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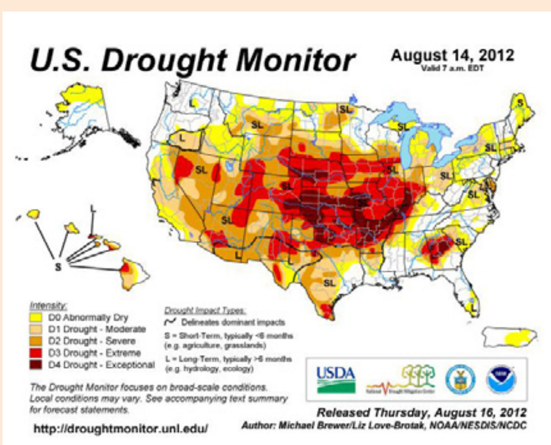
What Happens When the Well Goes Dry? And Other Agricultural Disasters

Dave Shideler, Guest Editor

JEL codes: Q18, Q54
Key Words: Disaster Response, Drought, Economic Impact, Water Availability

According to the U.S. Drought Monitor (Figure 1), as of August 14, 2012, 62% of the contiguous United States was experiencing some form of drought, more than one third of which was classified as extreme or exceptional. Most of the extreme or exceptional drought is located in America's breadbasket: Oklahoma, Kansas, Nebraska, Iowa, Missouri, Arkansas, Illinois, Kentucky and Indiana. Georgia is also experiencing vast areas of exceptional drought. These conditions directly affect agriculture with the combination of above average temperatures and below average precipitation making it difficult to cultivate and sustain crops and graze livestock. The short-run results are crop failure for farmers and increased feed costs and reduced weight gain for ranchers.

Figure 1: Estimated Drought Monitor Conditions from U.S. Drought Monitor, August 14, 2012



Articles in this Theme:

The 2010 and 2011 Arkansas Drought Experience

Agricultural Impacts of Texas's Driest Year on Record

Damages to Louisiana Agriculture from Natural Disasters

Drought Issues in Semi-arid and Arid Environments

Drought-induced shortages of corn will likely drive up food costs in the not so distant future. Additional longer-term impacts from the drought include:

- increased reforestation costs due to lost saplings, wildfire, and vulnerability to disease and pests;
- reduced productivity of pastures to produce hay;
- decreased livestock births and thus slower herd growth;
- and increased transportation costs on navigable waterways due to increased dredging and reduced barge capacity.

Add to these the compounding effects from multiyear drought conditions, as in Oklahoma, Arkansas and Texas, and the impacts are likely to be more severe.

Given these geographically far-reaching and enduring impacts, it is critical that policymakers, business owners, farmers and ranchers, and others understand the nature and magnitude of the drought impacts and know how to respond to them. These four articles provide such background and guidance. Two of the articles showcase the breadth of damage the 2011 drought had on Arkansas and Texas. The third article describes one response system used in Louisiana to assess the damage caused by natural disasters like drought. The final article presents mitigation strategies for addressing drought and longer-term water availability issues.

Watkins shares with us the experience of Arkansas agriculture's struggle during last year's drought. In addition to outlining the immediate impacts to crops and livestock, Watkins describes the longer-term impacts associated with drought, such as the reforestation costs incurred due to lost saplings, increased disease vulnerability, and wildfire. Anderson, Welch and Robinson provide quantitative estimates for Texas of many of the impacts Watkins describes; in their article, they describe how the $7.62 billion estimate of drought-related damages to Texas agriculture are calculated.

A common issue in generating drought, or more broadly disaster, estimates is gathering the data. Guidry and Pruitt present a system developed by the Louisiana State University Agricultural Center (LSU AgCenter). The LSU AgCenter method involves surveying personnel at the parish (county) level immediately following the disaster to establish an initial estimate, and then following up with the same staff using a more detailed survey several months later to generate a second estimate. This procedure enables quick estimation of disaster impacts, while ensuring data integrity, and the system serves as a model for other states.

This issue concludes with an overview of water-related mitigation and adaptation strategies presented by Schwabe and Connor. Since drought is beyond the control of decision makers, the logical question is: what can be done to mitigate or adapt to drought conditions? Schwabe and Connor discuss strategies that have been adopted throughout the world to address water scarcity issues in semi-arid and arid regions, such as Australia and California. Though the strategies discussed in this article are long-term solutions, the increasing probability of drought conditions across the U.S. due to increasing climate variability should cause decision makers to think beyond the immediate crisis.

For More Information

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The 2010 and 2011 Arkansas Drought Experience

K. Bradley Watkins

JJEL Classification codes: Q1 R1
Keywords: Arkansas, Cattle, Drought, Forest, Hay, Impacts, Irrigation, Precipitation, Replacement Heifers, Row Crops, Trees

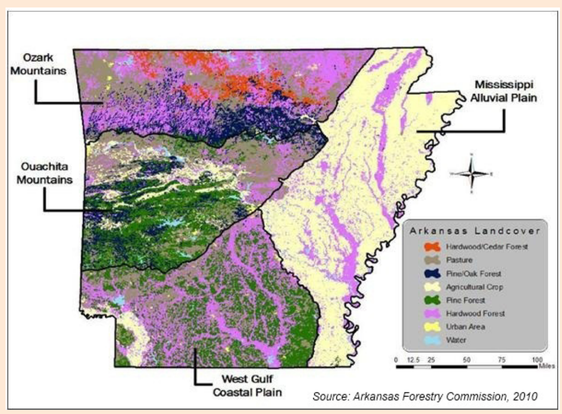
Arkansas, like most of the southern United States, experienced drought conditions in 2010 and 2011. Drought conditions developed in 2010 after a record wet 2009, and extreme summer temperatures prevailed throughout most of Arkansas that year. According to the National Oceanic and Atmospheric Administration, (NOAA) the largest 2010 precipitation deficits occurred in southern Arkansas, with departures from normal precipitation ranging from -17.85 inches in southwest Arkansas to -20.51 inches in southeast Arkansas (NOAA, 2010). Large precipitation deficits were also recorded in other parts of the state (-8.6 inches in western Arkansas; -13.96 inches in northeast Arkansas; -14.14 inches in central Arkansas) (NOAA, 2010). In 2011, record high temperatures and drought conditions continued in both the western and southern portions of the state, with precipitation deficits ranging from -15.3 inches in the south central portion of the state to -18.96 inches in the southwestern portion of the state (NOAA, 2011). The remainder of the state saw extreme flooding in late April and early May and for the most part had a precipitation surplus in 2011 (NOAA, 2011). This article reports on the impacts of the two drought years on Arkansas which has larger regional implications and considerations. Focus is placed on the areas of the state most affected by lack of precipitation and extreme high temperatures. Specifically, the paper highlights drought impacts on

- Trees;
- Cattle and hay production; and
- Row crop production

Arkansas Land Cover by Eco-Region

Basic knowledge of the typography and land use across Arkansas is important when describing drought impacts for the state. Eco-regions and land cover information for Arkansas is presented in Figure 1 (Arkansas Forestry Commission, 2010). Row crop production occurs primarily in the eastern part of the state depicted as the Mississippi Alluvial Plain in Figure 1.

Figure 1: Arkansas Eco-Regions



This portion of the state is flatter than other regions and accounts for nearly all of the state's harvested rice, soybean, cotton, corn, wheat, and sorghum acres (USDA, NASS, 2012a). The southern portion of Arkansas is rolling in topography and is composed primarily of pine and hardwood forest with some crop and pasture land located in the southwest corner of the state. This region is depicted as the West Gulf Coastal Plain which accounts for over 20% of the state's beef cattle production (USDA, NASS, 2012a) and the majority of the state's commercial timberland area (Arkansas Forestry Commission, 2010). The northern and western portions of the state (depicted as the Ozark Mountains and the Ouachita Mountains) are composed of ridges, hills, and valleys covered by a variety of forest types (pine, hardwood, oak, cedar) and pasture land. These regions collectively account for approximately 65% of the state's beef cattle (USDA, NASS, 2012a).

Arkansas Drought Intensity, 2010 and 2011

Drought severity across Arkansas during 2010 and 2011 is presented using U.S. Drought Monitor data in Figure 2 (National Drought Mitigation Center, 2012).

Drought severity is presented for two points in time, October 26, 2010 and November 1, 2011, roughly one year apart. Drought conditions ranged from severe to extreme in eastern and southern Arkansas during 2010, while drought conditions were extreme to exceptional in southwest Arkansas during 2011. In both years, the majority of the state was under moderate to extreme drought. It is evident from the data reported in Figure 2 that drought effects were most acute in the southern portion of the state, where drought effects ranged from severe to extreme during both years.

Figure 2: U.S Drought Monitor Data for Arkansas, October 26, 2010 and November 1, 2011

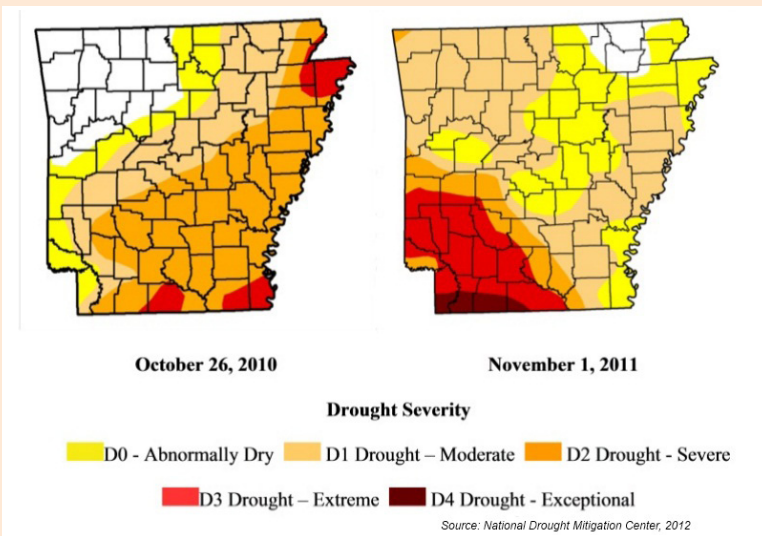


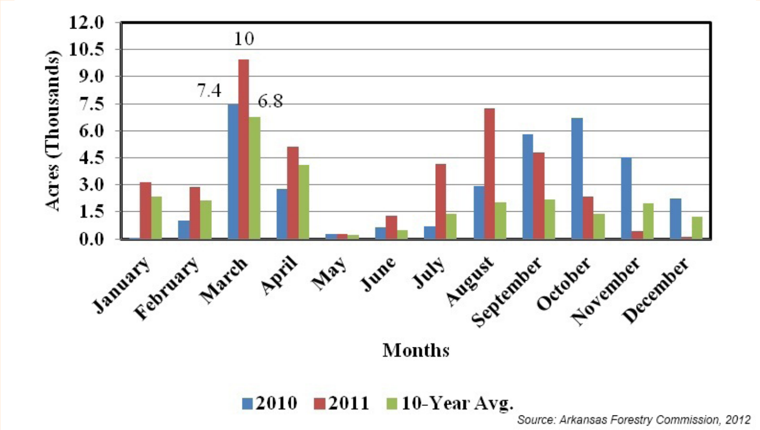
Figure 3: Forest Acres Affected by Wildfires in Arkansas, 2002 - 2011

Drought Impacts on Trees and Forestry Industry Costs

The areas of the state most severely affected by drought during 2010 and 2011 are heavily forested and have a large commercial timberland presence. Prolonged drought impacts trees through both stress and wildfires. Trees become drought stressed when there is not enough moisture in the soil to replace lost water leaving them vulnerable to insect pests, disease, death and fire. Severely drought stressed trees can die off four to five years after the initial drought period. There are no good numbers to quantify trees succumbing to drought stress in 2010 and 2011, but an estimated 10 to 15% of trees along I-30 between Arkadelphia and Texarkana, Arkansas have likely died due to drought stress (J. Barry, personal communication, January 19, 2012).

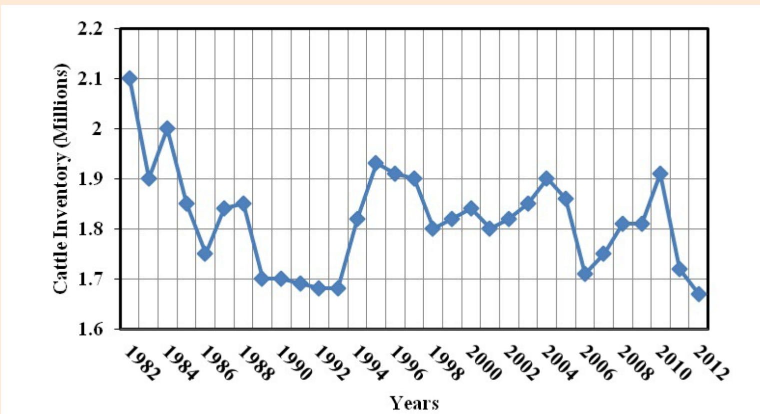
Wildfires are also more prevalent during periods of drought. The numbers of forest acres affected by wildfires in Arkansas per year for the period 2002 through 2011 are presented in Figure 3 (Arkansas Forestry Commission, 2012). The ten-year average for the period is 26 thousand acres. Affected acres for both 2010 and 2011 were above the ten-year average, as were affected acres in both 2005 and 2006, which were also dry years on record in Arkansas (NOAA, 2005; NOAA, 2006). Forest acres affected by wildfire per month for 2010 and 2011 are presented in Figure 4 (Arkansas Forestry Commission, 2012).

Figure 4: Forest Acres Affected by Wildfires in Arkansas by Month, 2010 and 2011



Source: Arkansas Forestry Commission, 2012

Figure 5: January 1 Arkansas Cattle and Calves Inventory, 1982 - 2012



Source: USDA, NASS, 2012c

Most of these wildfires occurred in the south and southwestern portions of the state where drought conditions were most acute in 2010 and 2011 and where most of the commercial timberland is harvested in the state. The recent drought has impacted the forest industry in Arkansas through loss of harvesting jobs and timber value, increased reforestation costs and increased wildfire control cost along with the lost environmental benefits of living forests. Reforestation is one way to replace commercially harvested timber, but drought can also increase the need for reforestation. Drought can necessitate the need for reseeding on stands that have already been reforested. Reforestation is costly, and the current drought is expected to have a major impact on reforestation efforts of both hardwoods and pine trees in Arkansas (M. Pelkki, personal communication, July 31, 2012).

The cost of combating and controlling wildfires also increases with drought. Recent changes in commercial timberland ownership in the state have affected wildfire control. Over the past decade, timberland ownership in Arkansas and the South has shifted largely away from vertically integrated forest products companies to institutional investors (M. Pelkki, personal communication, July 31, 2012). The primary driver of this ownership shift has been increased tax efficiency from moving to Real Estate Investment Trusts (REITs). These changes in timberland ownership have indirectly impacted the way wildfires are controlled in Arkansas. Most of the former vertically integrated forest product companies had firefighting components included to combat and control wildfires, whereas the new timberland owners do not. The cost of wildfire control is increasingly being born by both the Arkansas Forestry Commission (AFC) and local fire departments, and funding and resources (firefighter manpower for the AFC and equipment limitations for local fire departments) for both entities is limited (M. Pelkki, personal communication, July 31, 2012).

Drought Impacts on Cattle and Hay

The cattle industry in Arkansas is composed primarily of small cow-calf operations with over 75% of all beef cow farms having less than 50 head of cattle (USDA, NASS, 2009). The drought of the past two years has had an impact on Arkansas cattle numbers. Pastures have suffered, particularly in the southwest portion of the state where the two years of drought have been most critical. The result has been a liquidation of cattle from these areas where pasture forage has disappeared.

January 1 Arkansas cattle and calves inventory data are reported from 1982 through 2012 in Figure 5 (USDA, NASS, 2012c). Cattle inventories increased after 1993, peaking at 1.93 million head in 1995. Since 1993, Arkansas cattle inventories have remained within a range of 1.8 to 1.93 million head with the exception of four years: 2006, 2007, 2011, and 2012. In all four years, cattle inventories adjusted downward due to drought conditions (T. Troxel, personal communication, August 3, 2012). The low inventories of 1.71 and 1.75 million head observed in

Figure 6: January 1 Arkansas Replacement Beef Heifers, 1982 - 2012

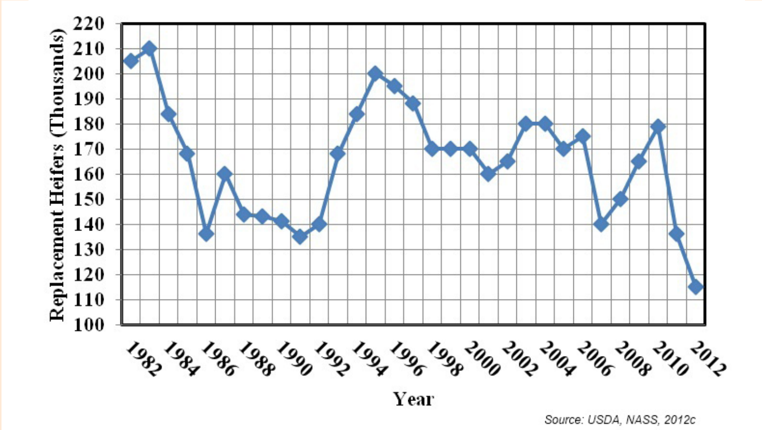


Table 1: Arkansas Hay Acreage, Yield, Production, Price, and Value, 2002 - 2011 (2011 Dollars).

Year	Harvested Acres (Millions)	Yield (Tons per Acre)	Tons of Production (Millions)	Season Avg. Price (Dollars per Ton)[1]	Dollar Value of Production (Millions)[1]
2002	1.430	2.31	3.303	91.99	303.8
2003	1,340	2.22	2.974	72.77	216.4
2004	1,420	2.51	3.570	65.08	232.3
2005	1,310	1.71	2.239	83.64	187.3
2006	1,465	1.72	2.519	104.34	262.8
2007	1,465	2.11	3.084	106.56	328.6
2008	1,405	2.21	3.111	93.29	290.2
2009	1,415	2.21	3.131	86.61	271.2
2010	1,480	1.81	2.681	87.60	234.9
2011	1,400	1.61[2]	2.247	99.50	223.6
Average	1,413	2.04	2.886	89.14	255.1

Source: USDA, National Agricultural Statistics Service (USDA, NASS, 2012b)

[1] Adjusted to 2011 dollars using the Producer Price Index for all commodities.

[2] Lowest hay yield since 1983 (1.59 tons per acre).

2006 and 2007, respectively, reflect liquidation of cattle resulting from drought conditions occurring from May 2005 (NOAA, 2005) and extending until December of 2006 (NOAA, 2006). The low January 1 cattle inventories for 2011 and 2012 of 1.72 and 1.67 million head, respectively, also represent cattle liquidation resulting from drought conditions occurring in both 2010 and 2011, primarily in the south and southwest parts of Arkansas. The January 1, 2013 inventory will likely be lower than the 2012 number because Arkansas is currently in its third year of drought at the time of writing.

Replacement heifer inventories are also good numbers for gauging the impact of drought years on cattle numbers. Replacement heifers are either retained or purchased by cattle producers to maintain or increase the size of their cow herds for calf production. Thus upward or downward movement of this number gives some indication about herd rebuilding intentions of cattle producers. January 1 replacement heifer numbers for 1982 through 2012 are reported in Figure 6 (USDA, NASS, 2012c). Replacement heifer inventories track cattle inventories in most years. For example, replacement heifer inventories trended downward during the 1982 to1992 period, reflecting downsizing of cattle herds during this period.

Replacement heifer inventories dropped from 179 thousand head in 2010 to 136 thousand head in 2011 and continued to fall to 115 thousand head in 2012. The cumulative drop in replacement heifer inventories from 2010 to 2012 represents the largest two year drop in inventories since 1982, and the 2012 inventory number of 115 thousand head is the lowest on record since 1961 (101 thousand head). Some of this drop in replacement heifer numbers can be attributed to profit taking resulting from cattle producers taking advantage of high cattle prices, but most of the drop is a direct result of drought conditions occurring in both years (S. Cheney, personal communication, August 6, 2012).

Arkansas hay area, production, and value numbers are presented for 2002 through 2011 in Table 1 (USDA, NASS, 2012b). Total hay production for Arkansas averaged 2.886 million tons over the 10-year period. Total hay production was below the 10-year average in 2005, 2006, 2010, and 2011, all years experiencing drought conditions, as mentioned above. Hay production was lower in the drought years of 2005 and 2006 than in the recent drought years of 2010 and 2011. This is likely due to the fact that drought conditions were more uniform across the state in the 2005 and 2006, whereas drought conditions were generally

Table 2: Eastern Arkansas Harvested Acres by Crop, 2011.

Crop	Irrigated	Nonirrigated	Total	Irrigated Percent	Nonirrigated Percent
Rice	1,154,000	0	1,154,000	100%	0%
Soybean	2,618,000	652,000	3,270,000	80%	20%
Cotton	590,000	70,000	660,000	89%	11%
Corn1	514,229	137,771	652,000	79%	21%
Wheat	0	520,000	520,000	0%	100%
Sorghum1	31,617	58,383	90,000	35%	65%
Total	4,876,229	1,379,771	6,256,000	78%	22%

Source: USDA, National Agricultural Statistics Service (USDA, NASS, 2012a)
[1] Irrigated and nonirrigated acre splits for corn and sorghum bsaed on percent irrigated and nonirrigated cropland splits recorded in 2007 Census of Agriculture (USDA, NASS, 2009).

confined to the south and southwest portions of the state in 2010 and 2011 (NOAA, 2010; NOAA 2011).

Season average prices in real 2011 dollars are also reported in Table 1. One would expect hay prices to be higher for drought years than for nondrought years. On first glance however, it appears that hay prices can sometimes be low for drought years and sometimes be high for nondrought years. For example, the hay prices reported for the drought years of 2005 and 2010 are $83.64 and $87.60 per ton, respectively, both at or slightly below the 10-year average price of $89.14 per ton. The hay price reported for 2007 (a nondrought year) is $106.56 per ton, followed by 2006 ($104.34 per ton) and 2011 ($99.50 per ton). This discrepancy in prices is due to the way season average hay prices are calculated by the National Agricultural Statistics Service (NASS) for Arkansas. NASS calculates season average Arkansas hay prices from May of the previous year to April of the current year. Therefore, a more accurate hay price for the current year would be the hay price reported the following year. Thus the 2006 hay price of $104.34 per ton more closely represents the actual hay price observed in 2005, the 2007 hay price of $106.56 per ton more closely represents the actual price observed in 2006, and the 2011 hay price of $99.50 per ton more closely represents the actual price observed in 2010 by cattle producers. The hay price that will eventually be recorded for 2012 is expected to be higher than that observed for 2011. Many cattle producers with depleted pastures began feeding hay in July or August of 2011 and ran quickly through their hay reserves. Most cattle producers trying to hold cattle through the summer months were compelled to purchase hay of varying types and quality from distant locations (other parts of Arkansas or from as far away as Mississippi and Missouri).

Drought Impacts on Row Crops

Row crop production occurs mostly in eastern Arkansas. During normal growing years, this region receives a large amount of precipitation, ranging from 46 inches per year in northeastern Arkansas to 52 inches per year in southeastern Arkansas (NOAA, 2009). However, most of this precipitation falls during the winter and early spring months. From late spring through early summer most precipitation in eastern Arkansas falls as rain from widely scattered thunderstorms, which is often insufficient for crop production (Schrader 2010). Consequently, most eastern Arkansas row crop farmers depend heavily on irrigation water to grow their crops. Nearly 80% of Arkansas' harvested cropland acres in 2011 were irrigated (Table 2). All rice acres and nearly all cotton acres were irrigated, while over three quarters of all soybean and corn acres were irrigated in 2011 (USDA, NASS, 2012a).

Most irrigation water is supplied by wells tapping into the Mississippi River Valley alluvial aquifer, which underlies nearly all of eastern Arkansas (Schrader 2010). Much more water needs to be applied during extremely dry growing seasons. This translates into higher pumping costs and reduced profit margins for producers. Groundwater is also an exhaustible resource in many parts of eastern Arkansas. Extensive pumping has caused a steady depletion of the alluvial aquifer in many areas of eastern Arkansas (Czarnecki 2010; Gillip and Czarnecki 2009; Schrader 2010), and several counties in eastern Arkansas have either partially or totally been designated as critical groundwater areas because of significant groundwater declines resulting from intensive irrigation (Czarnecki 2010; Gillip and Czarnecki 2009).

The two years of drought have also had a negative impact on production of the state's most intensively irrigated crop: rice. Arkansas is the leading producer of rice in the United States, accounting for nearly 48% of U.S. rice production (Childs 2012). The rice crop suffered in 2010 and 2011 because of high night time temperatures associated with the drought. High night time temperatures negatively affect rice in two ways: 1) increased incidence of bacterial panicle blight; and 2) heat stressed rice kernels. Bacterial panicle blight is a disease that thrives during very hot years having high night time temperatures during July and August. Heat stressed kernels occur most frequently during growing seasons with high night time temperatures above 75 degrees Fahrenheit. Most commercial rice varieties grown in Arkansas are susceptible to high night time temperature, and both rice yields and quality were affected by high night time temperatures in 2010 and 2011.

Impacts of the 2010 and 2011 Drought

The 2010 and 2011 drought years have impacted Arkansas. Impacts were largely localized in the south and southwestern portions of the state. The areas that were most affected by the 2010 and 2011 drought years were the cattle and forestry sectors. Row crops were least affected by the drought years because of irrigation. The main effects of the drought on row crops were higher pumping costs and continued downward pressure on an already limiting resource—groundwater. Some locations responded to limited groundwater supplies by constructing on-farm reservoirs to capture precipitation and field runoff. However, many of these reservoirs are drying up and making crop producers one again dependent on groundwater.

Drought impacts on trees will likely be seen several years into the future as severely drought stressed trees continue to die off and wildfires continue to burn throughout the state. Reforestation and wildfire control costs are expected to increase as Arkansas continues into its third consecutive year of drought. The AFC which is charged with fighting most wildfires in the state is currently facing a funding shortfall and is seeking appropriations from the Arkansas State Legislature to carry it through the 2012 fiscal year. Thus a large portion of these costs will likely be paid by taxpayers in the future.

The Arkansas cattle industry is also likely to see a continuation of herd liquidations in 2012 into 2013, as pastures remain severely stressed by extreme drought conditions. Herd rebuilding will be a costly endeavor in the future for Arkansas cattle producers. The large scale liquidation of cattle that occurred in Arkansas during the two drought years also occurred in Texas, Oklahoma, and other states heavily hit by drought. The result will be tighter beef supplies and higher prices in the future for replacement heifers, and cattle producers will have a harder time financing future herd rebuilding.

This article paints a picture of the varied impacts of the 2010 and 2011 drought years on Arkansas that will be familiar to those in other drought affected states. The diversity of Arkansas forestry and agricultural enterprises affected by drought as presented in this article has been provided as a context for impacts experienced in other states. This article did not quantify the economic losses to the state as a result of the two years of drought. It also did not account for indirect effects on the Arkansas economy as a result of the drought years, such as lost jobs, lost income, and reduced value added. These efforts are currently under way.

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Agricultural Impacts of Texas's Driest Year on Record

David P. Anderson, J. Mark Welch, and John Robinson

JEL codes: Q10, Q15, Q19
Key Words: Drought, Economic Impact, Texas

The year 2011 set two unwelcome records in Texas: the driest one year drought and the hottest year, as measured by 24 hour average temperature. The lack of rainfall eclipsed earlier marks set for dryness in 1956, the peak of the 1950s drought, long regarded as a watershed drought event in Texas, and 1918. The lack of rain was exacerbated by the extreme heat. Texas set a record for the contiguous United States for the hottest average 24 hour temperature.

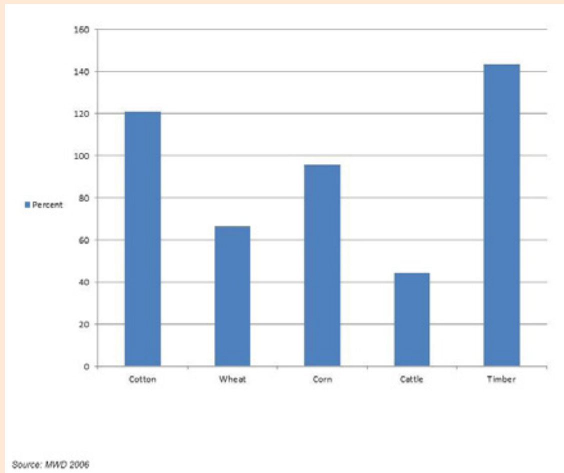
Extreme weather events, such as drought, floods, hurricanes, and other calamities, are news. Many in the general public are interested in these events and their implications. Beyond the general public, policy makers, businesses, news media, and others want to know the financial losses or impacts of the drought. Extreme weather events also provide an opportunity to educate the general public about agriculture and the business of agriculture and how it can affect their daily lives.

This article examines the estimated direct financial impact of the Texas drought on agriculture, some challenges in estimating these impacts, and a few lessons learned from the impacts of a number of droughts.

2011 Agricultural Losses

The 2011 direct financial losses for Texas crop and livestock agriculture are estimated to total $7.62 billion. That is more than $3.5 billion larger than the loss estimated for the 2006 drought, which was the previous costliest drought. The losses represented about 43% of the average value of Texas agricultural receipts over the last four years. Texas produces, on average, about $16 billion in cash receipts annually, which equals close to 6% of the nation's agricultural cash receipts. Drought losses are summarized in Figure 1 for some major agricultural products and discussed below by crop and livestock category.

Figure 1: 2011 Drought Loss As a Percent of Average Annual Cash Receipts from 2005-2009



Cotton

In August 2011, the USDA projected a relatively low average cotton yield of 636 pounds per harvested acre, which they subsequently revised down to 557 pounds per acre by December. In Texas, cotton growers abandoned a historically high number of acres, equivalent to 55 percent of planted acres. Compared to five year average yields and abandonment, 2011 represented a huge loss in potential production. Applied to USDA's measure of 7.1 million planted cotton acres in Texas, and valued at USDA's projected price of 91 cents per pound, this loss added up to $2.2 billion. It is noteworthy that $1.8 billion is the ten year average total value of cotton lint and cottonseed production in Texas. Therefore, Texas cotton growers lost more market income in 2011 than they would normally make for an entire cotton crop.

Grains and Hay

The drought of 2011 lowered grain production in Texas to about half of normal levels and is estimated to have cost wheat, corn, and sorghum grain farmers in Texas over $1.4 billion. Revised USDA acreage and yield estimates continually reduced the size of the crop as the season progressed.

Wheat

Texas wheat production in 2011 was 49.4 million bushels compared to a five-year average of 92.4 million, down 47%. Wheat yields were down from a five-year average of 30 bushels to 26 bushels per acre and acreage abandonment was up. The five-year average of wheat planted acres that are harvested for grain is 50%; only 36% of planted acres were harvested in 2011. That reduced the number of wheat acres for harvest by over a million compared to normal years. The combination of yield losses and reduction in harvested acres put the value of Texas wheat for grain losses at $314 million.

Corn

As the drought progressed in severity through the year, corn acres and yield projections were revised lower. Texas corn production was an estimated 136.7 million bushels compared to a five-year average of 255.4 million, down 46%. Harvested acres were 23% lower than usual due to higher abandonment rates and yields were down 30% statewide. The combination of yield losses and reduction in harvested acres put the value of lost Texas corn for grain at $736 million.

Sorghum

Texas grain sorghum production was estimated at 56.4 million bushels compared to a five-year average of 119.5 million, down 60%. The 1.6 million acres planted in the Spring of 2011 was the fewest in Texas' history. Then the drought further lowered yields and raised abandonment rates. The combination of yield losses and reduction in harvested acres put Texas grain sorghum losses at $385 million.

Hay

The value of hay production lost due to the drought was estimated to be $750 million. The lack of rain throughout the year led to the lack of hay to harvest. Corn stalks, grain sorghum, and wheat stubble from either failed grain crops or post-harvest residue is often baled during drought years, and was commonly done in 2011. The quality of these feeds is often very low and its value is commensurate with its quality. Although, in years like 2011, even the lowest quality feeds are used along with other supplemental feeds.

Livestock

Livestock losses due to the 2011 drought were estimated to be $3.23 billion. Losses include the increased cost of feeding livestock due to the lack of pastures and ranges and market losses. Market losses included the impact of fewer pounds sold per calf and the impact of relatively lower market prices due to the large number of cattle sold in a very short time period.

Timber

The historic drought took a severe toll on trees across the state. The commercial timber forested area of East Texas was among the hardest hit. An estimated $558 million of standing merchantable trees (diameter of 5 inches or larger) on forestland in East Texas have succumbed to the drought. The loss is roughly twice the stumpage value of annual timber harvest in Texas over the past three years. The drought also had a devastating impact on seedlings and saplings, which are normally more susceptible to severe drought of this scale. Economic loss to these premerchantable timber stands was estimated to be an additional $111 million. Taking the impacts to merchantable and premerchantable trees into account, the direct economic loss of East Texas Forest from the recent drought was estimated to be around $669 million measured in stumpage values (sale value of standing trees).

Challenges in Estimating Economic Losses

A number of questions always arise when doing these estimates of economic loss including:

- Time period to include reflecting drought starting date.
- Crops and livestock to include.
- Baseline for comparison.
- Regional and state-wide impacts.
- Multiyear effects.
- Avoiding double counting.

For the 2011 drought, a start date of the Fall of 2010 was used due to the drought stunted winter wheat crop that struggled to become established and to develop. The estimated drought losses, then, included wheat yield losses, but also the lost value of grazing stocker cattle on wheat pasture over the winter.

Being a large state, with many crops, the discussion involves what crops and livestock to include. Because financial estimates of droughts had been made in the past, estimated costs for the current drought were made including the same crops and livestock. In doing so, the estimates did not include losses to crops such as fruits and vegetables, peanuts, horticultural and nursery crops—all important crops in Texas. Urban forestry or urban losses were also not included. However, for the first time timber and forestry losses were included as a side report. The crops and livestock included represent about two-thirds of the agricultural cash receipts generated by Texas agriculture.

The size of Texas can result in more regionally located droughts. The drought of 2006 hit South Texas much harder than other parts of the state. But, the 2011 drought impact occurred state-wide.

Baselines for comparison must be defined. In many cases, average yields and prices over a number of years are used to provide a comparison base. Using multiple years allows avoidance of individual year's extraordinary events that can skew the results one way or another.

Care must be taken in estimating drought impacts in order to avoid double counting losses. It can be easy to count both the value of lost grazing and the effect of lost hay production, for example. Care must also be taken to clearly articulate what is included in estimates and what is not.

It is possible that one farmer's loss is another's gain. This is illustrated by the 2012 year drought affected commodity prices. Those with grain in storage benefit from the high prices while those whose crop has been destroyed by a drought might experience financial loss.

Even one-year droughts have multiyear impacts. It is common for the effects of drought in one year to result in lower conception rates and fewer calves born the next year. It can take years for pasture and range grasses to recover from drought resulting in continued reduced stocking rates for several years. Even through the severity of the 2011 drought, rice farmers receiving water from the Lower Colorado River Authority, which controls water on the Colorado River (the Texas Colorado River), were able to continue to irrigate. But, the lack of rainfall lowered water levels in the reservoirs resulting in no water allocated for crop irrigation in 2012. The financial impacts of surviving a drought can persist for years on a ranch or farm's cash flow and balance sheet.

Analyses of droughts also require assessments of "downstream impacts." Assessments of losses at the farm gate, or direct economic impacts, can miss significant financial impacts. Examples include effects on the cotton gins that had no cotton to gin, truckers that did not have grain or bales to haul, and compresses, oil mills, and exporters that had reduced business.

Some Lessons Learned Over the Years

Texas is a big state and experiences extreme weather events that necessitate understanding drought's impact on agriculture. Although this article was written before the 2012 crop year, the 2012 drought would provide a similar set of lessons. Given that 2011 was not a "first rodeo," a few important lessons have been gleaned over the years. A brief list of lessons learned includes:

- A transparent report that says what is and what is not included is important. However, it is very difficult to include everything.
- Keep everyone in the loop. The key is to communicate early that the drought impact estimates are being developed so that no one is caught off guard. Surprises are not often appreciated by those in authority. Although informing authority, publication to the public through a news release developed with Extension agricultural communications personnel has been the primary mode of delivery of information about the impacts of drought in Texas.
- The general public has an interest in this news and it is an opportunity to help educate people about agriculture, the drought impact on agriculture and work at the university.
- The results educate and inform decision makers who make decisions that have real effects on people. For example, these estimates are often used in petitions for disaster declarations, triggering policy responses to aid those impacted by drought.

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Damages to Louisiana Agriculture from Natural Disasters

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JEL Classifications: Q10, Q18, Q51, Q54
Key Words: Disaster Assessment, Economic Impact Methodologies, Natural Disasters,

Losses caused by natural disasters such as drought, excessive rains or hurricanes have had dramatic impacts on agricultural revenue and costs and the well-being of humans and animals. Losses of capital assets and other farm infrastructure have had far-reaching effects on economic viability. Louisiana State University Agricultural Center (LSU AgCenter) personnel are uniquely positioned and often called upon to assess the economic damage resulting after the occurrence of such natural disasters.

Unfortunately, Louisiana has had its share of natural disasters over the last several years. Since 2000, assessments of the physical damage sustained to the agricultural industry have been conducted and economic impacts have been estimated in eight out of 12 years for four major hurricanes, two tropical storms, three incidences of prolonged drought conditions, and one summer of excessive rains. The economic impacts associated with natural disasters have been estimated at nearly $5 billion to the Louisiana's agriculture, aquaculture, and fisheries industries.

While similarities can be found across agricultural disasters, the one thing that became increasingly evident over the years is that each disaster event has its own unique set of issues and impacts depending on the magnitude and duration of the event. In some cases, as with drought conditions, the impact tends to focus on lost revenue due to crop failure and lower productivity. In others, as was the case with the 2005 hurricanes, the number and extent of the impacts can be much more varied and challenging. Identifying these impacts and potential effects through assessments of physical and quality losses and estimates of resulting economic damages is important to policy makers, government

Table 1: Estimated Impacts to the Louisiana Agricultural, Aquacultural and Fisheries Industries from Natural Disasters, 2000 - 2011

Year	Event	Estimated Economic Impact (Million Dollars)	Estimated Aggregate Louisiana Farm Gate Value1 (Million Dollars)	Impact As a Percentage of Farm Gate Value (Percent)
2000	Drought	$571	$4,039	14.14%
2001	Tropical Storm Allison	$225	$3,900	5.77%
2002	Tropical Storm Isadore and Hurricane Lili	$540	$3,490	15.47%
2004	Early Season Excessive Rains Followed By Drought	$232	$5,035	4.61%
2005	Hurricanes Katrina and Rita	$1,500	$4,685	32.02%
2008	Hurricanes Gustav and Ike	$1,100	$5,320	20.68%
2009	Excessive Rains at Harvest	$363	$4,855	7.48%
2011	Mississippi River Flooding and Drought	$436	$6,086	7.16%
Total		$4,967	$37,410	13.28%

Source: LSU AgCenter, Department of Agricultural Economics and Agribusiness, Various issues of economic impact reports
[1] The estimated combined farm gate value of plant, animal, and fisheries enterprises in Louisiana.

agencies, and researchers in targeting assistance. Since these assessments are often requested of Extension with very short timelines, having a set of strategic procedures has proven to be necessary to meet deadlines and still maintain the reliability and accuracy of the assessment.

Damage assessment requests are typically made by government agencies and private organizations after a natural disaster. For Louisiana, these requests usually come to the Extension Service. The one common theme in the requests is that they all require the provision of estimates in a very short time, often less than a month.

The desire to respond quickly to these requests can compromise the ability to adequately and accurately depict the nature of the damage. Experience has shown that damage estimates calculated in haste can be significantly overstated. Overestimated damage does however provide additional political leverage to increase the money received from federal disaster programs (Kliesen, 1994). As such, there is a delicate balance that must be navigated between the timeliness and accuracy of a damage assessment.

Historically, agricultural damage assessments have been used to provide policy makers with a basis for seeking disaster assistance not provided in traditional farm policy legislation. The need to understand the depth and breadth of the impacts is critical to effectively assist the agricultural industry in formulating a plan to respond to and recover from a natural disaster. While the agricultural industry can experience multiple impacts, many such as crop failures, yield reductions, or liquidation of livestock typically have an effect of a year or less. Other impacts such as saltwater intrusion or coastal erosion resulting from hurricanes are longer run in nature and may need more comprehensive policy solutions to restore agricultural productivity or improve societal welfare. However, Extension's initial role in the time given is generally to come up with an assessment of more immediate agricultural damages.

Challenges in Determining Agricultural Damage

The short timeframe often faced when developing damage estimates requires having a strategic plan or system for conducting an assessment. During the first half of the previous decade, damage assessments in Louisiana focused predominately on revenue losses associated with drought and excessive rainfall. Given the direct nature of these impacts, little thought was given to developing a strategic plan for addressing more complex issues. When two major hurricanes made landfall in Louisiana, one in 2005 and then again in 2008, this informal approach to developing damage assessments proved to be inadequate to address the numerous impacts associated with the storms within a two to three week time frame that was being requested by policy makers.

The sheer magnitude of the 2005 and 2008 hurricanes showed the need for a system that would allow for an effective flow of information from the parish (county) level to the state level. Information on the physical damages collected at the parish (county) level had to flow to the state level where it was collected, summarized, and used in developing economic impact estimates. Variability in data collection made it extremely difficult to quickly and accurately develop statewide economic impact estimates. It was found that having a system that provided guidelines to parish (county) level personnel in conducting the physical damage assessment and which provided uniformity in the type and amount of information being collected, increased not only the timeliness of the assessment, but also provided an avenue to increase the detail and reliability of the estimates.

It also became apparent during the hurricanes that decisions had to be made on what issues could and could not be adequately addressed. Unlike direct impacts, indirect impacts to rural economies were found to be more difficult to identify and often evolve more slowly over time. Also, depending on the severity of the storm, economic linkages used in the creation of an industry multiplier for a region may no longer exist making them invalid for assessment purposes (Guidry, Caffey, and Fannin, 2008; Fannin and Guidry, 2010).

Evaluating Agricultural Damage in Louisiana

Louisiana economic assessments of natural disasters were limited to estimating short-term direct economic damage to agricultural commodities, aquaculture, fisheries and agricultural industries. This was mainly because LSU Agricultural Center personnel had the greatest knowledge and expertise in these areas.

A step towards a strategic set of procedures to evaluate damages was to develop a survey through which information could be collected and organized to be used in developing direct economic impacts. This involved a collaborative effort including all levels of the Cooperative Extension Service.

Once evidence emerged that significant damage had occurred over a large enough geographic area to warrant an economic assessment, an initial standardized survey was sent to parish (county) level agricultural agents and state-level commodity production specialists to get an overview of the physical damage experienced. This survey was typically limited to gathering information regarding yield losses and impacts on major commodities affected by the natural disaster.

To ensure that economic damage assessments reflected a uniform consideration of losses, multi-year impacts were qualitatively identified and discussed but were not included in the economic damage totals. Indirect impact issues were also identified but not included in the economic damage totals provided by the assessment report.

The initial survey sent to parish (county) level and commodity production specialists provided a standardized approach for identifying commodities, acres, and the expected yield impacts. Yield impacts were requested on a percentage basis rather than per bushel or per pound basis. This was done to prevent the potential for over-estimation based on overly optimistic predisaster yield potential. Past experiences suggest that overly optimistic predisaster yield estimates can lead to overestimating yield impacts associated with the disaster.

The information collected from these surveys are combined with published data to develop economic estimates of losses. Where possible, U.S. Department of Agriculture's National Agricultural Statistics Service (NASS) yield data is used to develop five year average yields that serve as a proxy for predisaster yields. Likewise, estimates from the World Agricultural Outlook Board's *World Agricultural Supply and Demand Estimates* report are used to establish baselines for commodity market prices used in determining revenue levels. With the number of assumptions that must be made to develop damage estimates within a short time frame and the inherently subjective nature of physical loss assessments, the ability to supplement assessments with data that is widely recognized and accepted helps to improve the accuracy and credibility of estimates.

Louisiana is fortunate to have an annual publication developed by the Department of Agricultural Economics and Agribusiness that provides acreage, yield, and price data by parish (county) for every commercially grown commodity in the state. The *Louisiana Summary: Agriculture and Natural Resources* is a cooperative effort with parish and state level Extension personnel and has become one of the most frequently used and referenced publications developed by the LSU AgCenter. If available, these types of additional data sources can be used to supplement data from USDA to add accuracy and creditability to damage assessments.

While an initial survey can be accomplished and a damage assessment developed within two to three weeks of the disaster event, there is generally a need for one or multiple subsequent assessments. This is particularly true depending on the time of the year that the natural disaster occurs. Disaster events that occur early in the growing season can prove extremely difficult in assessing yield impacts. With several weeks or months before the commodity is to be harvested, weather conditions that follow the disaster event can have as much or more impact on the final yield. As such, a second assessment is typically conducted at or around harvest time.

A second survey is sent to parish (county) Extension personnel which requests much more detailed information for all impacted commodities on a wider array of issues. This survey asks for updated estimates for acreage and yield losses and for other information that can be used to develop impacts such as increased production costs and infrastructure losses. Again, this information is combined with USDA data along with other published data such as estimated commodity production costs and returns found in enterprise budgets developed by the LSU AgCenter. Once this information is collected and tabulated, it is sent to commodity production specialists that help to verify and validate the numbers.

Crop Related Impacts

Drought or excessive rain conditions can result in fields going unharvested but, more typically, will result in some percentage yield reduction and quality loss. Information is gathered on acreage that experiences a total yield loss as well as on acreage that experiences partial yield loss.

Events that prevent harvest in a timely fashion can often cause lower grain quality and test weights in feed grain crops and lower fiber quality in cotton. Given that estimates for quality losses are generally much more subjective than yield loss estimates, the survey only requests information on the number of acres that would be expected to have quality losses. This information is combined with information obtained from a survey of commodity buyers throughout the state asking for the range in price discounts being seen for quality damage. Once the average price discount is determined, it is used to adjust the assumed market price for the commodity to determine the economic impact of quality losses from the natural disaster. An important point here is that the price discounts for quality losses are only applied to those acres identified from the survey at the reduced yield levels. Since the yield loss is accounted for, applying a price discount to "normal" or predisaster yields would result in overestimating potential impacts.

Depending on when a disaster impacts the agricultural industry, prevented plantings can also be experienced. Excessive drought or rain at planting can push planting beyond recommended time frames. In these instances, surveys provide estimates on the number of acres that were not able to be planted to the intended commodity and were not subsequently planted to any other commodity. In this case, the impact is defined as a loss of net revenue to the producer. LSU AgCenter enterprise budgets are used to estimate net returns that would have been expected under normal conditions and are used to determine the economic impact associated with prevented planted acres.

Another issue that is typical of many of the disasters faced in Louisiana is increased production costs.

Increased production costs are more typical with excessive rain events at harvest which reduce harvest efficiency and increase harvest time. However, in the 2011 drought, increased irrigation demand was a significant impact faced by many agricultural producers. Surveys provide information on acreages impacted by increased production costs as well as other information needed to estimate the economic impact of these increased costs.

Livestock Related Impacts

Assessing economic damages resulting from natural disasters to a livestock industry requires a different approach than for row crops. Yield losses from hay production are accounted for in a similar manner to crop damage estimates as hay production may suffer a reduction in yield, but also a decrease in the number of annual cuttings. Prices from USDA AMS' Market News Service are used to calculate an economic estimate of the total decrease in hay production. Hay prices are also important to value the lost grazing potential associated with pastures. Parish (county) Extension agents provide state specialists with information on the number of acres and days that grazing was impacted which are then used to place an economic value on the lost grazing potential through increased feeding of purchased hay. Losses are assumed using typical stocking rates and consumption of forages per cow.

Reduced grazing potential and hay production are only two aspects of livestock disaster estimates. Direct impacts on livestock production are also assessed through forced liquation of breeding stock above normal culling rates. The value of those breeding stock which are forced to be liquidated is calculated, but this only accounts for part of the economic loss. Should producers who cull above normal rates wish to replenish their breeding stock, they typically have to pay higher prices than what the animal sold for. The difference per head between the replacement value and the cull value is used to determine the economic estimate for forced liquidation of breeding stock. Higher than normal mortality is also accounted for in calculated economic damages for all classes of cattle.

The drought that Louisiana experienced in 2011 added a new dimension to calculation of livestock damage estimates. Previous experiences with natural disasters had not led to accounting for early weaning of calves to help maintain available pasture for mature females. Extension agents provided state specialists with estimates on the number of calves that were early weaned and the average difference in sale weight due to drought compared to normal weaning weights. Using information from USDA AMS' Market News Service and selected auction markets in Louisiana, the reduced value of calves sold was calculated.

As in other states, one challenge that has arisen in developing economic damages for the cattle industry has been a lack of price information. Market News Service cattle prices for Louisiana have not been available since September 2010. The Market News Service is a partnership between USDA AMS and participating states to document prices and transaction volumes of agricultural commodities. Limited and sporadic pricing information is available from selected auction markets in Louisiana through the Louisiana Department of Agriculture and Forestry's (LDAF) website. However, available prices are self-reported by the sale barns and may not cover the bulk of sales as with the Market News Service. Additionally, those barns that self-report prices through the LDAF website do not offer unbiased, third party verification which USDA AMS' Market News Service provides. The result of using prices from biased sources is economic damage estimates that are less reliable than for other agricultural commodities. As sale barns infrequently post prices, important information on the number of head liquidated pre- and post-disaster and price of animals sold is lost.

Issues and Lessons Learned

While conducting damage assessments can be viewed as an inexact science, years of conducting assessments in Louisiana have provided several lessons which might be applied in other states. First and foremost, a strategic plan for conducting and implementing the assessment is critical to guard against potential biases as well as the temptation to overestimate damages. Also, a plan is critical to be able to address in as accurate manner as possible policy makers, industry leaders, and others with a vested interest in the assessment. Since moving toward a standardized, strategic approach after the 2005 hurricanes, the ability to quickly respond to Louisiana agricultural damage assessment requests has improved as has the level of detail and the number of critical issues that are able to be addressed. The strategic survey approach has accomplished this by creating an environment in which all personnel involved have a clearer understanding of why and how the assessment will be conducted.

Every attempt is made to balance accuracy with timeliness. Credibility of the disaster estimates is improved by limiting initial assessments to major commodities directly impacted and by supplementing assessments with published data from respected sources. Follow-up can be done at a later time to conduct a more detailed, comprehensive assessment of the impacts of a natural disaster. However, in the future proposals for reducing data collected and the number of reports provided by the USDA and by state agencies may make use of published data more limited.

Another lesson learned is that the timing of the natural disaster will likely impact the accuracy of assessments. If a natural disaster event is experienced during the early part of the growing season, the exact nature of the impact on yield and quality will not likely be known for several weeks or months until harvest is completed. As a result, initial estimates need to err on the conservative side. Impacts will likely look worst shortly after an event. Taking an aggressive stance in estimating damage at that time, particularly when harvest is still several weeks away can lead to over estimation. In addition, crops are remarkably resilient and often can and will recover considerably following a natural disaster particularly if ideal weather conditions follow the event.

Impacts on commodities from natural disaster can vary significantly from disaster to disaster and within a disaster event. For some commodities, the impact may be limited to yield losses while others may have experienced yield losses in addition to quality losses and increased production costs. Lumping all of the impacts into one single damage estimate may miss the fact that a commodity was faced with multiple issues and impacts. Where possible, assessments conducted by the LSU AgCenter are categorized by major impacts on specific commodities such as yield reduction, quality losses and increased production costs.

The same shortcoming of lumping different types of impacts into a single damage estimate can be found by combining both short-term and longer-term impacts. Potential multi-year impacts that seem evident during the current production year can change drastically in a few months as weather conditions change. For example, during the 2005 hurricanes one of the multiyear impacts expected was a reduction in yields on acreage that had been impacted by storm surge. However, the full nature of that impact depended on weather conditions in the subsequent year. A year with average to above average rainfall would likely mitigate the impacts of salt levels deposited by the storm surge. Including estimates in the assessment for the 2005 hurricanes on the potential of storm surge on subsequent production would have brought in an additional level of error to the assessment. To prevent this type of error, assessments by the LSU AgCenter limit estimates of economic damages to current year disasters.

Finally, as noted in the discussion of valuing the sale of breeding stock and its replacement cost, consideration is given to the values of stock and flows for capital assets. Sales of capital assets such as breeding stock will result in higher farm incomes in the year of a natural disaster, but farm incomes will decline in subsequent years unless that stock asset is replaced. Estimates attempt to account for the increased cost incurred by agricultural producers to replace capital assets where appropriate. While producers have an incentive to replace capital assets and restore production as quickly as possible following a disaster, each disaster is different in nature. As a result, it can be difficult to accurately determine the true length of the disaster's impact and how long it will take an operation to return to normal.

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Drought Issues in Semi-arid and Arid Environments

Kurt A. Schwabe and Jeffery D. Connor

JEL Classification: Q1, Q2, Q3, Q5
Key Words: Demand-Side Management; Drought; Wastewater Reuse; Water Conservation; Water Scarcity

Drought is a common occurrence in arid and semi-arid (ASA) regions, with regions such as Australia's Murray-Darling River Basin (MDB, Figure 1) experiencing significant droughts once every ten years on average. Climate projections for many ASA regions suggest a future with increased aridity, longer periods without precipitation, and more frequent and intense meteorological drought (Seagar, et al. 2007). Recent drought events and climate analyses indicate such change already may be occurring. Over the past four decades, warm season duration, as measured by warm periods without sizable rainfall, has increased by approximately 3.5% in the Southwestern United States, and by 6.4%—15 days—within California and Nevada (Groisman and Knight, 2008), while the period from the late 1990s through 2009 is considered the driest on record in southeastern Australia. With rising water demands due to population growth, the frequency and degree to which the supply of water falls short of its demand will increases as well.

Figure 1: Map of the Murray-Darling River Basin

The impacts of sustained drought in ASA regions can be broad, with low priority water rights holders, notably the environment and groundwater systems, often suffering severely. There are numerous examples of how drought affects the natural environment through impacts on biotic communities, habitat availability, and ecosystem function, resilience, and services (Schwabe, et al. 2012). Similarly, the added reliance on aquifers during drought often results in overdraft, degradation of groundwater and groundwater dependent ecosystems, and land subsidence (Galloway, et al. 1998).

Not surprisingly, water intensive industries can be significantly impacted, namely agriculture and hydro-electric power. The 2009 drought, for instance, is estimated to have led to the fallowing of 285,000 acres, the loss of nearly 10,000 jobs, and $340 million in lost revenue in California's San Joaquin Valley (Howitt, MacEwan, and Medellin-Azuara, 2011), and a 20% reduction in the value of irrigated agriculture in Australia's MDB (Kirby, et al. 2012). In Spain, the estimated impacts from the 2004-05 drought include agricultural production losses of US$670 million, and reduced hydro-electric production that resulted in losses of US$123 million (Schwabe, et al. 2012).

While the impacts of drought can be far-reaching and impact energy, recreation, municipalities, industry, and residential households, analyses of drought show significant variability in the magnitude of the impacts—there are examples in which the impacts are severe and examples in which the impacts are minor (Wilhite, 1993; Lord, et al. 1995). What we learn about the impacts of drought from analyzing past events and model predictions is that the impacts, not surprisingly, vary over the time and location of the drought. Other factors influencing severity of impact include the vulnerability of the hydrologic system, the level of exposure, and the ability of agents and institutions to respond, mitigate, and adapt to the drought. In this article, we focus on examples of how agents and agencies, particularly in the southwestern United States and Australia, have responded to drought in ASA regions, identify past successes and concerns, and highlight opportunities for future advances.

Drought Adaptation and Mitigation in Semi-Arid and Arid Regions.

Consider three general categories for addressing and reducing the impacts of drought including: (1) modifying the impact of the meteorological event on the available supply of water (supply-side approaches), (2) reducing exposure and vulnerability to drought through demand-side adaptation/mitigation (demand-side approaches), and (3) increasing the ability of agents, sectors, and regions to respond, mitigate, and adapt to drought through institutional changes.

Supply-Side Approaches.

One of the most effective approaches to reduce drought impacts has been the development of water storage and conveyance infrastructure. Development of these structures modifies the distribution of water within and across years and space, and allows low-valued water to be used for high-valued purposes at some later date. Australia's MDB, for instance, has developed enough storage capacity in its dams to supply nearly three years' worth of water (Schwabe, et al. 2012), whereas the federal reservoirs of Lake Mead and Lake Powell can store nearly four times the mean annual flow of the Colorado River (Lord, et al. 1995).

Governments are increasingly considering aquifers as storage, likely in response to environmental concerns and the limited availability of well-suited and low-cost surface water storage opportunities. The use of aquifers as storage, referred to as conjunctive management, is not surprising given the abundant natural storage capacity of aquifers relative to the development of surface water systems in most regions. In California, for instance, where more than 65 water agencies engage in some form of conjunctive management, underground aquifers offer between four to 30 times more storage capacity than do existing surface reservoirs (Hanak, et al. 2011). This additional storage may become increasingly useful to help California adapt to the reduction in the free natural storage provided by the Sierra Nevada snowpack. This snowpack, which currently provides storage equal to approximately 50% of all major man-made storage in California, is predicted to decline as climate warms. Precipitation will increasingly fall as rain rather than snow resulting in earlier springtime runoff in volumes greater than current storage capacity can handle, with the excess flowing out of the basin.

Equally important to storage is the ability to move water around. Many countries with geographically variable rainfall and significant ASA regions transfer large amounts of water from rain-abundant basins to rain-scarce basins. Annual interbasin transfers in Australia's MDB, for example, average approximately a million acre-feet (maf), whereas the California State Water Project, which includes the 444 mile-long California Aqueduct (Figure 2), annually moves 1.4 to 4.0 maf of water from northern California to the Central Valley and southern California. In times of drought, though, it can be important to move water in low-value water areas to high-value water areas, often within the same basin. During the 2009 drought, for instance, approximately 0.5 maf of water was transferred within California's San Joaquin Valley, an adjustment estimated to have reduced the localized impact of drought significantly (Howitt, MacEwan, and Medellin-Azuara, 2011). The lesson

Figure 2: Map of the California Aqueduct

here is that when substantial basin-level variation exists with respect to water usage and value, there may be large returns from allowing intrabasin transfers that likely result in less third-party effects and have lower conveyance and evaporative losses relative to interbasin transfers.

Two other approaches that can extend water supplies in anticipation of drought include wastewater recycling, including storm water capture, and desalinization. The potential benefits of recycling and capture programs include access to a locally reliable source and less reliance on water imports, increases in drinking water supplies, and greater water supply portfolio diversity. Recycled wastewater and storm water capture serves as a replacement for water allocated to river and stream ecosystem restoration, and more recently have been increasingly used as the replenishment source in place of imported water for conjunctive use management.

Traditionally, recycled wastewater and storm water have been used to generate gray water for irrigation and industrial uses. For instance, Adelaide, Australia now receives about 20% of its water supply from recycled wastewater which is used primarily for irrigating horticultural and vegetable crops and green space. More recently, though, treatment processes have been added so that the recycled water can meet drinking water standards. This water, in both California and Australia, typically is injected into groundwater or recharge basins for a period of time before it can be extracted and used as a drinking water source, a procedure called indirect potable reuse (IPR). Southern California agencies, for example, have embraced recycled wastewater as part of their water portfolio as evidenced by the Orange County Water District's Groundwater Replenishment System (GRS). Since 2008, the GRS, the largest IPR project in the world, has produced nearly 0.273 maf of high-quality water that exceeds all state and federal drinking water standards (Dunivin, Patel, and Clark, 2011). The treated water is injected into recharge basins where it improves groundwater quality and, ultimately, provides drinking water to nearly 600,000 people.

Advances in reverse osmosis technology, coupled with water agencies' desire for a more reliable water supply, has resulted in a push for more desalinization plants. As of 2010, nearly 13,000 industrial-scale desalinization plants existed worldwide. Spain, for example, has nearly 700 ocean desalinization plants along its Mediterranean Coast (Schwabe, et al. 2012), while Australia recently built plants in Adelaide, Perth, Sydney, and Melbourne, with designs for a large plant in Victoria. In California, desalinization is an evolving alternative with 17 proposed ocean desalinization facilities along its coast, including the recently approved Carlsbad plant just north of San Diego which would be the western hemisphere's largest ocean desalinization plant.

Significant concerns exist with ocean desalinization, though, especially surrounding energy use, air emissions, and impacts on marine species and ecosystems from both the intake of water and discharge of brine. From an energy and cost perspective, for instance, new desalinization in major Australian cities is typically supplying water at two to three times more cost per unit of water supply than older surface and groundwater supply sources, with a two- to four-fold increase in energy intensity (Kenway, et al. 2010). The proposed Carlsbad plant in Southern California, meanwhile, which was approved by the state in 2009 and would produce 56,000 acre-feet annually, now faces two hurdles, not completely unexpected: will it be able to sell the water at a competitive price to local water agencies, and will there be additional environmental restrictions on its intake of ocean water? Less controversial is the desalinization of brackish groundwater since it can be locally produced at a lower cost than ocean desalinization and does not need to be near a coast. In contrast, there are other approaches which include measures such as improved outdoor water use practices that can save both money and reduce energy use in water supply.

Demand-Side Approaches.

Historically, the drivers behind reducing water use during, or in anticipation of, drought have been water use restrictions, opportunistic programs promoting water conservation—for example, rebates for water efficient indoor appliances, subsidies for irrigation—and, more recently, water pricing. The agricultural sector, which accounts for over 75% of the water use in many ASA regions, has responded to these drivers with adaptation and mitigation strategies that include deficit irrigation, irrigation efficiency improvements, the intermittent fallowing of low-valued crops, and changing to the production of less water-intensive crops. For example, in a survey of grower responses to the 1987-92 drought in California, Zilberman and colleagues found that within the agricultural rich yet arid regions of the Central Valley, sprinkler and drip irrigation adoption increased significantly in place of furrow and border irrigation; in addition to some fallowing, cotton and alfalfa cultivation was reduced in favor of tomatoes and other higher-valued vegetable crops (Zilberman, et al. 1998). In addition to increases in water-use efficiency, these drivers have led to increases in economic efficiency as water has moved from low to higher valued crops thereby raising the value per unit of irrigated water. During Australia's recent Millennium Drought, for instance, the gross value of irrigated agriculture per unit of irrigated water in Australia's MDB increased by 241%, though part of this productivity improvement may be a long-term trend rather than a specific response to drought (Kirby, et al. 2012).

Significant per capita reductions in residential water use have also occurred, mostly through the adoption of water conserving indoor appliances, including high-efficiency washers, toilets, and shower heads. From 1995 to 2005, for instance, average per capita urban water use in California decreased by approximately 25% (Hanak, et al. 2011). While such measures have helped to reduce water scarcity and, consequently, the vulnerability of any particular region to drought, there seems to be significant opportunities for further reduction through improvements in landscape irrigation and design. Not surprisingly, then, a major focus of many water agencies in ASA regions is on improvements in urban outdoor water use, which accounts for over one half the water use in most ASA cities. California's water agencies, for instance, have been mandated to reduce their water use by 20% by 2020, which certainly seems possible when compared to urban water use in other countries. As noted by Hanak and colleagues, urban water use in California averages 201 gallons per capita per day (gpcd), whereas in Australia's major cities water use is between 80 to 130 gpcd, and in Israel and Spain it is 84 gpcd and 76 gpcd, respectively (Hanak, et al. 2011).

From an economic perspective, drought impacts will be largely a function of an economy's reliance on water. Reliance can be reduced through efficiency gains, but also by changes in the composition of economic activity. California is a prime example of this, with an agricultural sector that is currently responsible for approximately 75% of the state's water use yet contributes less than 3% to its GDP and labor force. Interestingly, as the proportional value of agriculture to the entire economy decreases, the relative value of water in nonconsumptive uses increases over time. As a result, the cost of drought to economic activities that use water non-consumptively is now often greater than the costs to economic activities that use water consumptively, such as irrigation. For example, Lord and colleagues found that more than 50% of the damages from an extreme drought in the Colorado River arise from losses in hydropower opportunity, decreases in water quality, and lost tourism (Lord, et al. 1995).

Implications from Past and Recent Successes.

Historically, the main response to water scarcity and drought in many ASA regions was to build more surface water storage. Looking forward, opportunities for increased surface water storage appear to be quite limited. Significant future opportunities to adapt and mitigate drought likely involve further institutional developments that (1) increase the opportunities to allocate water more efficiently across space and time through the use of water markets and water banks, and (2) promote cooperation within and across water catchment areas and among diverse water use interests.

Water markets and water banks provide regions and countries with an efficient mechanism for allocating water to its highest valued consumptive uses dynamically with changing conditions. The presence of well-functioning temporary and permanent water markets in Australia, which arguably has the most sophisticated and advanced water markets globally, has reduced the impacts of drought significantly. From 2007 to 2010, nearly one third of all water in the MDB has been traded and this is estimated to have reduced the economic impact of drought on the irrigation economy by 50%. The ability to bank water across seasons has recently been introduced to irrigators in the MDB with estimated gains in agricultural productivity near 12% in one case study (Hughes, 2009). While water banks are not abundant in the southwest United States, they do exist and have been shown to help reduce drought. For example, California Emergency Drought Bank established in the early 1990s is estimated to have reduced the damages of drought by $104 million (Easter, Rosegrant, and Dinar, 1998).

An important reform necessary in many contexts to facilitate wide spread water markets and banking involves improved monitoring and metering of surface and groundwater extractions with property rights consistently defined in volumetric terms. Such actions would provide more accurate price signals of the scarcity value of water which, in turn, can promote more efficient water use. More accurate monitoring and metering is critical to governments who use water markets to cost-effectively provide for the environment. Water trusts and government entities in the Pacific Northwest and Australia, for example, are buying or leasing water through markets and achieving better environmental outcomes at less opportunity cost to consumptive uses (Garrick, et al. 2012). Improvements that will further develop water markets to better manage drought include: infrastructure improvements to allow more flexible interbasin trading, and streamlining the approval process for trades through mechanisms such as zone-based trading ratios or preapproved trades that identify and account for third-party effects (Hanak, et al. 2011).

Finally, one of the great challenges in effectively addressing drought is that many diverse and geographically dispersed interests are involved. As outlined above, opportunities exist to reduce the impacts of drought through the reallocation of water across space and time via inter- and intrabasin transfers, water banking, and from greater storage through aquifer use. Experience shows, however, that the benefits are less often realized when coordinated actions across state, national, and catchment borders are required, and when cooperation across diverse water use interests such as irrigation and the environment are required. Institutions that facilitate information sharing and involve representation from key stakeholders can, however, significantly improve prospects for cooperative, multiparty adaptations to drought. Spain has some of the best examples of information systems, information sharing, and negotiation processes that facilitate drought mitigation. This involves both quantitative analysis of measures that minimize drought impacts using integrated river basin models to monitor drought risk and the effects of specific mitigation strategies, and the sharing of this information with drought management committees comprised of diverse stakeholders from key economic and environmental water interests.

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