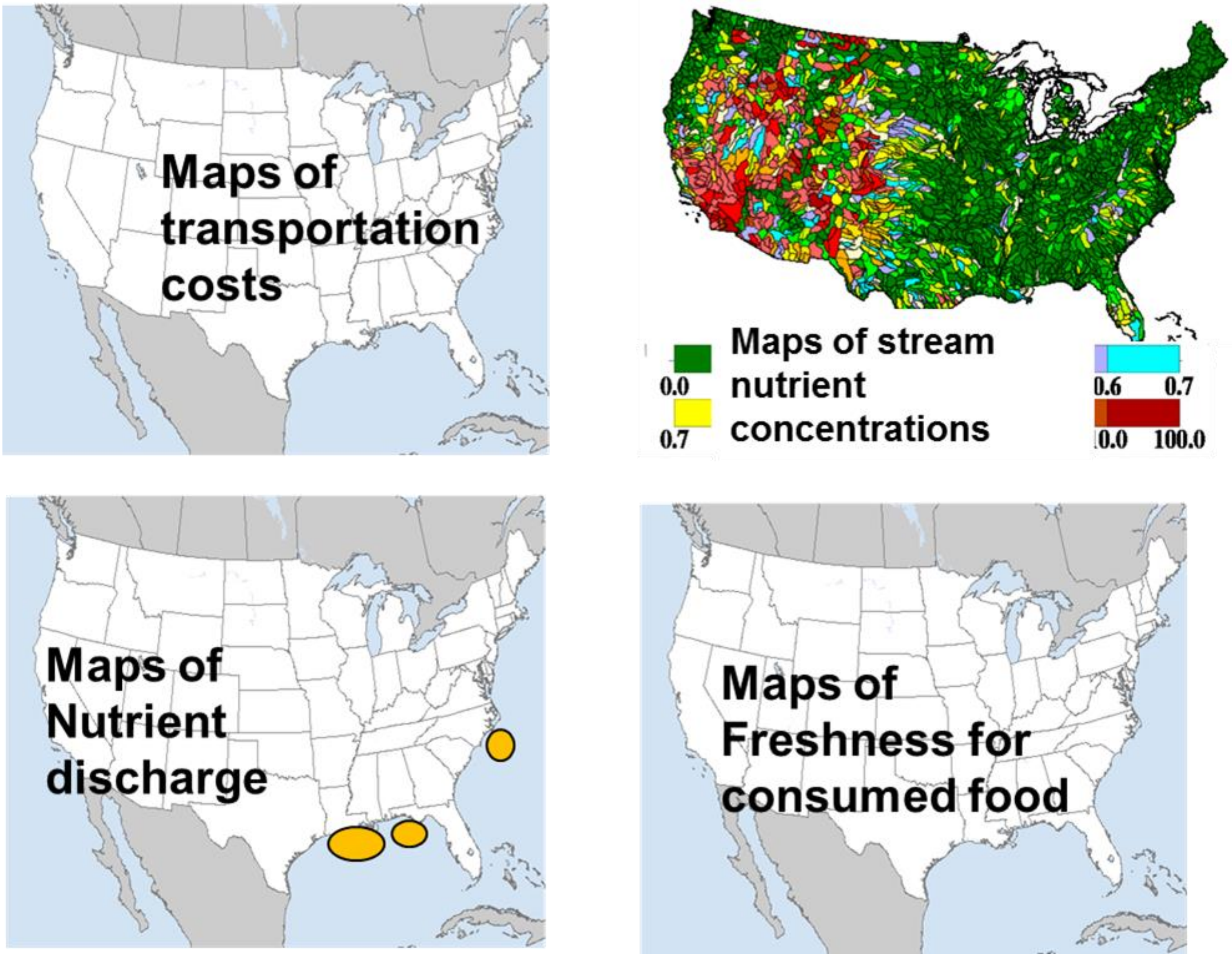


Figure 31 Examples of maps of metrics that might be mapped for geographical sustainability. The image in the top left is a water availability image but illustrates hydrologic basins as a background.

7.2 Tools and Models

Throughout the workshop a talks were provided on tools that might be used to build the metrics and maps discussed above. While maps of metrics can be based on fixed data, models are needed to test systems against changes in environment, energy or water and describe a new system status. For, example future climate change scenarios or paleo-climate scenarios would need to be used in both crop and hydrologic models to examine profit. Models of future energy costs might be included in transportation costs for agricultural products.

Life Cycle Assessment Tools – Example Geographical Location of Dairy Herds. One of the first examples of a system tool for evaluating water/energy/agricultural impacts was provided by Heller with the geographic positioning of dairy herds as the focus. The analysis was evaluated in the context of methodologies of Life Cycle Assessment Tools. Figure 32 sets the question by showing the current distribution of dairies compared to water availability and asks where the trade-off between shipping products and feed compared to local availability of water.

Figure 33 shows the output of the study in which the costs of production are displayed by state. While this analysis is graphical it could be represented as a map display. The example here shows many of the key metrics that must be considered in a geographical sustainability research effort. It begins with economics, computing the geographical costs of pumping water and energy costs to transport grain from different geographic production regions. However, it considers the potential environmental/water resource impact by considering competing uses of water compared to supply.

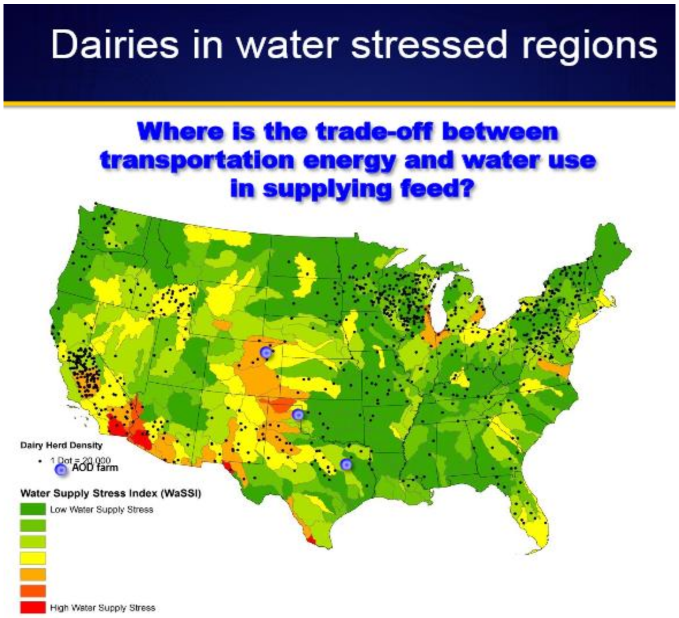


Figure 32 Map showing distribution of dairy herds against a map of water stress (WaSSI see also figure x). Presented by [Heller.](#)

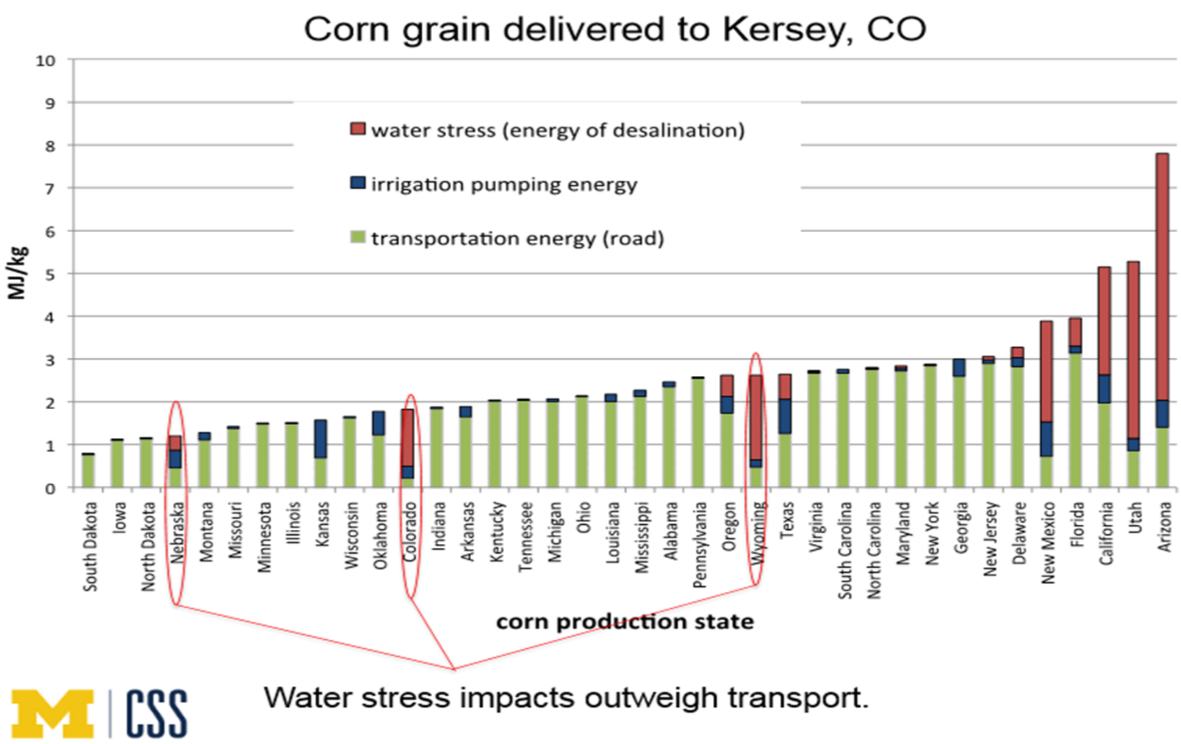


Figure 33 Example of irrigation energy, water stress and transportation costs for shipping grain to dairy herd in Kersey, CO. Presented by [Heller](#).

Coupled Crop and Hydrologic Modeling Tools- Example Irrigation Demand in the Southeast U.S.: Hoogenboom presented a gridded crop modeling system based on the DSSAT suite of crop models that uses weather/climate and soils data to develop geographical variations in yields, irrigation demand and economics. Such tools have been incorporated as part of climate change studies such as AgMIP, so that soils/weather are generally available for analysis. The irrigation component is a key factor in economical geographical sustainability from water costs to energy pumping demands. Irrigation demand depends on the weather, but also the phenological stage of the plant. Thus, the crop model can integrate these two components.

In addition to crop irrigation demand a key environmental factor is whether water is available for irrigation. Hoogenboom presented a system which couples a hydrologic water supply system (WaSSI – Caldwell et al. 2012, Sun et al. 2011) to the irrigation demand from the crop model (McNider et al 2015). This is illustrated in figure 34 which shows the crop model irrigation demand coupled to the hydrologic basins through the NASS Crop Scape Data Layer. The Crop Scape data allows the irrigation demand to be allocated to where specific crops are grown.

The use of coupled crop and hydrologic models are likely to be a core piece of geographical sustainability analyses since they can respond to climate scenarios both in food and yield production, but also in the hydrologic system. Thus, they integrate the economics of crop production to water/energy demands and finally to energy/water competition from thermo-electric, industrial and public water supply demands.

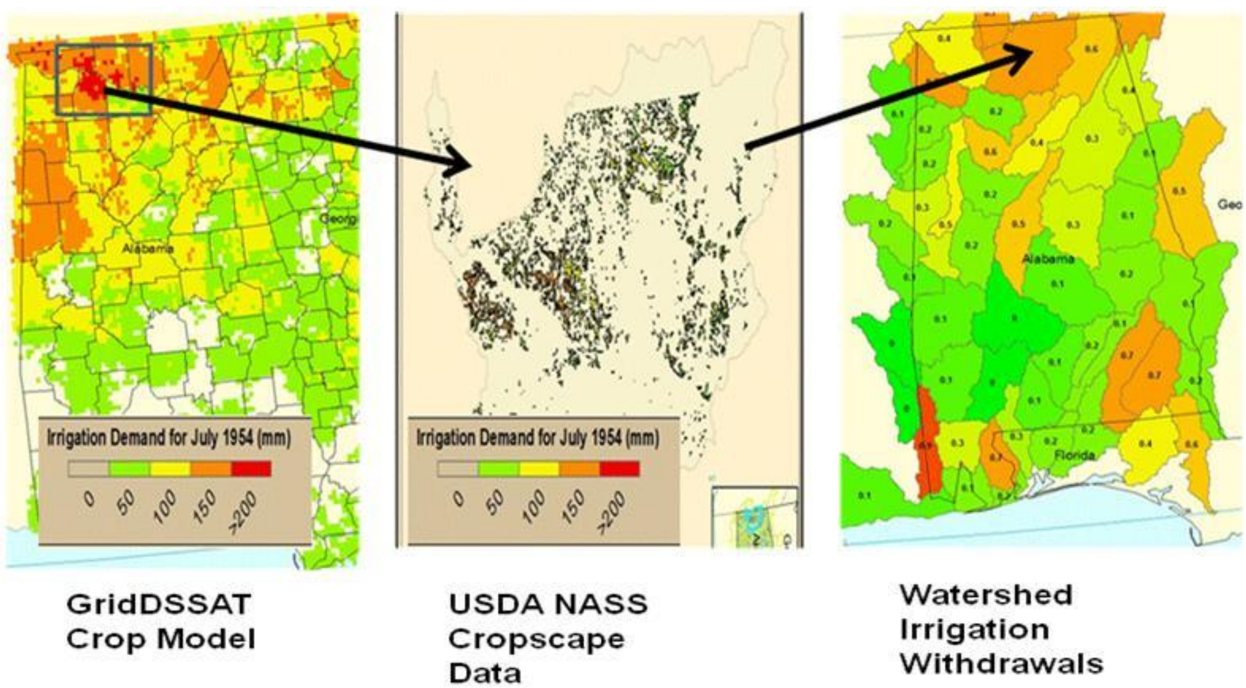


Figure 34 Example of coupling the irrigation demand from a crop model to a watershed hydrologic model. Left shows irrigation demand which is a function of weather and crop needs. Middle shows NASS Crop Data which allows irrigation demand to be applied where crops are grown. Right shows the hydrologic basins from which the water is withdrawn.

Modeling Sustainable Water Withdrawals: In examining geographical sustainability it is critical that ultimate sustainable limits on resource use are defined. In the geographic shift to the west in the last century there was little forethought given to when competing uses of water would oversubscribe the system. Thus, there was no determination ahead of time as to how many acres could be sustainably irrigated. This led to depletion of both surface and ground water sources. A similar situation occurred with nutrient loading in the Midwest. There were no studies ahead of time that foresaw limits that the watershed could take in terms of nutrients. Thus, both in the West and Midwest we are now in a remedial situation.

Srivastiva made a pertinent presentation on this topic of limits to irrigation in the Southeast U.S. As noted above in this section under Environmental Metrics, despite large annual volumes stream flows in the Southeast are drastically reduced in the warm season. Thus, a strategy is to fill on-farm reservoirs when streams have water to give. While water is generally not overly subscribed in the Southeast at the present the question is can limits be set ahead of time on the area that can be irrigated without having deleterious effects on the regions aquatic ecosystems. Srivastava used basin scale hydrologic models and ecological flow characteristics defined for the Apalachicola-Chattahoochee-Flint River system. The results showed that about 10% of the basin might be irrigated and all ecological flow criteria met (figure 35). This was based on 18 inches of withdrawal needed (irrigation plus evaporative loss). There was some discussion that this might be too high an irrigation demand. If so demands of 9-12 inches might yield irrigation limits of 15-20% of the basin (Paudel et al. 2005). But, the important point is that limits on irrigation might be set ahead of time before impairing streams. Minton noted that California in 1956 passed a law that would limit withdrawals so that streams would not be harmed. However, there was not enough specificity to actually curtail withdrawals.

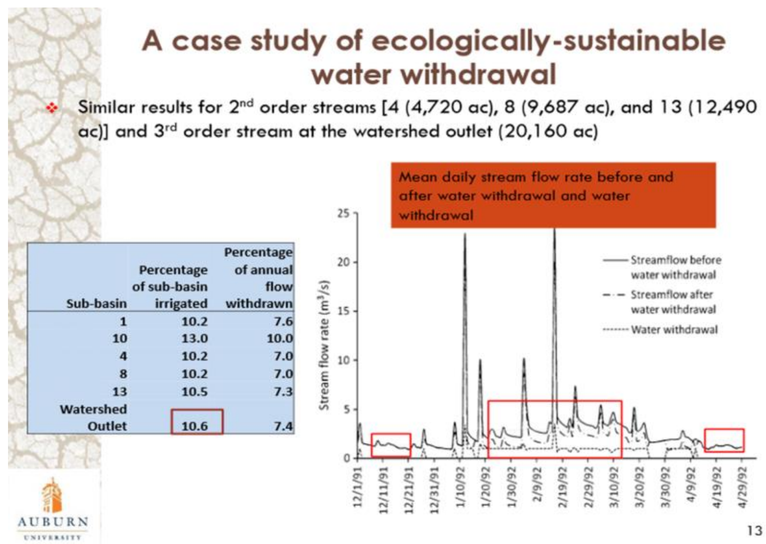


Figure 35 Depiction of analysis to define limits on watershed irrigation that allow environmental flows to be maintained.

Hydrologic/Energy Scenario Models: In the West hydrology and water are governed not only by precipitation but by the amount of manmade storage and transfer. The rule of Prior Appropriation also controls when and where water will be withdrawn. Thus, managing water depends on modeling not only the natural inputs, but also the man-made system. Yates provided examples of the WEAP model which has been used in California and other parts of the West. WEAP has the capability to lay out reservoirs, canals and consumption through which scenarios of allocations can be imposed. Such an ability to move and allocate water is also consistent with the combination hydro-agro tools developed at UC Davis reported by Medellin-Azuara. Yates also described an energy/water model LEAP that can provide water/energy scenario analysis. Of particular interest was a case study looking at the water energy response to a paleo-guided future climate scenario (figure 36). Here both climate change and paleo records were used to define a restrictive water scenario for California. An analysis was provided looking at changes in water transfers, energy use and environmental flows into the Sacramento Delta.

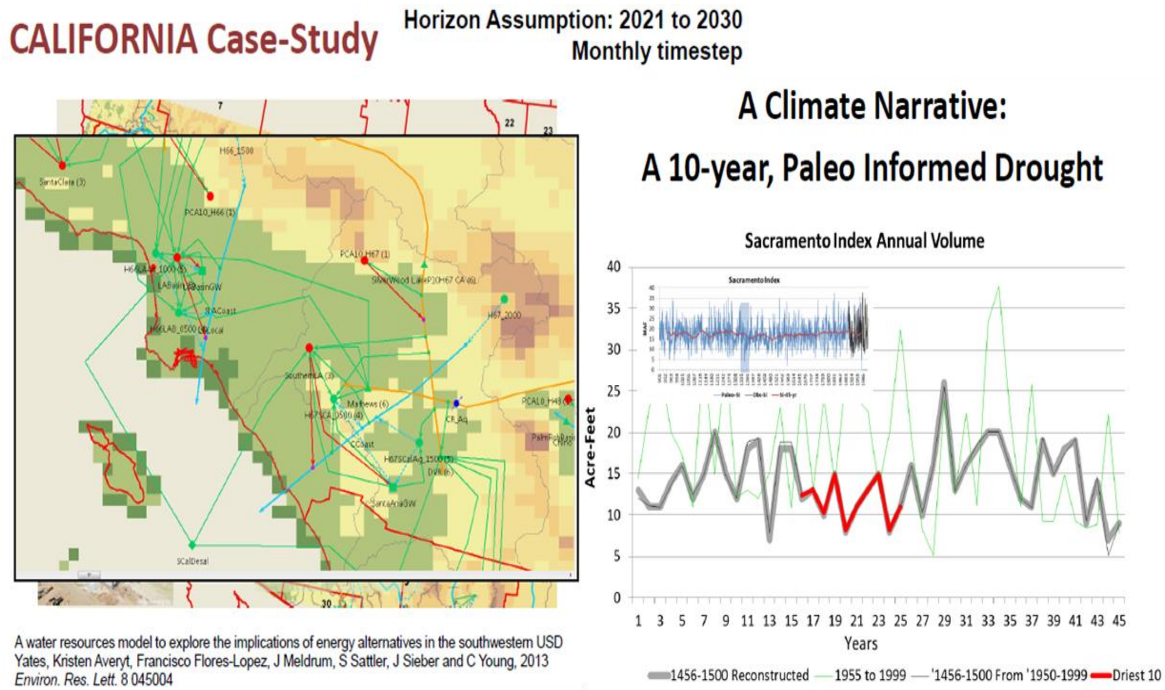


Figure 36 Example of use of WEAP/LEAP planning in a paleo-guided climate scenario in California. Presented by [Yates.](#)

Data Tools: Tools to acquire, filter, process, and visualize data are essential to provide the information needed for scientific analyses and decision makers. Graves presented information on cyberinfrastruture components such as software tools to mine data and automate the gathering of online resources around events using geospatial technologies and multiple visualization approaches. Data tools were discussed among the participants as essential to acquire the data needed to develop derived knowledge or information for decision and policy makers.

The Utility of Geographical Sustainable Information For Policy Makers and the Private Sector: While the concept of planning for geographical sustainability has received high marks in previous reviews and proposals for innovation, there has been a small minority of comments that question how the information might be used. This has generally been followed by the remark that "we don't have a planned agricultural economy and that the government does not tell producers what to grow. What producers decide to grow is a free market decision." Thus, some time at the workshop was devoted to the utility of the information that might be provided to the private sector and to policy makers.

As noted above, the shift in agriculture that occurred in the last century was spurred by government policies and public investment in water infrastructure. The Bureau of Reclamation programs of land grants and low cost water spread agricultural production throughout the West.

The locks and dams on the Mississippi, Ohio, Missouri and Tennessee Rivers allowed grain to be shipped out of the Midwest to the Southeast for consumption and also exported to the world. Little known programs in Farm Bills prohibited farmers in protected commodities from growing vegetables. Thus, it is clear that government programs impact the trajectory of production.

Never-the-less, the comments are on the mark that individual producers select what they grow and they measure the risk involved. It is believed that such risk-reward decisions are best made when good information is available to producers making these decisions. In the last century when Southern agriculture was collapsing, many farmers in the South simply did not have the information to understand that transportation and western irrigation had changed their world. Having farmed for generations and looking at their production costs all they could see was that commodity prices were too low and the weather too bad (especially in the 1950's). Thus, many farmers tried to hang on thinking better prices and good weather would eventually come. In the new world of Midwest grains and irrigated agriculture this simply put Southern rain-fed farmers further in debt and many lost everything.

7.3 Providing Big Picture Information on Water/Energy/Food Production

It is felt that an appropriate role of academia is to provide the best understanding of climate, water, energy and production for the private sector to use in making decisions. Thus, the maps of geographical economics, environmental impacts, energy production/usage, and water availability may provide cues to western producers that their world is changing now (just as Eastern farmer's world changed in the last century). The water that was critical to the success of agriculture in the west may not be available in the future.

For Midwestern farmers the constraints that may be placed on production due to nutrient limitations may increase their costs. Drought losses with perhaps less protection in Farm Bills may endanger their large investments.

Thus, the geographical sustainability products to be produced under an NSF/USDA/DOE Food Energy Water research effort will be the type of information that farmers and agro-business can use in making key investment decisions.

Such information can also be used by policy makers in government to make needed infrastructure investments. As mentioned, the West flourished under the investments made by the Bureau of Reclamation and states. If the U.S. wants to sustain its agricultural production in the coming century, investments may need to be made in Eastern agricultural water infrastructure. The information to be developed under a FEW research effort could determine the economic and environmental sustainability of the creation of such infrastructure.

7.4 Role of the Private Sector

As noted above, while government policy decisions can drive crop and production strategies, many of the individual production decisions are based on a farmers understanding of their own capability factoring in expected costs of production and final product price. While some decisions are year to year, many are long-term such as investing in new farm equipment or irrigation. Agri-businesses play a role by both guiding and responding to changes in long-term trends. At the workshop the private sector was represented by irrigation equipment suppliers (Lindsay and Valley), farm real-estate brokers (National Farm Reality), large agri-business

(Monsanto), and electric utilities (EPRI). Below are several examples of private sector roles in a geographical sustainability/migration initiative.

Private Sector Real-estate Products:

The farm real-estate presenters Walter, Sinatra and Ingram provided a description of a unique platform that might convey the Food/Energy/ Water information to the private sector. National Land Reality has developed a national GIS system that characterizes farm land in terms of soils, agricultural indexing, slopes, water, topography, and other data layers. Figure 37 provides an example of soil data for an area in Mississippi. It was noted that the system is currently being used to locate and move farm production. Examples were provided of old agricultural land in North Carolina that had been converted to forests, but in a recent land transaction the land was converted back to farm land.

It is felt that potential FEW products such as yield, net profit, irrigation demand, energy costs, water availability etc. would be a valuable part of the real-estate data base. These data along with price information would allow real-estate buyers, farmers and agri-businesses to compare the relative value of land for agricultural production. As noted by Taylor, farm land in the Midwest has increased substantially in value because of the high level of grain production found in the deep hydric soils of the region. However, if irrigated grain yields/profit in the Southeast are compared to profits in the Midwest, it may show the better land values are now outside the Midwest. The costs of nutrient reductions could also be factored into this analysis. Likewise comparisons of costs of western cotton/rice production could be compared within the national real-estate data base to equivalent production in other parts of the country.

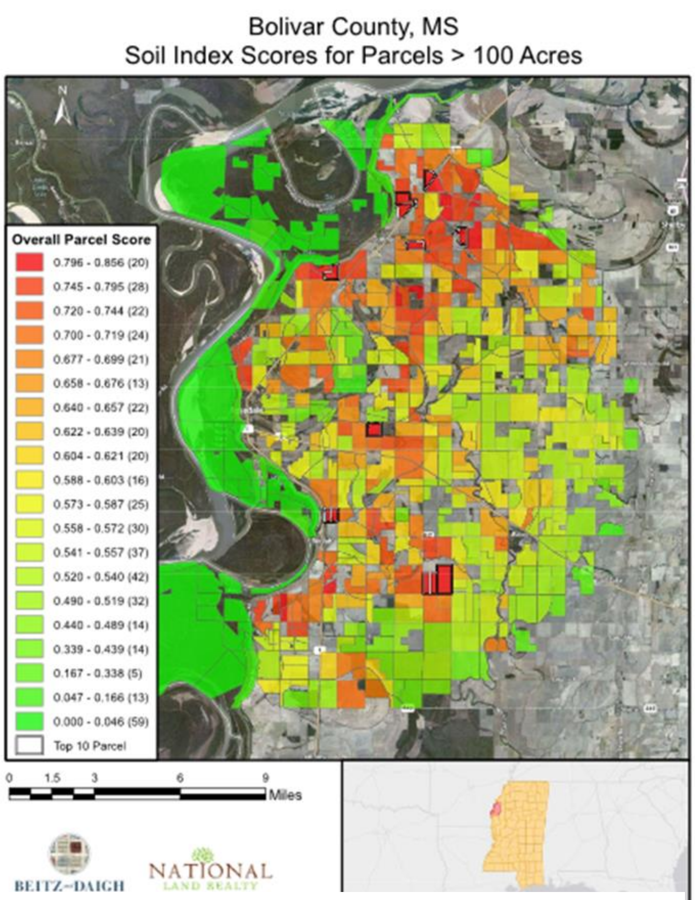


Figure 37 Example of agricultural soil data information in a national GIS real-estate system. Presented by Walter.

Thus, the products that were demonstrated by National Land Reality may be exactly the type of GIS platforms that can convey the economic and water information that producers need to make land and production decisions.

Near the end of the workshop Piccinni (Global Supply Chain Production Sustainability Lead for Monsanto) gave an overview of how a large company might deal with issues such as climate change and other pressures on production. He began by noting that information such as model projections must be vetted and that limitations on models must be understood with a key question being what part of the models can be useful for decision making. For example, "Climate models have yet to replicate and predict variation important to agriculture".

He began by noting that certain projections and outcomes through different models provide consistency and confidence. For example, there seems no doubt that global demand for food and food quality will increase. How can this be handled with some of the pressures outlined at the workshop such as water limits or nutrient loading in the grain belt? He also noted that migration will occur if driven by cost efficiencies.

In terms of developing a resilient system he did note that academia, agricultural extension and federal agencies can provide big picture information to agri-businesses and producers through participation in workshops and planning. There is also a need to understand global markets. New areas of agricultural production are emerging around the globe. Are these going to be competitive to U.S. exports?

Finally, he said that companies like Monsanto will respond to new realities and information and strive to have products in place that will help deal with environmental pressures.

Electric Utilities: Rao of EPRI noted that EPRI was committed to working with NSF on the FEW initiative. Their present priorities are water conservation in the utility sector and energy efficiency, especially the role of systems integration, in achieving these goals. For EPRI scientists and research managers, the following areas are of high importance:

Desalination and Water Reuse: Examples - use of process heat streams for desalination vs reverse osmosis, combined renewable/solar energy and desalination technology;

Integration of water and energy systems, and sensor technologies: Examples - water infrastructure for storage of water and energy, Low-grade energy for wastewater treatment and ;

Water and Energy Use Efficiency and Water Treatment/Reuse: Examples-water/energy efficiency technologies in residential, commercial, agricultural, and industrial sectors.

8. Research Issues/Questions Defined

On the final day of the workshop a session was held to define the overarching questions related to understanding geographical sustainability and its role as a tool in migration of agriculture to maintain production. The following attempts to classify and categorize the major research questions and sub-questions.

The Boulder FEW Workshop was built around three overarching questions.

1. **Should the geographical positioning of agriculture be considered as a path to sustain agricultural production in the U.S.?** This would be an additional path for coping with climate, water, energy and environmental pressures on agricultural production. Previously discussed paths have been conservation, genetics (drought and salt tolerant cultivars) and additional water infrastructure (storage and transfer).
2. **How can geographical sustainability be defined; that is what metrics need to be considered?** Example economic metrics might be yield, profit, etc. Environmental

metrics might be water availability, nutrient export, etc. Societal metrics might be rural poverty, unemployment etc.

3. **Of what use would be the geographical information to policy makers and the private sector?**

These general questions were part of the program and presentations made. **Given, the interest and response to the workshop and the discussions at the workshop there is a consensus among the participants that consideration of understanding of geographical sustainability is a worthwhile goal of NSF's FEW Initiative.**

In addition to these overarching questions there was consideration of sub-questions that need to be answered to address geographical sustainability. The following lists and discusses these questions.

8.1 Economics

What are the economic metrics to be produced? Examples discussed at the workshop included profit, yield, gross production (e.g. Gross Agricultural Impact including costs of production and economic multipliers). These should perhaps be decided based on proposals to the FEW program.

How can agro-economic analyses be constructed that demonstrate competitiveness of agricultural systems in the Southeast with the West and world? While the emphasis and details of geographic assessment must be made at the national and regional level, it is imperative that global agricultural production be included at least through boundary conditions that impact supply, demand and price.

Do we need to focus on national or regional economics or both?

What is the integrated balance between food, fiber, feed and fuel?

8.2 Environmental

While one goal of migration might be reduced nutrient loading on the upper Mississippi are there other issues with nutrient loading in other locations?
What are the differences in the nutrient transport processes/systems in Midwest and Southeast?

While decreased loading may reduce hypoxia in the one part of the Gulf of Mexico, will additional loading in other river systems create similar problems in other marine/coastal zones?

Can we evaluate the limits of irrigated agriculture in the face of other demands, so we don't over subscribe the system?

What are the sustainability boundaries or ecological limits of various hydrological alterations?

How can we avoid the silo approach in the West and more effectively get agricultural and environmental interests engaged to ensure sustainable agricultural and ecological systems?

How can we create maps on smaller watersheds to see how irrigation increases ET for the entire region?

8.3 Climate

The current western drought and the Midwest 2012 drought exposes the geographical vulnerability of the present production system. Can future climate scenarios be developed to test future geographies? As discussed at the workshop this will likely require blending of climate change and paleo-climate scenarios to examine future resilience.

What is the role of changing extremes in adaptation and the benefits and limits of equilibrium based approaches? This is an important question in that while movement of agricultural production to the Southeast may reduce pressures on water in the West, it may open up vulnerability to other parts of the climate system such as hurricanes, floods and storms.

What other approaches can we develop that account for volatility in a system? Climate will not be the only stressor.

8.4 Energy

Is migration sustainable given energy demands? The current geography of energy for water and agriculture has evolved over the last 50 years. Will a new geography of agricultural production be compatible with the existing geography of energy availability?

One of the goals is to make agriculture energy self-sufficient. Is this an issue that should be part of the FEW program in geographical sustainability?

What impact will migration have on CO2 emissions or other greenhouse gases such as methane?

Will conversion of forest lands back to agricultural lands in the East impact strategies for carbon sequestration?

What impact will energy pricing have on migration scenarios? As noted worldwide energy use has grown exponentially. Can the relatively low prices for pumping and transportation which supported the current geography be maintained in the future against the backdrop of increased energy requirements?

Most ethanol/biofuel plants are in the upper Midwest. Would a more distributed system of production of grains require a new geography of biofuel facilities?

Would a more distributed grain production help ameliorate competition between food and energy for fuel stocks?

What will be the competitiveness of nutritious food production within the migration concept?

8.5 Societal

What is the uniformity of impact among the populace of the increase in GDP associated with migration of agricultural production? That is, even if agricultural production is maintained, of what economic value is this to local populations? Will only a few profit and others be negatively impacted by the associated negative impact of agricultural production?

How can those areas which may lose agricultural production be protected?

What changes in water policy framework are needed to provide incentives for further migration?

What is the importance of crop and water insurance, intermittent regulations, and financial services to make migration work?

What are the diets of the future? This is important. It is not only climate that changes but also the type foods. In the last century diets in the U.S. changed dramatically to a higher meat and prime cut diet. Will the world follow this path or will the U.S. return to a greater grain/vegetable diet?

What is the potential for urban agriculture to address food security? At the present there are the beginnings of a buy local movement – will this persist or is it a fad?

What is the influence of the rural to urban interface on food supply, and water and energy footprints to transport food to consumers?

8.6 Programmatic

How can a FEW Program coordinate and foster the disparate pieces of the overall long-range goal of developing information to guide geographic production?

How can we craft collaborative data frameworks between remote sensing and management for information services to support adaptation in a changing environment?

How can Earth System models and integrated system models be effectively applied to study the FEW nexus?

How can we determine the optimal methods to use for life cycle analysis to analyze tradeoffs? Heller made a compelling presentation that life cycle tools and analyses may be key to carrying out geographic sustainability analyses.

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10. Appendix

A.1 Workshop on Migration of Agriculture as One Path to Sustainability

AGENDA

<u>Wednesday, October 21 - Foothills Lab 2 - Room 1022</u>

1:45 PM **Welcome and Format**: Maury Estes, University of Alabama in Huntsville

Begin Overview Talks: Moderator: Maury Estes, University of Alabama in Huntsville

2:00 PM **Overview of Migration as a Path to Sustainability**: Dick McNider, University of Alabama in Huntsville

2:30 PM **Data Needs**: Sara Graves, University of Alabama in Huntsville

2:35 PM **Agricultural Perspective on Migration**: Jim Jones, University of Florida

2:55 PM **Climate Perspective, Instrumental and Models**: John Christy, University of Alabama in Huntsville

3:15 PM **Paleo Climate Perspective**: Glenn Tootle, University of Alabama

3:35 PM **Climate/Food Security/Nutrition Threats to Agriculture**: Molly Brown, University of Maryland

3:55 PM **Break**

4:15 PM **Energy, Water Perspective**: Mike Hightower, DOE Sandia Laboratories

4:35 PM **Overview of Current Drought, Climate Change and Agriculture in California/West**: Amrith Gunasekara, California Dept. of Agriculture

4:55 PM **Response of California Agriculture to Water Reductions**: Josue Medellin-Azuara, University of California - Davis

5:15 PM **Water Resources, East and West**: Jim Cruise, University of Alabama in Huntsville

5:35 PM **Environmental Concerns/Limits on Withdrawal**: Puneet Srivastava-Auburn University

5:55 PM **Adjourn**

Dinner on Your Own

<u>Thursday, October 22 - Foothills Lab 2 - Room 1022</u>

7:45 AM Continental Breakfast

Continue Overview Talks: Moderator: Dick McNider

8:30 AM **Western Water and Climate – Threats to Western Water Availability**: Brad Udall-Colorado State University

8:50 AM **Recent Trends/Challenges in Irrigated Agriculture**: Steve Evett, USDA ARS

9:10 AM **Geographic Example Energy –Water –Transportation – Grains/Dairy**: Martin Heller, University of Michigan

9:30 AM **Drought and Nutrient Export Challenges to Midwest Grain Production**: Elwynn Taylor/Ray Arritt, Iowa State University

9:50 AM **Land, Agricultural and Energy Barriers/Opportunities to Increased Production in the East**: William Batchelor, Auburn University

10:30 AM **Break**

10:10 AM **Legal Barriers to Transparent Water Markets in the West and Access to Surface Water in the East**: Ray Huffaker, University of Florida

Liz Kramer University of Georgia (10 minutes)

BEGIN SERIES OF FOCUS DISCUSSIONS

The purpose of this session is to have discussions on issues that are reasons for examining migration of agriculture and to barriers to migration with attention given to water, energy and food. Each issue will be allocated 30 minutes. If some topics finish earlier, this will leave additional time for other topics. There will be a panel of lead discussants. Here a few selective slides may be used by the panel lead discussants. But all the audience will be included in the discussion of the topic as time allows.

Panel Discussion Moderators: Dick McNider, Jim Jones and John Christy

10:50 AM **Climate and Agricultural Vulnerability of the West to Drought – what are likely consequences if drought persists or deepens**: Amirth Gunasekara, California Dept. of Agriculture; Nancy Cavallaro, USDA-NIFA; John Christy, University of Alabama in Huntsville; Josue Medellin-Azuara, University of California – Davis; Glenn Tootle, University of Alabama; Tom Hopson, NCAR

11:20 AM **Environmental Issues Related To Migration from West (potential reduced pressure in West, potential increased pressure in East)**: Jonas Minton, Conservation and Policy League; Mitch Reid, Alabama Rivers Alliance; Puneet Srivastava, Auburn University; K.C. Das, University of Georgia

11:50 AM **Environmental/Climate Issues Related To Grain Migration from Midwest to East (potential decreased pressure in Midwest increased pressure in East)**: Elwynn Taylor, Iowa State University; Ray Arritt, Iowa State University; Lee Ellenburg, University of Alabama in Huntsville; William Batchelor, Auburn University; Tom Hopson, NCAR

12:20 PM **Lunch**

Panel Discussions Continue – Moderators: Jim Jones, John Christy and Dick McNider

1:20 PM **Water Resource Availability – East, High Plains, Central, And West**: Puneet Srivastava, Auburn University; Steve Evett, USDA; Don Anderson, Bureau of Reclamation, Jonas Minton, Conservation and Policy League

1:50 PM **Legal Issues for Water Markets in West and Access to Surface Water in the East**: Ray Huffaker-University of Florida; Mitch Reid, Alabama Rivers Alliance; Mitt Walker, Alabama Farm Bureau; Brad Udall, Colorado State University

2:20 PM **Energy Issues – Water Competition-Transportation**: Michael Hightower-DOE Sandia; Nalini Rao, EPRI; John Schramski, University of Georgia; Martin Heller, University of Michigan

3:00 PM **Break (Change room to 1001)**

3:20 PM **Water Infrastructure Needs – East and West**: John Christy, University of Alabama in Huntsville; Yolanda Smith, Bureau of Reclamation; Don Anderson, Bureau of Reclamation; Bill Taylor, Bureau of Reclamation, James Cruise, University of Alabama in Huntsville

3:50 PM **Agricultural Issues – Production, Distribution and Processing**: Sergio Alverez, Florida Dept. of Agriculture; Glen Zorn, Alabama Dept. of Agriculture; Amrith Gunasekara, California Dept. Agriculture; Giovanni Piccinni, Monsanto

4:20 PM **Agricultural Issues – Economics, Disease, Pest, Fungus, And Eastern Broccoli Project**: Giovanni Piccinni, Monsanto; Bill Taylor, Bureau of Reclamation; Molly Brown, University of Maryland

4:50 PM **Agricultural Issues – Land Availability in the East, Nut Crops**: Jason Walter, National Land LLC; Jerry Ingram, National Land LLC; Bill Batchelor, Auburn University

5:20 PM **Pressures on Irrigation in the High Plains -West/Impediments to Expansion of Irrigation in the East**: Steve Evett, USDA; Jake LaRue, Valmont; Steve Melvin, Lindsay Corp

5:55 PM **Adjourn**

7:00 PM Group Dinner at Brew Pub

Boulder Beer Brewery & Pub
2880 Wilderness Place
Boulder CO 80301
(303) 444 - 8448
http://boulderbeer.com/contact/

Friday, October 23 - Foothills Lab 2 - 1022

7:45 AM **Continental Breakfast**

Overview Talks: Moderator: Maury Estes

8:30 AM **Opening Comments**: Dick McNider, University of Alabama in Huntsville

8:45 AM **Crop Models as a Tool to Evaluate Yields, Profit, and Nutrient Export**: Gerrit Hoogenboom, Washington State University

9:00 AM **Hydrologic Models as Tools to Assess and Optimize Use of Water Resources**: David Yates, NCAR

9:15 AM **Tools for Prescribing Climate/Weather in Crop/Hydro/Environmental Models**: Tom Hopson, NCAR

9:30 AM **Data and Cyberinfrastruture to Support Sustainability**: Sara Graves, University of Alabama in Huntsville

Open General Discussions: This is the time to formulate White Paper to impact the NSF – Food Energy Water Program

Moderators: Dick McNider and Jim Jones

9:45 AM **Is Agricultural Migration a Path That Should Be Further Explored to Sustain University Agricultural Production?**

Overview of Discussions: Major Pros, Cons and Issues: Giovanni Piccinni, Monsanto,

Threats to Production? Merits? Concerns?

Will it happen anyway due to resource and economic pressures?

10:15 AM **Break**

10:30 AM **Continue Open Discussions**

What are the major research questions?

What are the social and economic impacts of migration?

What is the uniformity among the populace of the increase in GDP associated with migration of AG production?

Is it sustainable given climate change in Paleo records?

Climate change effect on water?

Is it sustainable given energy demands?

Is it sustainable given marine ecological impacts?

What practices and technologies are needed to create sustainability?

Can we develop empirical evidence on the success of practices and technologies?

What are the differences in the nutrient transport processes/systems in MW and SE?

What is the role of changing extremes in adaptation and the benefits and limits of equilibrium based approaches?

How can we craft collaborative frameworks between remote sensing and Management for information services to support adaptation in a changing environment?

What is an appropriate framework for assessing if we are effectively evaluating desirable outcomes?

Can we develop Agro-economic analyses that demonstrate competitiveness of AG? Systems in the SE with the West and world?

Do we need to focus on national or regional economics or both?

What is the impact of migration on sustainable water mgmt. in the SE?

Water quality and quantity (consumptive use) focus

What impact will migration have on CO2 emissions?

What impact will energy pricing have on migration scenarios?

What is the integrated balance between food, fiber, and fuel?

Biofuels important

What will be the competitiveness of nutritious food production within the migration concept?

How do we determine what is the next weak link after unknown water supply?

What is the optimal geographic distribution of food production?

What is an appropriate dynamic economic analysis that addresses the nexus of FEW on a national scale considering multiple objectives?

What other approaches can we develop that account for volatility in a system?

What changes in water policy framework to make the migration happen?

What is the importance of crop and water insurance, intermittent regulations, and financial services to make migration work?

Can we evaluate the limits of irrigated AG in the face of other demands, so we don't over subscribe the system?

What are the sustainability boundaries or ecological limits of various hydrological alterations?

What are the voids in knowledge or data that need to be fulfilled to move forward?

How can we create maps on smaller watersheds to see how irrigation increases ET for the entire region?

What are the opportunities in the entire AG production cycle to reduce energy use and accompanying CO2 generation and what incentives could be made available from other section such as energy and climate fighting to subsidize those extraordinary energy saving methods?

What is the optimal geographic distribution of food resources?

How can Earth System models and integrated system models be effectively applied to study the FEW nexus?

What are the likely impacts on the global food and trade system on migration of AG within US?

Would production more likely be exported?

<u>Where are the Opportunities (Low Hanging Fruit)?</u>

How can we use existing models to explore migration impacts to the SE as a case study?

What kind of first order screening analysis can we do with existing models? (food processing, which crops)

What is the potential for urban Ag to address food security?

How can we model the effectiveness of interventions of alternative varieties of drought tolerant crops?

What are the diets of the future?

How do we gather empirical data and information on other migrations?

(Do a lit review of options, alternatives, and solutions that have been done. (historical migrations, current trends, etc.)

<u>What are the tradeoffs in the Food, Energy, and Water nexus?</u>

What are the impacts to water supply for energy, hydropower in particular, water intake for energy use, and impacts of water quality from discharges?

Determine methods to use life cycle analysis to analyze tradeoffs?

What is the influence of the rural to urban interface on food supply, water and energy footprints to transport food to consumers?

11:45 AM **Framework for Developing White Paper** – Maury Estes

Process to develop the final workshop report

October 26 - 30: Organize notes and presentation materials from the workshop

November 1 - 5: Prepare a rough draft for review by Organizing Committee

November 9 - 17: Revise rough draft and request comments from workshop participants

November 18 - 25: Period for comments from workshop participants on draft 1

December 1 - 8: Integrate comments from participants

December 9: Send draft 2 to workshop Organizing Committee for review

December 10 - 15: Review period for organizing committee members

December 16 - 20: Integrate final comments from the organizing committee

December 21: Submit to NSF

January 2016: Submit final report to BAMS, EOS or other appropriate publication source

Strawman Outline for Final Report

Migration of Agriculture Concept

Incentives

Barriers

Tradeoff in the nexus of food, energy, and water

Research challenges in the FEW nexus

Recommendations (include discussion of opportunities)

References

12:00 PM **Adjourn**

A.2 Workshop Presentations

http://www.nsstc.uah.edu/users/maury.estes/Presentations_Share/

User: workshop
Password: The4tie7

A.3 List of Workshop Attendees

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