

**Estimating the Economic Value of Water for Agriculture and Other Industries in  
Tennessee**

**A Thesis Presented for the  
Master of Science  
Degree  
The University of Tennessee, Knoxville**

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## **Dedication**

*This thesis is dedicated to my parents. I wouldn't have such a curious mind and passion to learn about the world around me if it wasn't for you. I'm so grateful for all that you've done.*

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## **Abstract**

Tennessee's currently abundant water resources could eventually become stressed as population continues to rise, climate change impacts water resources, and as agricultural producers continue to increase irrigation. These stresses could impact the productivity of the agricultural sectors and other economic sectors as competition for limited water resources increases. Farmers, policymakers, and researchers alike could benefit from quantifying the economic value of water to help formulate cost-effective and sustainable water use practices. This analysis establishes the water withdrawals (also referred to as "water use") per dollar of output for competing economic sectors and uses those values in an Input-Output Linear Programming (IOLP) model to maximize gross regional product to the Tennessee economy. Shadow values are also determined for each industry using the IOLP model. The accounting matrix of economic activity is from the Impact Analysis for Planning model (IMPLAN), and total water withdrawals and water withdrawal coefficients were found using a combination of data from the United States Geological Survey (USGS), the United States Department of Agriculture (USDA), and IMPLAN.

The results of this model indicate that water use in the agricultural and governmental sectors have relatively low economic values while water use in the real estate, forestry inputs, and insurance sectors have high economic values. These results are observed with both the water use coefficients in Chapter 1 and the marginal contributions to gross regional product in Chapter 2.

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## **CHAPTER 1: Introduction**

Two-thirds of the global population is expected to live in areas with moderate to high water stress by 2025 (Sharma, 2009). The western United States (US) and many other regions have been dealing with water scarcity and allocation issues for decades, but the eastern US has largely avoided water quantity and allocation dilemmas. However, with the US Department of Commerce projecting US population to grow from around 321 million people in 2015 to almost 417 million people by 2060 (USDOC, 2015), the pressure on eastern water resources is expected to rise.

In addition to population growth, climate change is also expected to stress water resources. The absolute effects of climate change on water resources are unknown, and water stress expectations vary by region. In some regions, climate change is expected to increase the water stress whereas in other regions, climate change is expected to alleviate water stress (Arnell, 2004; Elliott et al., 2014; Nelson et al., 2009). In the southern United States, the expected effect of climate change is to increase water stress and also decrease agricultural yield (Siikamäki, 2008). With little to no information on how climate change will affect specific states, Tennessee residents have voiced concerns over the potential outcome. A random sample of Tennessee residents taken between 2008-2010 indicated that 41% of respondents felt that having enough water was currently a problem, probably a problem, or were unsure if it was a problem in the area where they lived, and 22% felt that having enough water would be a problem within 10 years. In addition, 40% of respondents thought global warming would lead to a decrease in rainfall in their area, whereas only 5% thought global warming would lead to an increase in rainfall (Borisova et al., 2013). This survey indicates that the general public is unsure and possibly concerned about water scarcity in Tennessee, and as a result, it is reasonable for policy makers to be proactive in preparing for potential water quantity issues.

In the United States in 2010, irrigation accounted for 33% of total fresh and saline withdrawals (Maupin et al., 2014). Tennessee specifically has shown a 211% increase in acres irrigated from 1997 – 2012 (USDA, 2012), a number which could potentially be underestimated as farmers are likely to overwater once irrigation systems are installed (Henry and Bowen, 1981). Since the agriculture industry withdraws large volumes of water, and most of the agricultural sector's water goes towards irrigation (UNPF, 2003), evaluating the value of water among agricultural sectors could be useful for policy makers and farmers alike. The evaluation could help Tennesseans decide what route they want to take in the future to alleviate any potential water stress within the agricultural sector and also other sectors that are competing for Tennessee's water resources. The evaluation also helps policymakers anticipate sources of water stress and develop plans now to mitigate the stress. There is a gap in knowledge about the economic value of water in Tennessee for both agricultural and non-agricultural industries because water is not traded on a free market and little is known about the relative value of water in its many uses.

The literature does not provide economic values of water for competing Tennessee users and has little information on Tennessee water demand, withdrawal, and use outside of what the USGS provides. Therefore, there is a lack of knowledge on which sectors of the Tennessee economy, whether agriculture or other industries have higher economic values for water and which sectors provide the largest contribution to the state's gross regional product (GRP) based on water withdrawals. It is also unclear how the economy will respond to variation in water availability. This information could provide insight on how water can be conserved and allocated efficiently among users to maximize the benefits to the economy and to sustain water resources.

## **Research Objectives**

The objectives of this study are to 1) determine the amount of water used by economic sectors per dollar of output, 2) estimate the shadow value of water for each industry, and 3) evaluate economic implications of changes in water availability on competing sectors.

Chapter 2 discusses estimating water use coefficients for use in an input-output model, and Chapter 3 discusses use of an input-output linear programming model to maximize gross regional product for Tennessee's economy and to find shadow values for water.

## **CHAPTER 2: Determining Water Use Coefficients for an Input-Output Model**

## **Abstract**

Providing an economic valuation for water is a complex issue for many reasons including public perception of water policies, the life cycle of water resources, and the uncertainty of water quality and quantity in years to come. Due to the controversy surrounding the use and management of water resources, it is difficult to quantify how much water is worth to an individual, a nation, or any entity in between. This chapter provides a valuation of water based on empirical data that does not answer the question of how Tennessee should value water but rather answers the question of how Tennessee is using its water and the value of economic activity associated with those uses. This valuation estimates water use in acre feet per dollar of output for 536 economic sectors identified in the Impact Analysis for Planning model (IMPLAN). The resulting water use coefficients can effectively be used in an Input-Output model to evaluate linkages between industries and to establish the foundation needed to develop plans for sustainable water use and economic prosperity in Tennessee.

## **Problem Identification and Explanation**

Tennessee falls under the riparian rights doctrine which grants landowners the right to use water adjacent to or on their land as long as the use is “reasonable with respect to the requirements of all other riparian owners” (SRWP, 2015). Registration of withdrawals is only required for withdrawals over 10,000 gallons per day (gpd), and this excludes water used for agriculture and water purchased from an industry (NCSL, 2015). The Tennessee Water Resources Information Act of 2002 created The Water Resources Technical Advisory Committee (WRTAC) that advises the Tennessee Department of Environment and Conservation (TDEC), and although funding is currently not in place for a regional water plan, with two pilot studies underway, WRTAC urges state agencies to lobby for one (TDEC, 2013).

The WRTAC concludes that among other benefits, a regional water resource plan would

- help prepare the state for uncertainty caused by climate variability,
- increase sustainability, and
- encourage counties to cooperate in dealing with water resource and supply issues (TDEC, 2013).

A regional water plan could help guide the sustainable use of Tennessee's water resources by providing guidelines on water allocation and withdrawal limitations. Following the concept of Integrated Water Resources Management (IWRM), which is "a process which promotes the coordinated development and management of water, land, and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems," a regional plan can emphasize teamwork among state agencies to both protect water resources as well as promote economic development, growth, and prosperity (GWP, 2015). Much like a Tennessee regional water plan, however, IWRM has yet to be clearly defined and implemented (Biswas, 2004; Rahaman and Varis, 2005; Jonch-Clausen and Fugl, 2001).

Assuming that policy makers will want to follow IWRM principles and develop a regional plan that maximizes economic and social welfare, it is useful to assign an economic value of water to each withdrawing sector that can be related to the economy. Before determining value, the quantity of water required to meet the existing or projected production levels is needed.

## **Research Objectives**

The objective of this chapter is to estimate water withdrawals used to meet current production levels for each economic, government, and household sectors in Tennessee.

## **Literature Review**

Ward and Michelson (2002) provide a synopsis of the economic principles used for evaluating the values of water and give an idea of what types of methods can be used to do so. A few of the methods used to estimate the economic value of water include:

- market and administered prices such as paid to utility companies,
- changes in net income due to water use when water is an intermediate good such as in hydroelectric power generation, and
- measurements of productivity such as increases in yield for increases in water applied to irrigated crops.

Young and Loomis (2014) also provide an explanation and critique of methods for finding the economic value of water. The methods and critiques are summarized in Table 1. There is no single economic value for water, and each method mentioned is useful under certain circumstances. For this application, shadow values are needed to evaluate impacts of future policy proposals (Ward and Michelson, 2002). Future policy proposals may include policies that limit water withdrawals, allocate water supply, or regulate water withdrawals to maintain and protect the economy and natural resources.

The method chosen to evaluate the economic value of water is referred to as input-output analysis (IOA). IOA was chosen because it incorporates supply chain linkages by sector. Supply chain linkages are useful for analyzing the connection between sectors and the impacts of water withdrawal variability throughout the economy.

Young and Loomis (2014) provide an in-depth critique of IOA as a means of estimating a value for water. The main issues discussed include that IOA:

- does not account for product substitution in consumption or input substitution in production,
- does not consider the constrained optimization or resource constraints of a firm, and
- the values of water and related impacts tend to be overstated.

Another area of concern is that the model assumes proportionality where a 20% increase in output leads to a 20% increase in water use (Hendrickson et al., 1998).

IOA was first developed in the 1930s as a way to evaluate the interdependencies of different economic sectors through use of monetary data (Leontief, 1936). In the late 1960s and early 1970s, IOA began to be applied to natural resource issues such as pollution (Isard et al., 1968; Leontief, 1970) and to examining the benefits of resources to residents (Gray and English, 1976). Since then, IOA has continued to evolve and has been applied to several different types of environmental issues including emissions, energy, and water (Cicas et al., 2007; Reynolds et al., 2015; Norman et al., 2007; Sun and Pratt, 2014).

IOA was originally designed to be used on a macro scale using national data to evaluate direct and indirect linkages between sectors. (Leontief, 1936; Cicas et al., 2007). However, not all indirect contributions can be determined because of the continuous circular cycle of trade among industries (Hendrickson et al., 1998). To complete life cycle assessment analysis on a regional level, hybrid methods must be used that combine national accounts with regional data (Blackhurst et al., 2010; Cicas et al., 2007; Hendrickson et al., 1998). Regional economic and environmental data are often limited or non-existent making it difficult to use IOA on a regional, state, or local basis. However, by aggregating available data in combination with regional

economic modelling software, such as IMPLAN, a regional model can be achieved (Cicas et al., 2007).

IMPLAN was initially developed in 1976 by the USDA Forest Service (IMPLAN, 2015; Young and Loomis, 2014) and provides a detailed IO framework of the United States economy by disaggregating the economy into over 500 sectors (IMPLAN, 2015; NAICS 2015). IMPLAN is versatile in its applications and provides the coefficients for the total requirements matrix as well as multipliers that can be used to assess economic activities (Otto and Johnson, 1993). Multipliers show how the economy will be affected by each additional dollar of final demand. Common multipliers include output, income, and employment multipliers (Otto and Johnson, 1993). IMPLAN provides Type 1 multipliers which means the multipliers include both direct and indirect effects (Cicas et al., 2007; Otto and Johnson, 1993). There are other models that use Type 2 multipliers which also include induced effects, but for purposes in this study only Type 1 multipliers are needed for finding the impacts of changes in direct and indirect water use (Otto and Johnson, 1993). Direct water use includes water withdrawn for the sector itself whereas indirect water use includes water in the sector's supply chain (Blackhurst et al., 2010).

Previous IOA studies have found agriculture to be the highest water user and as a result, many have concluded that the agriculture industry should be regulated (Mubako et al., 2013; Guan and Hubacek, 2007; Velazquez, 2006; Hubacek and Sun, 2005). Lenzen (2009) mentioned that their study was initially conducted for the Australian government as a way of demonstrating that agricultural users were not the only ones who need to be monitored. Duarte et al. (2002) found that reducing agriculture's water use could economically affect other industries. Based on their results and similar studies, it is expected that the results of this model will show that agriculture has the lowest value of water even though it will most likely be one of the highest

water users among the industries (Mubako et al., 2013; Velazquez, 2006; Hubacek and Sun, 2005).

As mentioned previously, before determining value, the quantity of water used by each sector to meet current production is needed. While the United States Geological Survey (USGS) does provide water withdrawals by county for different categories, the categories provided are not sufficient for what is needed in this study. The USGS withdrawals are not sufficient because they are not specific on the amount of withdrawals from each sector. For example, the USGS provides data for total irrigation withdrawals but does not provide information on withdrawals for specific crops. Therefore, the irrigation withdrawal category has to be proportionally redistributed so that the withdrawals can be related to individual economic sectors, such as the oilseed and grain farming sector. Similarly, all USGS water withdrawal categories need to be distributed among economic sectors to estimate water withdrawals per sector that can be used in determining water use coefficients useful for IOA modelling such as in Chapter 2.

## **Available Data and Methods**

### **Water Withdrawals**

The data for this study consist of a combination of publicly available data from the USGS (2010) and the United States Department of Agriculture (USDA, 2012; USDA 2013) as well as transactions data purchased from IMPLAN Group, LLC (2013). These data were combined to generate water withdrawal estimates and water used per dollar of output estimates.

The Tennessee 2010 water withdrawal estimates were provided by USGS for eight categories (USGS, 2015; Maupin et al., 2014). The estimated per gallon per day water estimates provided by USGS are an average daily rate of withdrawal over a single year (Maupin et al., 2014). The eight categories are:

1. Public Supply – This sector is comprised of water withdrawn by public and private water suppliers. This includes “public supply total self-supplied withdrawals, total, in mgal/d.” However, because there is not an economic sector that represents household water use, “public supply deliveries to domestic, in mgal/d” was subtracted out to reflect the value in Table 2 (Blackhurst et al., 2010). “Public supply deliveries to domestic” represents 470.45 mgal/d or 6.11% of total Tennessee water use that is not accounted for in the IOA.
2. Domestic – This sector is comprised of water withdrawals that are self-supplied, from streams or wells, for domestic use. This is “domestic total self-supplied withdrawals, fresh, in mgal/d.” Domestic self-supplied withdrawals were not included with the industrial water sector because households are included in final demand of the IOA (Blackhurst et al., 2010).
3. Irrigation – This sector is comprised of water withdrawn to sustain horticultural or agricultural practices from both surface and groundwater reserves. This consists of “irrigation, total self-supplied groundwater withdrawals, fresh, in mgal/d” and “irrigation, total self-supplied surface-water withdrawals, fresh, in mgal/d.”
4. Thermoelectric Power – This sector is comprised of water withdrawn to generate electricity where the water is mainly used for cooling. This includes “total thermoelectric power total self-supplied withdrawals, total, in mgal/d.”
5. Industrial – This sector is comprised of water withdrawals that are self-supplied, from streams or wells, for manufacturing, processing, and other industrial activities. It consists of “Industrial total self-supplied withdrawals, in mgal/d.”
6. Mining – This sector is comprised of water withdrawn to facilitate the extraction of minerals. This consists of “mining total self-supplied withdrawals, in mgal/d.”

7. Livestock – This sector is comprised of water withdrawals that are self-supplied, from streams or wells, for livestock operations such as watering. This consists of “livestock total self-supplied withdrawals, fresh, in mgal/d.” This sector does not include water used for on-farm irrigation.
8. Aquaculture – This sector is comprised of self-supplied water withdrawals from streams or wells, for raising organisms that live in water. This consists of “aquaculture total self-supplied withdrawals, fresh, in mgal/d.” (USGS, 2010; USGS 2015)

The withdrawals (Table 2) for the eight aggregate USGS categories were distributed across 536 economic sectors according to the IMPLAN structure. For the agricultural sectors, the eight categories were first allocated to North American Industry Classification System sectors (NAICS). NAICS sectors were used for the agricultural sectors because NAICS data were available from the USDA and provided a benchmark throughout the calculation of water withdrawal estimates. The NAICS sectors can be related to the IMPLAN sectors using relationship tables provided by NAICS (2015). These data were used to estimate water withdrawals by sector using total industry output estimates provided in the transactions data for all non-agricultural sectors.

### **Irrigation, Livestock, & Aquaculture**

First, the number of irrigated acres for each crop for each county had to be determined for the seven NAICS crop sectors that could then be disaggregated into the ten corresponding IMPLAN crop sectors. Because the USGS Livestock category water withdrawal estimate does not include water used for on-farm irrigation, all irrigated acres on livestock operations from the seven NAICS livestock sectors had to also be accounted for in the USGS Irrigation sector.

First this was done for the seven NAICS crop sectors. To do this, irrigated acres and irrigated number of farms data for each county were taken from the 2007 Census of Agriculture (USDA, 2007) for each specific crop that fell within a specific NAICS sector. Data for most of the crops contained several “(D)” values in the irrigated acres column which meant the information was withheld for that county to avoid disclosing data for individual farms. The formula to estimate the number of “missing” irrigated acres the (D) values contain for each crop is:

$$T_j^{Cen} - \sum_i P_{ij} = N_j \quad (1)$$

where:  $T_j^{Cen}$  is the total number of irrigated acres for crop  $j$  in all counties in Tennessee,  $P_{ij}$  is the number of known irrigated acres available from the data in county  $i$  for crop  $j$ , and  $N_j$  is the value for the total number of missing irrigated acres for crop  $j$  in all counties (USDA, 2012). The  $N_j$  value can be allocated to counties with missing values by using regional farm size ratios written as:

$$\frac{P_{jr}}{F_{jr}} = B_r \quad (2)$$

where:  $r$  is Agricultural Statistic District (ASD) (NASS, 1988) in Tennessee,  $P_{jr}$  is the total number of known irrigated acres for crop  $j$  in ASD  $r$ ,  $F_{jr}$  is the total number of known irrigated farms for crop  $j$  in ASD  $r$ , and  $B$  is the ratio of number of irrigated acres per irrigated farm in ASD  $r$ . The regional ratio can then be multiplied by the number of farms to fill in the missing values. This equation is written as:

$$B_r \cdot F_{ij}^{NAICS} = N_{ij} \quad (3)$$

Where:  $F_{ij}^{NAICS}$  is the number of NAICS farms in county  $i$  for crop  $j$ , and  $N_{ij}$  is the number of irrigated acres assigned to the missing value for crop  $j$  in county  $i$ . After all of the missing values have been assigned a value for number of irrigated acres, the sum of total irrigated acres,  $T^{Irr.}$ , needs to be benchmarked to the total number of irrigated acres provided by the Census of Agriculture. To avoid changing any of the known irrigated acres values, only those that were previously missing values are changed to benchmark to the state total. This is done by multiplying the calculated irrigated acres of each missing value by the ratio:

$$\frac{T_j^{Cen} - \sum_i P_{ij}}{T^{Irr.} - \sum_i P_{ij}} = B^{NASS} \quad (4)$$

where:  $B^{NASS}$  is the ratio of the state total of irrigated acres minus the sum of the total number of reported irrigated acres in the state divided by the calculated total of irrigated acres including inferred values minus the total number of reported irrigated acres. The sum of the total irrigated acres should be equal to the state total provided by the Census of Agriculture. The next step is to look at the number of NAICS farms in each county. For counties that show farms within the NAICS sector, leave the irrigated acres the same. For counties that show zero farms within the NAICS sector, zero out the number of irrigated acres. Sum up this total of irrigated acres and then benchmark it to the state NAICS total for irrigated acres using the equation:

$$\frac{T^{NAICS} - P_j}{N_j} = B^{NAICS} \quad (5)$$

where:  $T^{NAICS}$  is the total number of irrigated acres in the NAICS sector,  $P_j$  is the total number of known irrigated acres for crop  $j$ ,  $N_j$  is the total number of irrigated acres assigned to the (D) values for crop  $j$ , and  $B^{NAICS}$  is the ratio used to benchmark irrigated acres to the NAICS total. If the benchmark ratio was negative, meaning that the total number of irrigated acres provided by

NASS was greater than the total number of irrigated acres provided by NAICS, then a ratio of NAICS total number of irrigated acres divided by NASS total number of irrigated acres was used to benchmark the acreage back to the NAICS total.

Due to the lack of data available in the Greenhouse NAICS sector, all crops (D) values were filled in using an average farm size ratio at the state level and then benchmarked to NAICS using a NAICS divided by NASS ratio. For the Livestock sectors, a NAICS state total for number of irrigated acres was not available so the calculations stop after acres are subtracted out for counties that do not have NAICS farms. The new number is assumed to be the NAICS state total.

As mentioned previously, because the USGS Livestock sector estimated withdrawal does not include water used for on-farm irrigation, all irrigated acres on livestock operations from the seven NAICS livestock sectors has to also be accounted for and added in to the USGS Irrigation sector. NAICS sectors are based on primary activities which means irrigation of crops would not be the primary activity of a livestock sector. For this reason the number of irrigated crop acres from the livestock NAICS' sectors need to be determined using similar methods as before. The state level irrigated acres for "Cattle Feedlots" and "Sheep and Goat Farming" NAICS sectors show as missing values so the number of irrigated acres missing was inputted using:

$$T^{Livestock} - \sum_k T_k^{Livestock} = N^{Livestock} \quad (6)$$

where:  $T^{Livestock}$  is the total number of irrigated acres published for all livestock NAICS sectors and  $k$  is the NAICS sectors (USDA, 2012). Once the total number of acres in the (D) values was determined, the number of acres for each NAICS sector with a (D) value was determined as:

$$N^{Livestock} \cdot \frac{T_k^{Livestock \text{ Ac.}}}{\sum_k T_k^{Livestock \text{ Ac.}}} = N_k^{Livestock} \quad (7)$$

where:  $T_k^{Livestock\ Ac.}$  is the total number of irrigated and non-irrigated acres in sector  $k$ . After all state level irrigated acres values are calculated, a ratio can then be used to determine the number of irrigated farms in each county:

$$\frac{T_{ik}^{Livestock\ Farms}}{T_k^{Livestock\ Farms}} \cdot T_k^{Irr.Livestock\ Farms} = T_{ik}^{Irr.Livestock\ Farms} \quad (8)$$

where:  $T_{ik}^{Livestock\ Farms}$  is the total number of irrigated and non-irrigated farms in county  $i$  for sector  $k$ ,  $T_k^{Livestock\ Farms}$  is the total number of irrigated and non-irrigated farms in sector  $k$ ,  $T_k^{Irr.Farms}$  is the total number of irrigated farms in sector  $k$ , and  $T_{ik}^{Irr.Livestock\ Farms}$  is the total number of irrigated farms in county  $i$  for sector  $k$ . Next the irrigated acreage for each county in each NAICS sector was determined using the average farm size ratio:

$$T_{ik}^{Irr.Livestock\ Farms} \cdot \frac{N_k^{Livestock}}{T_k^{Irr.Livestock\ Farms}} = N_{ik}^{livestock} \quad (9)$$

All of the livestock sectors' irrigation then has to be assigned to NAICS crop sectors. This can be written as:

$$N_i^{livestock} \cdot \frac{N_{ik}}{\sum_k N_{ik}} = N_{ik}^{livestock} \quad (10)$$

To get the final sum of irrigated acres in each NAICS crop sector per county, add the acres initially calculated for the crops sectors plus the acres calculated from the livestock sectors to each crop sector. Once all irrigated crop sector acres have been calculated, the estimated water withdrawal of each crop within a county can be found using a non-linear proportional reallocation method (NPR). For the Irrigation and Livestock sectors, NPR, similar to what Lambert et al. (2014) used to come up with post-stratification weights and Ireland and Kullback (1968) used to balance two-way classification tables, was used to allocate the total USGS self-supplied irrigation/livestock water withdrawals for each county to different NAICS sectors

within the county by portioning out the total USGS withdrawal using weights specific to each NAICS sector and an estimated multiplier. The NPR method was used because it allows for the inclusion and proportioning of total water based on biological water requirements. The NPR equation can be written as:

$$\text{Min}_\lambda Z = 0$$

Subject to:

$$W_i^{USGS} - \sum_{j=1}^j \exp(-1 - \lambda \cdot A_j^{Irr.}) \cdot A_j^{Irr.} = 0 \quad \forall i \quad (11)$$

where:  $Z$  is the difference between the USGS water withdrawal estimate and the estimate calculated in the second part of the constraint  $\sum_{j=1}^j \exp(-1 - \lambda \cdot A_j^{Irr.}) \cdot A_j^{Irr.}$ ,  $i$  represents the 95 Tennessee counties,  $j$  represents the different crops including corn for grain, rice, soybeans, wheat, corn for silage, vegetables and melons, fruit and tree nuts, tobacco, cotton, greenhouse and floriculture, and other miscellaneous crops,  $W_i^{USGS}$  is the USGS water withdrawal estimate for county  $i$ ,  $\exp(-1 - \lambda \cdot A_j^{Irr.})$  is the calculated weight for each crop  $j$  in county  $i$ ,  $\lambda$  is a proportional weighting factor, and  $A_j^{Irr.}$  is a weight that can be used for each crop sector. In the case of the Irrigation sector calculations,  $A_j^{Irr.}$  is the number of irrigated acres of crop  $j$  multiplied by the water requirement for each crop type (USDA, 1978). In the Livestock sector, it would be the number of head multiplied by the water requirement per head (Ontario, 2010; Clemson, 2015) for that particular kind of animal in acre feet per year. Biological water requirements (Clemson, 2015; Ontario 2015; USDA 1978) were considered to capture the differences in water consumption among different crop and livestock breeds.

For consistency in explanation, the Irrigation example will be used going forward. When the calculated weight  $\exp(-1 - \lambda \cdot A_j^{Irr.})$  is multiplied by the irrigated acreage for crop  $j$  in

county  $i$ , it returns the estimated water withdrawal for crop  $j$  in county  $i$ . To get the final irrigation withdrawal per NAICS sector, simply add the estimated water withdrawals for all of the crops within that NAICS sector.

Upon completion of calculating water withdrawals for all NAICS sectors within the irrigation USGS sector, the water withdrawals in the NAICS sectors can then be distributed to the ten economic crop sectors in IMPLAN. As an example, the Oilseed and Grain Farming NAICS sector can be split into the Oilseed IMPLAN sector and the Grains IMPLAN sector. Since water withdrawals were determined for individual crops, add the withdrawals for crops that fall into a certain NAICS/IMPLAN sector. For example, the withdrawals for corn, rice, soybeans, and wheat could be added together to get the total withdrawal for the NAICS sector Oilseed and Grain Farming. Corn, rice, and wheat could be separated out to then get the total withdrawal for the IMPLAN Grain Farming sector.

For aquaculture, USGS estimated county water withdrawals were added to the livestock NAICS sector “Animal aquaculture and other animal production (1125,1129)” and to the IMPLAN sector “Animal products, except cattle and poultry and eggs (including aquaculture).” Aquaculture was not separated out into types of aquaculture due to lack of detailed and available information.

### **Public Supply**

The USGS public supply category withdrawal consists of water delivered to domestic users and economic sectors. USGS only reports total self-supplied withdrawals for Public Supply meaning they only report how much water a county supplies publicly to itself from water resources within the county. However because many counties buy and sell water from surrounding counties, to get the net Public Water Supply, purchases and sales also have to be

included (Harris, 2016). Public Supply deliveries to domestic were subtracted from the net public supply withdrawals because households are not represented in the 536 IMPLAN sectors (Table 2). The remaining water which is “non-domestic public supply” is what is used for the calculation, and the following public supply calculations only include water delivered to the 536 IMPLAN sectors, some of which also self-supply water. To get the non-domestic, public supply water withdrawal for each county, Public supply withdrawals were found for the IMPLAN sectors using a method similar to Blackhurst et al. (2010) assuming that sewage and water charges are the same across all counties. The equation is:

$$\frac{G_{ni|3051}}{\sum_n G_{ni|3051}} * W_i^{USGS} = W_{ni}^{Public} \quad (12)$$

where:  $W_{ni}^{Public}$  is the estimated Public Supply water withdrawal for IMPLAN sector  $n$  in county  $i$ ,  $G$  is sector  $n$ 's purchase in county  $i$  from sector 3051 which is the IMPLAN sector for “Water, Sewage, and Other Systems,” and  $W_i^{USGS}$  is the USGS non-domestic, public supply deliveries water withdrawal for county  $i$ .

### **Mining and Industry**

For the USGS Mining and Industry sectors, water withdrawal coefficients from Blackhurst et al.'s national economic input-output model (CMU, 2016) were used to create water withdrawal coefficients applicable to current regional output. The national coefficients needed to be updated to reflect current sectoral outputs that could be related to current regional withdrawals. The original coefficients were found using the equation:

$$\frac{W_n^B}{E_n^B} = u_n^B \quad (13)$$

where:  $W_n^B$  is the water withdrawal from Blackhurst et al.'s national model  $B$  for sector  $n$ ,  $E_n^B$  is the direct economic output from Blackhurst et al.'s model  $B$  for sector  $n$ , and  $u_n^B$  is the water withdrawal coefficient for sector  $n$  using the data from Blackhurst et al.'s model  $B$ . These coefficients were then updated using the equation:

$$u_n^B * O_{ni}^{2013} = W_{ni}^{est.} \quad (14)$$

where:  $O_{ni}^{2013}$  is the 2013 total industry output (TIO) for sector  $n$  in county  $i$ , and  $W_{ni}^{est.}$  is the estimated water withdrawal for sector  $n$  in county  $i$ . To benchmark each county's estimated withdrawal to the USGS's county estimated withdrawal, the non-USGS estimated withdrawal for each sector was multiplied by a ratio of the two. The equation is:

$$W_{ni}^{est.} * \frac{W_i^{USGS}}{W_i^{est.}} = W_{ni} \quad (15)$$

where:  $W_i^{USGS}$  is the USGS estimated water withdrawal for county  $i$ , and  $W_{ni}$  is the updated water withdrawal for sector  $n$  in county  $i$ , such that:

$$\sum_n W_{ni} = W_i^{USGS} \quad (16)$$

### **Thermoelectric**

For the USGS thermoelectric category, IMPLAN sectors 519 – “Federal Electric Utilities” and 525 – “Local Government Electric Utilities” were combined into one sector that was labeled “Government Utilities Power Generation.” TIO for sectors 519 and 525 therefore had to be combined to derive the “Government Utilities Power Generation” sector water coefficients. However, IMPLAN includes both “power generation” and “transmission and distribution” in the final TIO number, and the USGS self-supplied thermoelectric withdrawal only includes water used for power generation. To separate the water that was used for power

generation from the water that was used for transmission and distribution, another sector was created called “Government Utilities Electric Power Transmission and Distribution.” All of the USGS self-supplied thermoelectric water was put into the “Government Utilities Power Generation” sector. Then the estimated withdrawals for sectors 519 and 525 that were estimated during the Public Supply calculations needed to be allocated to the two new sectors. To do this, each county’s estimated public supply withdrawal for sector 519 and 525 was multiplied by the percentage of total TIO that went to power generation for that county and sector and was assigned to the new sector “Government Utilities Power Generation.” The remaining water was assigned to the “Government Utilities Electric Power Transmission and Distribution” sector. The final list of sector numbers and descriptions are in Table 3.

### **Limitations of Methods**

The sectors’ withdrawals, in many cases, are distributed by TIO with the assumption that TIO is a valid determinant on how much a sector withdraws. However, some sectors will use more, or less, water to produce the same amount of TIO as another sector. Therefore, it would be useful to use other weighting factors when available.

There is a concern that the Public Supply calculation does not separate water from sewage purchases. While this concern is not corrected in this analysis, future studies could benefit from making a distinction between purchases made for water and purchases made for sewage or other services. Making this distinction would help avoid over-estimation of the amount of water delivered to sectors from public supply. Future studies could also determine pricing among different utility companies in different counties to account for the variation in water withdrawals based on pricing. For example, if water is priced relatively high in a specific

county, it may lead users to purchase less water in that county than in a county where the price of water is relatively low.

### **Water Use Coefficients**

Once water withdrawals for all 536 IMPLAN sectors have been determined the water coefficients that represent water withdrawals per unit or dollar of production can be determined by dividing water withdrawals in each sector by output for each sector (Blackhurst et al., 2010; Hendrickson et al., 1998; Velazquez, 2006). This can be written as:

$$u_{ni} = \frac{W_{ni}}{Z_{ni}} \quad (17)$$

where:  $u_{ni}$  is the water coefficient for IMPLAN sector  $n$  in county  $i$ ,  $W_{ni}$  is the total water withdrawal for IMPLAN sector  $n$  in county  $i$ , and  $Z_{ni}$  is the total industry output (TIO) for IMPLAN sector  $n$  in county  $i$ . Coefficients cannot be found for sectors within counties that do not have a TIO in IMPLAN. For this reason, if there is not a TIO, then a withdrawal is not allocated to that county and sector. The absence of a TIO value in a sector means that the sector does not exist or produce within that county

## **Results and Discussion**

### **Results**

Water use coefficients were found for each of the 536 IMPLAN sectors at the county level for each of Tennessee's 95 counties. Coefficients were estimated for each sector at the county level so that individual sector or county analysis could be conducted. Having the data defined by the sector and county level allows for the aggregation of sectors and counties to specific regions and aggregated sectors for unique analysis. For example, in this analysis counties were aggregated into 4 hydrologic unit regions based on watershed boundaries (USGS, 2016), and similar IMPLAN industries were aggregated into 21 sectors (Table 3). This

aggregation allows for the evaluation of relatively different competing sectors in four geographical areas in Tennessee for an overall synopsis of the state withdrawals. Figure 1 depicts which hydrologic region each county falls into, and the aggregated sectors are defined in reference to Table 3 as follows:

- *Primary Agriculture Crops* – Consists of economic sectors 1 through 10 and 19
- *Primary Agriculture Livestock* – Consists of economic sectors 11 through 14, 17, and 18
- *Forestry Inputs* – Consists of economic sectors 15 and 16
- *Mining* – Consists of economic sectors 20 through 38
- *Services* – Consists of economic sectors 39, 40, 415 through 432, 442 through 471, 474-512, and 517
- *Utilities* – Consists of economic sectors 41 through 50
- *Water, sewage and other systems* – Consists of economic sector 51
- *Construction* – Consists of economic sectors 52 through 64
- *Secondary Agriculture* – Consists of economic sectors 65 through 106 and 108 through 133
- *Manufacturing* – Consists of economic sectors 107, 154 through 168, 173 through 209, 211 through 261, 264 through 268, 270 through 367, 375, and 379 through 394
- *Primary Forestry* – Consists of economic sectors 134, 135, 146 through 148, and 269.
- *Secondary Forestry* – Consists of economic sectors 136 through 145, 149 through 153, 368 through 374, and 376 through 378
- *Agriculture Inputs* – Consists of economic sectors 169 through 172, 210, 262, and 263
- *Wholesale trade* – Consists of economic sector 395
- *Retail Trade* – Consists of economic sectors 396 through 407

- *Transportation* – Consists of economic sectors 408 through 414
- *Finance* – Consists of economic sectors 433 through 436 and 439
- *Insurance* – Consists of economic sectors 437 and 438
- *Real Estate* – Consists of economic sectors 440 and 441
- *Government* – Consists of economic sectors 472, 473, 518 through 524, and 529 through 536
- *Miscellaneous* – Consists of economic sectors 513 through 516 and 525 through 528

The final water use coefficients in Tables 4 through 7 provide some details on water withdrawals per dollar of output for competing sectors. The government sector uses more water per dollar of output than any other sector in three out of the four regions. Only in the Mississippi River region does the government sector come second to the primary agriculture livestock sector. Primary agriculture livestock comes in second in every other region. Primary forestry has the third highest water use per dollar of output in the Lower and Upper Tennessee River regions and primary agriculture crops have the third highest water use per dollar of output in the Cumberland River and Mississippi River regions. The high relative water use per dollar of output demonstrated for agriculture-related sectors corresponds with what previous studies have found in other geographic locations (Mubako et al., 2013; Velazquez, 2006; Hubacek and Sun, 2005). Further, government and agricultural industries generate the least industry output in dollars for each acre foot of water used indicating a relatively higher water withdrawal for each unit of output produced than other competing sectors.

In contrast, the forestry inputs, real estate, and insurance sectors use the smallest quantities of water per dollar of output across the regions. Naturally, agricultural-related sectors require more water to generate a unit of output, but competing sectors that withdraw relatively

smaller quantities of water in some cases are producing more total output in dollars. Therefore, competing sectors generate more economic activity per acre foot of water. For this reason, effects of possibilities such as an increase in output for high water use sectors or a decrease in water withdrawals for low water use sectors could be considered in evaluating the sustainability of the state's water resources.

Interestingly, the Upper Tennessee River region contains about half of the state's total water withdrawals but only produces a little over one third of the state's total output. In contrast, the Cumberland River region withdraws less than one third of the state's total withdrawals yet generates over one third of the state's total TIO. Similarly to the Upper Tennessee River region, the Lower Tennessee River region produces a smaller percentage of TIO than the percentage of water withdrawn in that region, but the Mississippi River region is more similar to the Cumberland River region in that it generates a higher percentage of output than the percentage of water it has available. Service and manufacturing sectors appear to generate the highest total value of output for each region, but further investigation needs to be done on individual industries to explain why certain regions' TIOs seem low for their water withdrawals, specifically why the Upper Tennessee River region withdraws the largest amount of water but does not generate the highest value of output. The correlation between water withdrawal and output could be determined to see if withdrawal indicates TIO value. Factors such as the water market in Tennessee and what determines the value of output for each sector would be useful in applying these coefficients.

### **Application of Results**

The water use coefficients provided in this chapter are useful for an array of analyses. They can be combined with IOA and used to estimate direct and indirect water use per sector

(Blackhurst et al., 2010), estimate the average value of water to gross regional product (Henry and Bowen, 1981), and estimate shadow values of water for each sector which will be discussed in Chapter 2 (Henry and Bowen, 1981). Using these coefficients with IOA provides insight on the linkages between sectors which is useful in considering a regional water plan, determining which type of industries to recruit into the state, planning for trade with other states and regions, and evaluating sustainable water use. Since agriculture for example needs a relative large amount of water compared to other sectors to produce one dollar of output, it could be useful to look at best management practices within the livestock and crop industries that can be implemented to improve water use efficiency. For example, it would be useful if best management practices could be implemented that use the same or less amount of water but produce more output. It's important to note, however, that even if the agricultural industry makes water use improvements such as increased irrigation efficiency, it does not necessarily mean there will be more water available for other industries to use (Ward and Pulido-Velazquez, 2008). It would also be useful to examine the linkages between sectors to see how a change in water use in one sector would affect the output of other sectors. Since many sectors are connected, an increase or decrease in output in one sector could affect the inputs needed for output in other sectors.

Aggregating the data to hydrologic regions gives more insight on what is happening within certain geographical areas and watersheds which is useful when thinking about the effects of climate change on water resources, and since the water use coefficients were estimated at the county level, they can be aggregated a number of other ways to consider regions specific to different analyses. Similarly, the economic sectors can also be aggregated in a number of ways to depict specific industries or they can be used at the disaggregated level to compare different

economic activities such as types of crops within agriculture or types of manufacturing within industries.

## **Discussion**

The resulting water use coefficients are a building block to answering the questions Tennessee faces currently and will face in the future regarding water availability, use, sustainability, and conservation. These results should be examined in conjunction with other studies to determine the best way to move forward to create a resilient economy for Tennessee that is not at the expense of water resources. Similar coefficients could be determined for other resources and emissions as well to really hone in on what the costs and benefits of our different sectors are and to determine which industries to nurture going forward and which ones to re-assess. Climate change, population growth, and aging infrastructure are inevitable, but with the right tools Tennessee can be proactive in negating potential issues surrounding the availability and use of water for the foreseeable future.

## **Limitations of Results**

While the results of this chapter provide useful information, it is important to consider the limitations of these results. One important limitation with the results revolves around the data. The IMPLAN data was from year 2013 whereas crop data was from year 2007, and water data was from 2010. These sets of data represent the most up-to-date information provided by their respective organizations with the exception that more recent crop data was available for 2012. However, because 2010 was the most recent water data available, which was partially based off of the 2007 crop dataset, the 2007 crop dataset was used. In addition, each organization providing data uses different surveys and methods to obtain their information which means the data sources may not always line up perfectly with one another. As research on water-related

topics expands and more data is available, it will be important to update the water use coefficients.

Another limitation of this chapter's results is that the water use coefficients were specifically estimated for Tennessee. While the coefficients provided may be useful to use in other states or regions where there is a lack of data available or perhaps a similar economy and water resources, it is encouraged that each state estimate its own water use coefficients to account for variation in industries, agricultural practices, data sources, and water availability and needs.

## References

- Arnell, N. W. "Climate Change and Global Water Resources: SRES Emissions and Socio-economic Scenarios." *Global Environmental Change-Human and Policy Dimensions* 14(April 2004): 31-52.
- Biswas, A.K. "Integrated Water Resources Management: A Reassessment." *Water International* 29(2004):248-256.
- Blackhurst, M., C. Hendrickson, and J.S. I Vidal. "Direct and Indirect Water Withdrawals for U.S. Industrial Sectors." *Environmental Science and Technology* 44(February 2010): 2126-2130.
- Borisova, T., J. Evans, M. Smolen, M. Olexa, D.C. Adams, and J. Calabria. "Current and Future Water Availability: Public Opinion in the Southern United States." *Journal of Extension* 51(February 2013): 1RIB7.
- Carnegie Melon University (CMU). Internet site:  
<http://www.eiolca.net/Models/USmodels/US02ProducerPrice.html> (Accessed April 01, 2016).
- Cicas, G., C.T. Hendrickson, A. Horvath, and H.S. Matthews. "A Regional Version of a US Economic Input-Output Life-Cycle Assessment Model." *The International Journal of Life Cycle Assessment* 12(September 2007):365-372.
- Clemson University – Clemson Cooperative Extension (Clemson). Internet Site:  
[http://www.clemson.edu/extension/ep/food\\_water\\_req.html](http://www.clemson.edu/extension/ep/food_water_req.html) (Accessed on November 1, 2015).
- Duarte, R., J. Sanchez-Choliz, and J. Bielsa. "Water Use in the Spanish Economy: an input-output approach." *Ecological Economics* 43(November 2002):71-85.
- Elliott, J., D. Deryng, C. Mueller, K. Frieler, M. Konzmann, D. Gerten, M. Glotter, M. Florke, Y. Wada, N. Best, S. Eisner, B.M. Fekete, C. Folberth, I. Foster, S.N. Gosling, I. Haddeland, N. Khabarov, F. Ludwig, Y. Masaki, S. Olin, C. Rosenzweig, A.C. Ruane, Y. Satoh, E. Schmid, T. Stacke, Q.H. Tang, and D. Wisser. "Constraints and Potentials of Future Irrigation Water Availability on Agricultural Production under Climate Change." *National Academy of Sciences of the United States of America* 111 Proceedings, 2014, pp. 3239-3244.
- Finnveden, G., M.Z. Hauschild, T. Ekvall, J. Guinee, R. Heijungs, S. Hellweg, A. Koehler, D. Pennington, and S. Suh. "Recent Developments in Life Cycle Assessment." *Journal of Environmental Management* 91(October 2009):1-21.
- Global Water Partnership (GWP). Internet site: <http://www.gwp.org/The-Challenge/What-is-IWRM/> (Accessed on May 28, 2015).
- Gray, J.R., and B.C. English. "National Forest Benefits Accruing to Rural Residents of North-Central New Mexico." *Agricultural Experiment Station, New Mexico State University*

- and Rocky Mountain Forest And Range Experiment Station Forest Service, U.S. Department of Agriculture (January 1976).
- Guan, D., and K. Hubacek. "Assessment of Regional Trade and Virtual Water Flows in China." *Ecological Economics* 61(February 2007):159-170.
- Harris, M. Written Communication. USGS/TDEC, February 2016.
- Hendrickson C., A. Horvath, S. Joshi, and L. Lave. "Economic Input-Output Models for Environmental Life-Cycle Assessment." *Environmental Science and Technology* 32(April 1998): 184A-191A.
- Henry, M.S and E. Bowen. "A Method for Estimating the Value of Water Among Sectors of a Regional Economy." *Southern Journal of Agricultural Economics* 13(December 1981): 125-132.
- Hubacek, K. and L. Sun. "Economic and Societal Changes in China and their Effects on Water Use. *Journal of Industrial Ecology* 9(January 2005):187-200.
- IMPLAN Group, LLC, IMPLAN System (2013 data and software),16740 Birkdale Commons Parkway, Suite 206, Huntersville, NC 28078 [www.IMPLAN.com](http://www.IMPLAN.com).
- IMPLAN. Internet Site: <http://www.implan.com/> (Accessed June 9, 2015).
- Ireland, C.T. and S. Kullback. "Contingency tables with given marginal." *Biometrika* 55(March 1968): 179-188.
- Isard, W., K. Bassett, C. Choguill, J. Furtado, R. Izumita, J. Kissin, E. Romanoff, R. Seyfarth, and R. Tatlock. "On the Linkage of Socio-Economic and Ecologic Systems." *Papers in Regional Science* 21(January 1968):79-99.
- Jonch-Clausen, T., and J. Fugl. "Firming up the Conceptual Basis of Integrated Water Resources Management." *International Journal of Water Resources Development* 17(2001):501-510.
- Lambert, D.M., B.C. English, D.C. Harper, S.L. Larkin, J.A. Larson, D. F. Mooney, R.K. Roberts, M. Velandia, and J.M. Reeves. "Adoption and Frequency of Precision Soil Testing in Cotton Production." *Journal of Agricultural and Resource Economics* 39(2014):106-123.
- Lenzen, M. "Understanding Virtual Water Flows: A Multiregion Input-Output Case Study of Victoria." *Water Resources Research* 45(September 2009):W09416.
- Leontief, W. "Environmental Repercussions and the Economic Structure: An Input-Output Approach. *The Review of Economics and Statistics* 52(August 1970):262-271.
- Leontief, W.W. "Quantitative Input and Output Relations in the Economic Systems of the United States." *The Review of Economics and Statistics* 18(August 1936):105-125.

- Maupin, M.A., J.F. Kenny, S.S. Hutson, J.K. Lovelace, N.L. Barber, and K.S. Linsey. *Estimated Use of Water in the United States in 2010*. Washington, DC: U.S. Department of the Interior, U.S. Geological Survey, Circular 1405, 2014.
- Mubako, S., S. Lahin, and C. Lant. "Input-Output Analysis of Virtual Water Transfers: Case Study of California and Illinois." *Ecological Economics* 93(September 2013):230-238.
- Mundy, K., and W. Purcell. "Measuring the 'Ripple Effect': Economic Multipliers. *Horizons* 16(July/August 2004): 409-412.
- National Agricultural Statistics Service (NASS). *Geographic Code Systems Manual*. U.S. Department of Agriculture, National Agricultural Statistics Service, Washington, D.C. (May 1988).
- National Conference of State Legislatures (NCSL) – State Water Withdrawal Regulations. Internet Site: <http://www.ncsl.org/research/environment-and-natural-resources/state-water-withdrawal-regulations.aspx> (Accessed on May 27, 2015).
- Nelson, G. C., M.W. Rosegrant, J. Koo, R. Robertson, T. Sulser, T. Zhu, C. Ringler, S. Msangi, A. Palazzo, M. Batka, M. Magalhaes, R. Valmonte-Santos, M. Ewing, and D. Lee. "Climate Change: Impact of Agriculture and Costs of Adaptation." Washington, DC: International Food Policy Research Institute, Food Policy Report, 2009.
- Norman, J., A.D. Charpentier, and H.L. MacLean. "Economic Input-Output Life-Cycle Assessment of Trade between Canada and the United States." *Environmental Science and Technology* 41(March 2007):1523-1532.
- North American Industry Classification System (NAICS). Internet Site: <http://www.census.gov/eos/www/naics/concordances/concordances.html> (Accessed on November 2, 2015).
- Ontario – Ministry of Agriculture, Food, and Rural Affairs (Ontario). Internet Site: <http://www.omafra.gov.on.ca/english/engineer/facts/07-023.htm> (Accessed on November 1, 2015).
- Otto, D.M., and T. G. Johnson. *Microcomputer-Based Input-Output Modeling*. Boulder, Colorado: Westview Press, Inc., 1993.
- Rahaman, M.M., and O. Varis. "Integrated Water Resources Management: Evolution, Prospects, and Future Challenges." *Sustainability: Science, Practice, & Policy* 1(April 2005):15-21.
- Rebitzer, G., T. Ekvall, R. Frischknecht, D. Hunkeler, G. Norris, T. Rydberg, W.-P. Schmidt, S. Suh, B.P. Weidema, and D.W. Pennington. "Life Cycle Assessment: Part 1: Framework, Goal and Scope Definition, Inventory Analysis, and Applications." *Environmental International* 30(July 2004):701-720.
- Reynolds, C.J., J. Piantadosi, J.D. Buckley, P. Weinstein, and J. Boland. "Evaluation of the Environmental Impact of Weekly Food Consumption in Different Socio-Economic

- Households in Australia Using Environmentally Extended Input-Output Analysis.” *Ecological Economics* 111(March 2015):58-64.
- Sharma, V.A. “Sustainability and Water.” American Institute of Physics 1157 Conference Proceedings, 2009, pp. 128-137.
- Siikamäki, J. “Climate Change and U.S. Agriculture: Examining the Connections.” *Environment* 50(July 2008):36-49.
- Southern Regional Water Program (SRWP) – A Partnership of USDA, NIFA, & Land Grant Colleges and Universities. Internet Site: <http://srwqis.tamu.edu/program-information/focus-areas/water-policy-and-economics.aspx> (Accessed May 27, 2015).
- Sun, YY., and S. Pratt. “The Economic, Carbon Emission, and Water Impacts of Chinese Visitors to Taiwan: Eco-efficiency and Impact Evaluation.” *Journal of Travel Research* 53(November 2014):733-746.
- Tennessee Department of Economic and Community Development (TNECD). Internet site: <http://www.tn.gov/ECD/> (Accessed on May 27, 2015).
- Tennessee Department of Environment and Conservation (TDEC) – March 2013 Regional Water Resources Planning Guidelines for Tennessee. Internet Site: [http://www.tn.gov/environment/water/docs/regionalplanning/regional\\_water\\_resources\\_planning\\_guidelines.pdf](http://www.tn.gov/environment/water/docs/regionalplanning/regional_water_resources_planning_guidelines.pdf) (Accessed on May 27, 2015)
- U.S. Census Bureau – North American Industry Classification System (NAICS). Internet Site: <http://www.census.gov/eos/www/naics/> (Accessed June 9, 2015).
- U.S. Department of Agriculture (USDA) – Soil Conservation Service (SCS). *Crop Consumptive Irrigation Requirements and Irrigation Efficiency Coefficients for the United States*. June 1978.
- U.S. Department of Agriculture (USDA) 2007 & 2012 Census of Agriculture. Internet Site: [http://www.agcensus.usda.gov/Publications/2007/Full\\_Report/Volume\\_1,\\_Chapter\\_1\\_State\\_Level/Tennessee/](http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_1_State_Level/Tennessee/) (Accessed February 11, 2015).
- U.S. Department of Agriculture (USDA) 2013 Farm and Ranch Irrigation Survey. Internet Site: [http://www.agcensus.usda.gov/Publications/2012/Online\\_Resources/Farm\\_and\\_Ranch\\_Irrigation\\_Survey/](http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/) (Accessed June 9, 2015).
- U.S. Department of Commerce (USDOC) U.S. Census Bureau. Internet site: <http://www.census.gov/population/projections/data/national/index.html> (Accessed February 9, 2015).
- U.S. Department of the Interior - U.S. Geological Service (USGS) Water Use in the United States. Internet Site: <http://water.usgs.gov/watuse/> (Accessed on June 9, 2015).
- U.S. Department of the Interior – U.S. Geological Survey (USGS) Hydrologic Unit Maps. Internet site: <http://water.usgs.gov/GIS/huc.html> (Accessed May 12, 2016).

- U.S. Department of the Interior – U.S. Geological Survey (USGS) National Water Information System – 2010 Water Use Data for Tennessee. Internet site:  
[http://waterdata.usgs.gov/tn/nwis/water\\_use?format=html\\_table&rdb\\_compression=file&wu\\_area=County&wu\\_year=2010&wu\\_county=ALL&wu\\_category=ALL&wu\\_county\\_nms=--ALL%2BCounties--](http://waterdata.usgs.gov/tn/nwis/water_use?format=html_table&rdb_compression=file&wu_area=County&wu_year=2010&wu_county=ALL&wu_category=ALL&wu_county_nms=--ALL%2BCounties--) (Accessed June 9, 2015).
- United Nations Population Fund (UNPF). “Global Population and Water: Access and Sustainability.” New York, New York: United Nations Population Fund, Population and Development Strategy Series, 6, 2003.
- Velazquez, E. “An Input-Output Model of Water Consumption: Analysing Intersectoral Water Relationships in Andalusia.” *Ecological Economics* 56(February 2006):226-240.
- Ward, F.A., and A. Michelsen. “The Economic Value of Water in Agriculture: Concepts and Policy Applications.” *Water Policy* 4(2002):423-446.
- Ward, F.A., and M. Pulido-Velazquez. “Water Conservation in Irrigation Can Increase Water Use.” Proceedings of the National Academy of Sciences of the United States of America, 2008, pp. 18215-18220.
- Young, R.A. and J. B. Loomis. *Determining the Economic Value of Water: Concepts and Methods* (2nd Edition). New York: RFF Press, 2014.

## Appendix A: Tables and Figures used in the Manuscript

### Tables

**Table 1. Types of Water Valuation Methods - Their Uses and Critiques**

| Method                                           | Brief Description                                                                                                                                                                                                                                              | Critique                                                                                                                                                                                                                                                |
|--------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Basic Residual Method                            | Deductive method most frequently used to approximate value marginal product. Calculates water value as net producer's income after all costs are accounted for. Useful in the single product case. Solved using budgeting procedures and spreadsheet analysis. | Judgements and decisions on empirical issues have to be made on the specific policy problem being studied. After decisions are made, it can be difficult to find adequate data. There are also aggregation issues. Simple model that can be elaborated. |
| Change in Net Rents Method                       | Deductive method similar to the residual method but more useful in the multiple product case. Solved using budgeting procedures and spreadsheet analysis.                                                                                                      | Judgements and decisions on empirical issues have to be made on the specific policy problem being studied. After decisions are made, it can be difficult to find adequate data. There are also aggregation issues. Simple model that can be elaborated. |
| Mathematical Programming Method                  | Deduction method that uses residual models and optimization to find net producer's income or marginal costs.                                                                                                                                                   | Model formulation must reflect the policy problem being studied using appropriate empirical parameters that are sometimes overlooked. For instance, sometimes short run objective functions are used to address long run issues.                        |
| Alternative Cost Method                          | Deductive method that calculates water value based on the next cheapest alternative.                                                                                                                                                                           | Similar issues as the residual method. Main issue is that some alternative is always available that is more expensive, creating an estimate of cost savings and positive net benefits.                                                                  |
| Observations of Water Market Transactions Method | Inductive method that calculates water value based on observed prices from water leases or the sale of water rights.                                                                                                                                           | There is a limited number of observable markets and large fluctuations in water prices.                                                                                                                                                                 |

**Table 1. Continued. Types of Water Valuation Methods - Their Uses and Critiques**

| Method                        | Brief Description                                                                                                                                                 | Critique                                                                                                                                                                                                                                                                                                                                                                      |
|-------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Hedonic Property Value Method | Inductive method that calculates water value by looking at revealed preference from property transactions.                                                        | Social value is not attainable using this method. It also cannot accurately account for things such as droughts. The property values that are used are also affected by several factors such as interest rates that cannot necessarily be excluded from the water valuation. Developing countries may not have real property markets or enough data to implement this method. |
| Travel Cost Method            | Inductive method that calculates water value by looking at revealed preference found from studying travel costs and determining WTP for water related recreation. | Wide ranges of benefit estimates can sometimes be obtained from the same data set. This method can evaluate historical experience which is not always applicable to the current issue being addressed.                                                                                                                                                                        |
| Contingent Valuation Method   | Inductive method that calculates water value based on stated preferences of how much a person is willing to pay given a hypothetical scenario.                    | Hypothetical bias or overstating WTP and compliance bias or giving the answers they think are wanted are common issues. Scenario mis-specification or not understanding the question, taking on different roles such as consumer and citizen while answering the questions, and insensitivity to scope all cause other problems.                                              |
| Choice Modeling Method        | Inductive method that calculates water value based on states preferences of alternative scenarios.                                                                | Cost is just one attribute studied and is less prominent in choice modeling than contingent valuation which has led to high WTPs found in choice modeling that contingent valuation.                                                                                                                                                                                          |
| Benefit Transfer Method       | Inductive method that calculates water value by using a valuation from an existing study or studies to determine valuation of a different study.                  | New study may have different characteristics than then study it's being compared to.                                                                                                                                                                                                                                                                                          |

Source: Young and Loomis (2014)

<sup>a</sup>This is a combination of the authors' table and information from the chapters. Other methods not included in this table that can be found in the text include: econometric estimation of production and cost functions, econometric estimation of municipal water demand functions, defensive behavior, damage cost, benefit function transfer, and general equilibrium models.

**Table 2. Tennessee Estimated Water Withdrawals by Category**

| <b>USGS Sector</b>   | <b>Water Withdrawals<br/>(000s of Acre Feet<br/>Per Year)</b> | <b>% of Total Water<br/>Withdrawal</b> |
|----------------------|---------------------------------------------------------------|----------------------------------------|
| Public Supply †      | 507                                                           | 5.88%                                  |
| Domestic             | 43                                                            | 0.50%                                  |
| Irrigation           | 81                                                            | 0.93%                                  |
| Thermoelectric Power | 6493                                                          | 75.27%                                 |
| Industrial           | 869                                                           | 10.08%                                 |
| Mining               | 16                                                            | 0.19%                                  |
| Livestock            | 31                                                            | 0.36%                                  |
| Aquaculture          | 59                                                            | 0.68%                                  |

† “Public Supply Deliveries to Domestic” was not included in the Public Supply sector because there is not an economic sector in IMPLAN for household water use, and these withdrawals were included in the USGS “Domestic” category. Public Supply Deliveries to Domestic withdraws 527 (1000s of acre feet per year).

**Table 3. Economic Sector Numbers and Descriptions**

| Sector Number | Sector Description                                                                         |
|---------------|--------------------------------------------------------------------------------------------|
| 1             | Oilseed farming                                                                            |
| 2             | Grain farming                                                                              |
| 3             | Vegetable and melon farming                                                                |
| 4             | Fruit farming                                                                              |
| 5             | Tree nut farming                                                                           |
| 6             | Greenhouse, nursery, and floriculture production                                           |
| 7             | Tobacco farming                                                                            |
| 8             | Cotton farming                                                                             |
| 9             | Sugarcane and sugar beet farming                                                           |
| 10            | All other crop farming                                                                     |
| 11            | Beef cattle ranching and farming, including feedlots and dual-purpose ranching and farming |
| 12            | Dairy cattle and milk production                                                           |
| 13            | Poultry and egg production                                                                 |
| 14            | Animal production, except cattle and poultry and eggs                                      |
| 15            | Forestry, forest products, and timber tract production                                     |
| 16            | Commercial logging                                                                         |
| 17            | Commercial fishing                                                                         |
| 18            | Commercial hunting and trapping                                                            |
| 19            | Support activities for agriculture and forestry                                            |
| 20            | Extraction of natural gas and crude petroleum                                              |
| 21            | Extraction of natural gas liquids                                                          |
| 22            | Coal mining                                                                                |
| 23            | Iron ore mining                                                                            |
| 24            | Gold ore mining                                                                            |
| 25            | Silver ore mining                                                                          |
| 26            | Lead and zinc ore mining                                                                   |
| 27            | Copper ore mining                                                                          |
| 28            | Uranium-radium-vanadium ore mining                                                         |
| 29            | Other metal ore mining                                                                     |
| 30            | Stone mining and quarrying                                                                 |
| 31            | Sand and gravel mining                                                                     |
| 32            | Other clay, ceramic, refractory minerals mining                                            |
| 33            | Potash, soda, and borate mineral mining                                                    |
| 34            | Phosphate rock mining                                                                      |
| 35            | Other chemical and fertilizer mineral mining                                               |
| 36            | Other nonmetallic minerals                                                                 |
| 37            | Drilling oil and gas wells                                                                 |
| 38            | Support activities for oil and gas operations                                              |
| 39            | Metal mining services                                                                      |
| 40            | Other nonmetallic minerals services                                                        |

**Table 3. Continued. Economic Sector Numbers and Descriptions**

| Sector Number | Sector Description                                                             |
|---------------|--------------------------------------------------------------------------------|
| 41            | Electric power generation - Hydroelectric                                      |
| 42            | Electric power generation - Fossil fuel                                        |
| 43            | Electric power generation - Nuclear                                            |
| 44            | Electric power generation - Solar                                              |
| 45            | Electric power generation - Wind                                               |
| 46            | Electric power generation - Geothermal                                         |
| 47            | Electric power generation - Biomass                                            |
| 48            | Electric power generation - All other                                          |
| 49            | Electric power transmission and distribution                                   |
| 50            | Natural gas distribution                                                       |
| 51            | Water, sewage and other systems                                                |
| 52            | Construction of new health care structures                                     |
| 53            | Construction of new manufacturing structures                                   |
| 54            | Construction of new power and communication structures                         |
| 55            | Construction of new educational and vocational structures                      |
| 56            | Construction of new highways and streets                                       |
| 57            | Construction of new commercial structures, including farm structures           |
| 58            | Construction of other new nonresidential structures                            |
| 59            | Construction of new single-family residential structures                       |
| 60            | Construction of new multifamily residential structures                         |
| 61            | Construction of other new residential structures                               |
| 62            | Maintenance and repair construction of nonresidential structures               |
| 63            | Maintenance and repair construction of residential structures                  |
| 64            | Maintenance and repair construction of highways, streets, bridges, and tunnels |
| 65            | Dog and cat food manufacturing                                                 |
| 66            | Other animal food manufacturing                                                |
| 67            | Flour milling                                                                  |
| 68            | Rice milling                                                                   |
| 69            | Malt manufacturing                                                             |
| 70            | Wet corn milling                                                               |
| 71            | Soybean and other oilseed processing                                           |
| 72            | Fats and oils refining and blending                                            |
| 73            | Breakfast cereal manufacturing                                                 |
| 74            | Beet sugar manufacturing                                                       |
| 75            | Sugar cane mills and refining                                                  |
| 76            | Nonchocolate confectionery manufacturing                                       |
| 77            | Chocolate and confectionery manufacturing from cacao beans                     |
| 78            | Confectionery manufacturing from purchased chocolate                           |
| 79            | Frozen fruits, juices and vegetables manufacturing                             |
| 80            | Frozen specialties manufacturing                                               |

**Table 3. Continued. Economic Sector Numbers and Descriptions**

| Sector Number | Sector Description                                         |
|---------------|------------------------------------------------------------|
| 81            | Canned fruits and vegetables manufacturing                 |
| 82            | Canned specialties                                         |
| 83            | Dehydrated food products manufacturing                     |
| 84            | Fluid milk manufacturing                                   |
| 85            | Creamery butter manufacturing                              |
| 86            | Cheese manufacturing                                       |
| 87            | Dry, condensed, and evaporated dairy product manufacturing |
| 88            | Ice cream and frozen dessert manufacturing                 |
| 89            | Animal, except poultry, slaughtering                       |
| 90            | Meat processed from carcasses                              |
| 91            | Rendering and meat byproduct processing                    |
| 92            | Poultry processing                                         |
| 93            | Seafood product preparation and packaging                  |
| 94            | Bread and bakery product, except frozen, manufacturing     |
| 95            | Frozen cakes and other pastries manufacturing              |
| 96            | Cookie and cracker manufacturing                           |
| 97            | Dry pasta, mixes, and dough manufacturing                  |
| 98            | Tortilla manufacturing                                     |
| 99            | Roasted nuts and peanut butter manufacturing               |
| 100           | Other snack food manufacturing                             |
| 101           | Coffee and tea manufacturing                               |
| 102           | Flavoring syrup and concentrate manufacturing              |
| 103           | Mayonnaise, dressing, and sauce manufacturing              |
| 104           | Spice and extract manufacturing                            |
| 105           | All other food manufacturing                               |
| 106           | Bottled and canned soft drinks & water                     |
| 107           | Manufactured ice                                           |
| 108           | Breweries                                                  |
| 109           | Wineries                                                   |
| 110           | Distilleries                                               |
| 111           | Tobacco product manufacturing                              |
| 112           | Fiber, yarn, and thread mills                              |
| 113           | Broadwoven fabric mills                                    |
| 114           | Narrow fabric mills and schiffli machine embroidery        |
| 115           | Nonwoven fabric mills                                      |
| 116           | Knit fabric mills                                          |
| 117           | Textile and fabric finishing mills                         |
| 118           | Fabric coating mills                                       |
| 119           | Carpet and rug mills                                       |
| 120           | Curtain and linen mills                                    |
| 121           | Textile bag and canvas mills                               |

**Table 3. Continued. Economic Sector Numbers and Descriptions**

| Sector Number | Sector Description                                    |
|---------------|-------------------------------------------------------|
| 122           | Rope, cordage, twine, tire cord and tire fabric mills |
| 123           | Other textile product mills                           |
| 125           | Other apparel knitting mills                          |
| 126           | Cut and sew apparel contractors                       |
| 127           | Mens and boys cut and sew apparel manufacturing       |
| 128           | Womens and girls cut and sew apparel manufacturing    |
| 129           | Other cut and sew apparel manufacturing               |
| 130           | Apparel accessories and other apparel manufacturing   |
| 131           | Leather and hide tanning and finishing                |
| 132           | Footwear manufacturing                                |
| 133           | Other leather and allied product manufacturing        |
| 134           | Sawmills                                              |
| 135           | Wood preservation                                     |
| 136           | Veneer and plywood manufacturing                      |
| 137           | Engineered wood member and truss manufacturing        |
| 138           | Reconstituted wood product manufacturing              |
| 139           | Wood windows and door manufacturing                   |
| 140           | Cut stock, resawing lumber, and planing               |
| 141           | Other millwork, including flooring                    |
| 142           | Wood container and pallet manufacturing               |
| 143           | Manufactured home (mobile home) manufacturing         |
| 144           | Prefabricated wood building manufacturing             |
| 145           | All other miscellaneous wood product manufacturing    |
| 146           | Pulp mills                                            |
| 147           | Paper mills                                           |
| 148           | Paperboard mills                                      |
| 149           | Paperboard container manufacturing                    |
| 150           | Paper bag and coated and treated paper manufacturing  |
| 151           | Stationery product manufacturing                      |
| 152           | Sanitary paper product manufacturing                  |
| 153           | All other converted paper product manufacturing       |
| 154           | Printing                                              |
| 155           | Support activities for printing                       |
| 156           | Petroleum refineries                                  |
| 157           | Asphalt paving mixture and block manufacturing        |
| 158           | Asphalt shingle and coating materials manufacturing   |
| 159           | Petroleum lubricating oil and grease manufacturing    |
| 160           | All other petroleum and coal products manufacturing   |
| 161           | Petrochemical manufacturing                           |
| 162           | Industrial gas manufacturing                          |
| 163           | Synthetic dye and pigment manufacturing               |

**Table 3. Continued. Economic Sector Numbers and Descriptions**

| Sector Number | Sector Description                                                          |
|---------------|-----------------------------------------------------------------------------|
| 164           | Other basic inorganic chemical manufacturing                                |
| 165           | Other basic organic chemical manufacturing                                  |
| 166           | Plastics material and resin manufacturing                                   |
| 167           | Synthetic rubber manufacturing                                              |
| 168           | Artificial and synthetic fibers and filaments manufacturing                 |
| 169           | Nitrogenous fertilizer manufacturing                                        |
| 170           | Phosphatic fertilizer manufacturing                                         |
| 171           | Fertilizer mixing                                                           |
| 172           | Pesticide and other agricultural chemical manufacturing                     |
| 173           | Medicinal and botanical manufacturing                                       |
| 174           | Pharmaceutical preparation manufacturing                                    |
| 175           | In-vitro diagnostic substance manufacturing                                 |
| 176           | Biological product (except diagnostic) manufacturing                        |
| 177           | Paint and coating manufacturing                                             |
| 178           | Adhesive manufacturing                                                      |
| 179           | Soap and other detergent manufacturing                                      |
| 180           | Polish and other sanitation good manufacturing                              |
| 181           | Surface active agent manufacturing                                          |
| 182           | Toilet preparation manufacturing                                            |
| 183           | Printing ink manufacturing                                                  |
| 184           | Explosives manufacturing                                                    |
| 185           | Custom compounding of purchased resins                                      |
| 186           | Photographic film and chemical manufacturing                                |
| 187           | Other miscellaneous chemical product manufacturing                          |
| 188           | Plastics packaging materials and unlaminated film and sheet manufacturing   |
| 189           | Unlaminated plastics profile shape manufacturing                            |
| 190           | Plastics pipe and pipe fitting manufacturing                                |
| 191           | Laminated plastics plate, sheet (except packaging), and shape manufacturing |
| 192           | Polystyrene foam product manufacturing                                      |
| 193           | Urethane and other foam product (except polystyrene) manufacturing          |
| 194           | Plastics bottle manufacturing                                               |
| 195           | Other plastics product manufacturing                                        |
| 196           | Tire manufacturing                                                          |
| 197           | Rubber and plastics hoses and belting manufacturing                         |
| 198           | Other rubber product manufacturing                                          |
| 199           | Pottery, ceramics, and plumbing fixture manufacturing                       |
| 200           | Brick, tile, and other structural clay product manufacturing                |
| 201           | Flat glass manufacturing                                                    |
| 202           | Other pressed and blown glass and glassware manufacturing                   |
| 203           | Glass container manufacturing                                               |
| 204           | Glass product manufacturing made of purchased glass                         |

**Table 3. Continued. Economic Sector Numbers and Descriptions**

| Sector Number | Sector Description                                           |
|---------------|--------------------------------------------------------------|
| 205           | Cement manufacturing                                         |
| 206           | Ready-mix concrete manufacturing                             |
| 207           | Concrete block and brick manufacturing                       |
| 208           | Concrete pipe manufacturing                                  |
| 209           | Other concrete product manufacturing                         |
| 210           | Lime manufacturing                                           |
| 211           | Gypsum product manufacturing                                 |
| 212           | Abrasive product manufacturing                               |
| 213           | Cut stone and stone product manufacturing                    |
| 214           | Ground or treated mineral and earth manufacturing            |
| 215           | Mineral wool manufacturing                                   |
| 216           | Miscellaneous nonmetallic mineral products manufacturing     |
| 217           | Iron and steel mills and ferroalloy manufacturing            |
| 218           | Iron, steel pipe and tube manufacturing from purchased steel |
| 219           | Rolled steel shape manufacturing                             |
| 220           | Steel wire drawing                                           |
| 221           | Alumina refining and primary aluminum production             |
| 222           | Secondary smelting and alloying of aluminum                  |
| 223           | Aluminum sheet, plate, and foil manufacturing                |
| 224           | Other aluminum rolling, drawing and extruding                |
| 225           | Nonferrous metal (exc aluminum) smelting and refining        |
| 226           | Copper rolling, drawing, extruding and alloying              |
| 227           | Nonferrous metal, except copper and aluminum, shaping        |
| 228           | Secondary processing of other nonferrous metals              |
| 229           | Ferrous metal foundries                                      |
| 230           | Nonferrous metal foundries                                   |
| 231           | Iron and steel forging                                       |
| 232           | Nonferrous forging                                           |
| 233           | Custom roll forming                                          |
| 234           | Crown and closure manufacturing and metal stamping           |
| 235           | Cutlery, utensil, pot, and pan manufacturing                 |
| 236           | Handtool manufacturing                                       |
| 237           | Prefabricated metal buildings and components manufacturing   |
| 238           | Fabricated structural metal manufacturing                    |
| 239           | Plate work manufacturing                                     |
| 240           | Metal window and door manufacturing                          |
| 241           | Sheet metal work manufacturing                               |
| 242           | Ornamental and architectural metal work manufacturing        |
| 243           | Power boiler and heat exchanger manufacturing                |
| 244           | Metal tank (heavy gauge) manufacturing                       |
| 245           | Metal cans manufacturing                                     |

**Table 3. Continued. Economic Sector Numbers and Descriptions**

| Sector Number | Sector Description                                                            |
|---------------|-------------------------------------------------------------------------------|
| 246           | Metal barrels, drums and pails manufacturing                                  |
| 247           | Hardware manufacturing                                                        |
| 248           | Spring and wire product manufacturing                                         |
| 249           | Machine shops                                                                 |
| 250           | Turned product and screw, nut, and bolt manufacturing                         |
| 251           | Metal heat treating                                                           |
| 252           | Metal coating and nonprecious engraving                                       |
| 253           | Electroplating, anodizing, and coloring metal                                 |
| 254           | Valve and fittings, other than plumbing, manufacturing                        |
| 255           | Plumbing fixture fitting and trim manufacturing                               |
| 256           | Ball and roller bearing manufacturing                                         |
| 257           | Small arms ammunition manufacturing                                           |
| 258           | Ammunition, except for small arms, manufacturing                              |
| 259           | Small arms, ordnance, and accessories manufacturing                           |
| 260           | Fabricated pipe and pipe fitting manufacturing                                |
| 261           | Other fabricated metal manufacturing                                          |
| 262           | Farm machinery and equipment manufacturing                                    |
| 263           | Lawn and garden equipment manufacturing                                       |
| 264           | Construction machinery manufacturing                                          |
| 265           | Mining machinery and equipment manufacturing                                  |
| 266           | Oil and gas field machinery and equipment manufacturing                       |
| 267           | Food product machinery manufacturing                                          |
| 268           | Semiconductor machinery manufacturing                                         |
| 269           | Sawmill, woodworking, and paper machinery                                     |
| 270           | Printing machinery and equipment manufacturing                                |
| 271           | All other industrial machinery manufacturing                                  |
| 272           | Optical instrument and lens manufacturing                                     |
| 273           | Photographic and photocopying equipment manufacturing                         |
| 274           | Other commercial service industry machinery manufacturing                     |
| 275           | Air purification and ventilation equipment manufacturing                      |
| 276           | Heating equipment (except warm air furnaces) manufacturing                    |
| 277           | Air conditioning, refrigeration, and warm air heating equipment manufacturing |
| 278           | Industrial mold manufacturing                                                 |
| 279           | Special tool, die, jig, and fixture manufacturing                             |
| 280           | Cutting tool and machine tool accessory manufacturing                         |
| 281           | Machine tool manufacturing                                                    |
| 282           | Rolling mill and other metalworking machinery manufacturing                   |
| 283           | Turbine and turbine generator set units manufacturing                         |
| 284           | Speed changer, industrial high-speed drive, and gear manufacturing            |
| 285           | Mechanical power transmission equipment manufacturing                         |

**Table 3. Continued. Economic Sector Numbers and Descriptions**

| Sector Number | Sector Description                                                          |
|---------------|-----------------------------------------------------------------------------|
| 286           | Other engine equipment manufacturing                                        |
| 287           | Pump and pumping equipment manufacturing                                    |
| 288           | Air and gas compressor manufacturing                                        |
| 289           | Measuring and dispensing pump manufacturing                                 |
| 290           | Elevator and moving stairway manufacturing                                  |
| 291           | Conveyor and conveying equipment manufacturing                              |
| 292           | Overhead cranes, hoists, and monorail systems manufacturing                 |
| 293           | Industrial truck, trailer, and stacker manufacturing                        |
| 294           | Power-driven handtool manufacturing                                         |
| 295           | Welding and soldering equipment manufacturing                               |
| 296           | Packaging machinery manufacturing                                           |
| 297           | Industrial process furnace and oven manufacturing                           |
| 298           | Fluid power cylinder and actuator manufacturing                             |
| 299           | Fluid power pump and motor manufacturing                                    |
| 300           | Scales, balances, and miscellaneous general purpose machinery manufacturing |
| 301           | Electronic computer manufacturing                                           |
| 302           | Computer storage device manufacturing                                       |
| 303           | Computer terminals and other computer peripheral equipment manufacturing    |
| 304           | Telephone apparatus manufacturing                                           |
| 305           | Broadcast and wireless communications equipment manufacturing               |
| 306           | Other communications equipment manufacturing                                |
| 307           | Audio and video equipment manufacturing                                     |
| 308           | Bare printed circuit board manufacturing                                    |
| 309           | Semiconductor and related device manufacturing                              |
| 310           | Capacitor, resistor, coil, transformer, and other inductor manufacturing    |
| 311           | Electronic connector manufacturing                                          |
| 312           | Printed circuit assembly (electronic assembly) manufacturing                |
| 313           | Other electronic component manufacturing                                    |
| 314           | Electromedical and electrotherapeutic apparatus manufacturing               |
| 315           | Search, detection, and navigation instruments manufacturing                 |
| 316           | Automatic environmental control manufacturing                               |
| 317           | Industrial process variable instruments manufacturing                       |
| 318           | Totalizing fluid meter and counting device manufacturing                    |
| 319           | Electricity and signal testing instruments manufacturing                    |
| 320           | Analytical laboratory instrument manufacturing                              |
| 321           | Irradiation apparatus manufacturing                                         |
| 322           | Watch, clock, and other measuring and controlling device manufacturing      |
| 323           | Blank magnetic and optical recording media manufacturing                    |
| 324           | Software and other prerecorded and record reproducing                       |
| 325           | Electric lamp bulb and part manufacturing                                   |

**Table 3. Continued. Economic Sector Numbers and Descriptions**

| Sector Number | Sector Description                                                                            |
|---------------|-----------------------------------------------------------------------------------------------|
| 326           | Lighting fixture manufacturing                                                                |
| 327           | Small electrical appliance manufacturing                                                      |
| 328           | Household cooking appliance manufacturing                                                     |
| 329           | Household refrigerator and home freezer manufacturing                                         |
| 330           | Household laundry equipment manufacturing                                                     |
| 331           | Other major household appliance manufacturing                                                 |
| 332           | Power, distribution, and specialty transformer manufacturing                                  |
| 333           | Motor and generator manufacturing                                                             |
| 334           | Switchgear and switchboard apparatus manufacturing                                            |
| 335           | Relay and industrial control manufacturing                                                    |
| 336           | Storage battery manufacturing                                                                 |
| 337           | Primary battery manufacturing                                                                 |
| 338           | Fiber optic cable manufacturing                                                               |
| 339           | Other communication and energy wire manufacturing                                             |
| 340           | Wiring device manufacturing                                                                   |
| 341           | Carbon and graphite product manufacturing                                                     |
| 342           | All other miscellaneous electrical equipment and component manufacturing                      |
| 343           | Automobile manufacturing                                                                      |
| 344           | Light truck and utility vehicle manufacturing                                                 |
| 345           | Heavy duty truck manufacturing                                                                |
| 346           | Motor vehicle body manufacturing                                                              |
| 347           | Truck trailer manufacturing                                                                   |
| 348           | Motor home manufacturing                                                                      |
| 349           | Travel trailer and camper manufacturing                                                       |
| 350           | Motor vehicle gasoline engine and engine parts manufacturing                                  |
| 351           | Motor vehicle electrical and electronic equipment manufacturing                               |
| 352           | Motor vehicle steering, suspension component (except spring), and brake systems manufacturing |
| 353           | Motor vehicle transmission and power train parts manufacturing                                |
| 354           | Motor vehicle seating and interior trim manufacturing                                         |
| 355           | Motor vehicle metal stamping                                                                  |
| 356           | Other motor vehicle parts manufacturing                                                       |
| 357           | Aircraft manufacturing                                                                        |
| 358           | Aircraft engine and engine parts manufacturing                                                |
| 359           | Other aircraft parts and auxiliary equipment manufacturing                                    |
| 360           | Guided missile and space vehicle manufacturing                                                |
| 361           | Propulsion units and parts for space vehicles and guided missiles manufacturing               |
| 362           | Railroad rolling stock manufacturing                                                          |
| 363           | Ship building and repairing                                                                   |
| 364           | Boat building                                                                                 |

**Table 3. Continued. Economic Sector Numbers and Descriptions**

| Sector Number | Sector Description                                                  |
|---------------|---------------------------------------------------------------------|
| 365           | Motorcycle, bicycle, and parts manufacturing                        |
| 366           | Military armored vehicle, tank, and tank component manufacturing    |
| 367           | All other transportation equipment manufacturing                    |
| 368           | Wood kitchen cabinet and countertop manufacturing                   |
| 369           | Upholstered household furniture manufacturing                       |
| 370           | Nonupholstered wood household furniture manufacturing               |
| 371           | Other household nonupholstered furniture manufacturing              |
| 372           | Institutional furniture manufacturing                               |
| 373           | Wood office furniture manufacturing                                 |
| 374           | Custom architectural woodwork and millwork                          |
| 375           | Office furniture, except wood, manufacturing                        |
| 376           | Showcase, partition, shelving, and locker manufacturing             |
| 377           | Mattress manufacturing                                              |
| 378           | Blind and shade manufacturing                                       |
| 379           | Surgical and medical instrument manufacturing                       |
| 380           | Surgical appliance and supplies manufacturing                       |
| 381           | Dental equipment and supplies manufacturing                         |
| 382           | Ophthalmic goods manufacturing                                      |
| 383           | Dental laboratories                                                 |
| 384           | Jewelry and silverware manufacturing                                |
| 385           | Sporting and athletic goods manufacturing                           |
| 386           | Doll, toy, and game manufacturing                                   |
| 387           | Office supplies (except paper) manufacturing                        |
| 388           | Sign manufacturing                                                  |
| 389           | Gasket, packing, and sealing device manufacturing                   |
| 390           | Musical instrument manufacturing                                    |
| 391           | Fasteners, buttons, needles, and pins manufacturing                 |
| 392           | Broom, brush, and mop manufacturing                                 |
| 393           | Burial casket manufacturing                                         |
| 394           | All other miscellaneous manufacturing                               |
| 395           | Wholesale trade                                                     |
| 396           | Retail - Motor vehicle and parts dealers                            |
| 397           | Retail - Furniture and home furnishings stores                      |
| 398           | Retail - Electronics and appliance stores                           |
| 399           | Retail - Building material and garden equipment and supplies stores |
| 400           | Retail - Food and beverage stores                                   |
| 401           | Retail - Health and personal care stores                            |
| 402           | Retail - Gasoline stores                                            |
| 403           | Retail - Clothing and clothing accessories stores                   |
| 404           | Retail - Sporting goods, hobby, musical instrument and book stores  |
| 405           | Retail - General merchandise stores                                 |

**Table 3. Continued. Economic Sector Numbers and Descriptions**

| Sector Number | Sector Description                                                              |
|---------------|---------------------------------------------------------------------------------|
| 406           | Retail - Miscellaneous store retailers                                          |
| 407           | Retail - Nonstore retailers                                                     |
| 408           | Air transportation                                                              |
| 409           | Rail transportation                                                             |
| 410           | Water transportation                                                            |
| 411           | Truck transportation                                                            |
| 412           | Transit and ground passenger transportation                                     |
| 413           | Pipeline transportation                                                         |
| 414           | Scenic and sightseeing transportation and support activities for transportation |
| 415           | Couriers and messengers                                                         |
| 416           | Warehousing and storage                                                         |
| 417           | Newspaper publishers                                                            |
| 418           | Periodical publishers                                                           |
| 419           | Book publishers                                                                 |
| 420           | Directory, mailing list, and other publishers                                   |
| 421           | Greeting card publishing                                                        |
| 422           | Software publishers                                                             |
| 423           | Motion picture and video industries                                             |
| 424           | Sound recording industries                                                      |
| 425           | Radio and television broadcasting                                               |
| 426           | Cable and other subscription programming                                        |
| 427           | Wired telecommunications carriers                                               |
| 428           | Wireless telecommunications carriers (except satellite)                         |
| 429           | Satellite, telecommunications resellers, and all other telecommunications       |
| 430           | Data processing, hosting, and related services                                  |
| 431           | News syndicates, libraries, archives and all other information services         |
| 432           | Internet publishing and broadcasting and web search portals                     |
| 433           | Monetary authorities and depository credit intermediation                       |
| 434           | Nondepository credit intermediation and related activities                      |
| 435           | Securities and commodity contracts intermediation and brokerage                 |
| 436           | Other financial investment activities                                           |
| 437           | Insurance carriers                                                              |
| 438           | Insurance agencies, brokerages, and related activities                          |
| 439           | Funds, trusts, and other financial vehicles                                     |
| 440           | Real estate                                                                     |
| 441           | Owner-occupied dwellings                                                        |
| 442           | Automotive equipment rental and leasing                                         |
| 443           | General and consumer goods rental except video tapes and discs                  |
| 444           | Video tape and disc rental                                                      |
| 445           | Commercial and industrial machinery and equipment rental and leasing            |
| 446           | Lessors of nonfinancial intangible assets                                       |

**Table 3. Continued. Economic Sector Numbers and Descriptions**

| Sector Number | Sector Description                                                                              |
|---------------|-------------------------------------------------------------------------------------------------|
| 447           | Legal services                                                                                  |
| 448           | Accounting, tax preparation, bookkeeping, and payroll services                                  |
| 449           | Architectural, engineering, and related services                                                |
| 450           | Specialized design services                                                                     |
| 451           | Custom computer programming services                                                            |
| 452           | Computer systems design services                                                                |
| 453           | Other computer related services, including facilities management                                |
| 454           | Management consulting services                                                                  |
| 455           | Environmental and other technical consulting services                                           |
| 456           | Scientific research and development services                                                    |
| 457           | Advertising, public relations, and related services                                             |
| 458           | Photographic services                                                                           |
| 459           | Veterinary services                                                                             |
| 460           | Marketing research and all other miscellaneous professional, scientific, and technical services |
| 461           | Management of companies and enterprises                                                         |
| 462           | Office administrative services                                                                  |
| 463           | Facilities support services                                                                     |
| 464           | Employment services                                                                             |
| 465           | Business support services                                                                       |
| 466           | Travel arrangement and reservation services                                                     |
| 467           | Investigation and security services                                                             |
| 468           | Services to buildings                                                                           |
| 469           | Landscape and horticultural services                                                            |
| 470           | Other support services                                                                          |
| 471           | Waste management and remediation services                                                       |
| 472           | Elementary and secondary schools                                                                |
| 473           | Junior colleges, colleges, universities, and professional schools                               |
| 474           | Other educational services                                                                      |
| 475           | Offices of physicians                                                                           |
| 476           | Offices of dentists                                                                             |
| 477           | Offices of other health practitioners                                                           |
| 478           | Outpatient care centers                                                                         |
| 479           | Medical and diagnostic laboratories                                                             |
| 480           | Home health care services                                                                       |
| 481           | Other ambulatory health care services                                                           |
| 482           | Hospitals                                                                                       |
| 483           | Nursing and community care facilities                                                           |
| 484           | Residential mental retardation, mental health, substance abuse and other facilities             |
| 485           | Individual and family services                                                                  |

**Table 3. Continued. Economic Sector Numbers and Descriptions**

| Sector Number | Sector Description                                                                    |
|---------------|---------------------------------------------------------------------------------------|
| 486           | Community food, housing, and other relief services, including rehabilitation services |
| 487           | Child day care services                                                               |
| 488           | Performing arts companies                                                             |
| 489           | Commercial Sports Except Racing                                                       |
| 490           | Racing and Track Operation                                                            |
| 491           | Promoters of performing arts and sports and agents for public figures                 |
| 492           | Independent artists, writers, and performers                                          |
| 493           | Museums, historical sites, zoos, and parks                                            |
| 494           | Amusement parks and arcades                                                           |
| 495           | Gambling industries (except casino hotels)                                            |
| 496           | Other amusement and recreation industries                                             |
| 497           | Fitness and recreational sports centers                                               |
| 498           | Bowling centers                                                                       |
| 499           | Hotels and motels, including casino hotels                                            |
| 500           | Other accommodations                                                                  |
| 501           | Full-service restaurants                                                              |
| 502           | Limited-service restaurants                                                           |
| 503           | All other food and drinking places                                                    |
| 504           | Automotive repair and maintenance, except car washes                                  |
| 505           | Car washes                                                                            |
| 506           | Electronic and precision equipment repair and maintenance                             |
| 507           | Commercial and industrial machinery and equipment repair and maintenance              |
| 508           | Personal and household goods repair and maintenance                                   |
| 509           | Personal care services                                                                |
| 510           | Death care services                                                                   |
| 511           | Dry-cleaning and laundry services                                                     |
| 512           | Other personal services                                                               |
| 513           | Religious organizations                                                               |
| 514           | Grantmaking, giving, and social advocacy organizations                                |
| 515           | Business and professional associations                                                |
| 516           | Labor and civic organizations                                                         |
| 517           | Private households                                                                    |
| 518           | Postal service                                                                        |
| 519           | Other federal government enterprises                                                  |
| 520           | State government passenger transit                                                    |
| 521           | State government electric utilities                                                   |
| 522           | Other state government enterprises                                                    |
| 523           | Local government passenger transit                                                    |
| 524           | Other local government enterprises                                                    |
| 525           | * Not an industry (Used and secondhand goods)                                         |

**Table 3. Continued. Economic Sector Numbers and Descriptions**

| Sector Number | Sector Description                                                |
|---------------|-------------------------------------------------------------------|
| 526           | * Not an industry (Scrap)                                         |
| 527           | * Not an industry (Rest of world adjustment)                      |
| 528           | * Not an industry (Noncomparable foreign imports)                 |
| 529           | * Employment and payroll of state govt, non-education             |
| 530           | * Employment and payroll of state govt, education                 |
| 531           | * Employment and payroll of local govt, non-education             |
| 532           | * Employment and payroll of local govt, education                 |
| 533           | * Employment and payroll of federal govt, non-military            |
| 534           | * Employment and payroll of federal govt, military                |
| 535           | Government Utilities Power Generation                             |
| 536           | Government Utilities Electric Power Transmission and Distribution |

**Table 4. Cumberland River Region Water Use Coefficients by Aggregated Sector**

| Sector                   | Water Use Coefficient (Acre Feet per Dollar of Total Industry Output * 1,000) | Sector Water Withdrawal (Acre-Feet) |
|--------------------------|-------------------------------------------------------------------------------|-------------------------------------|
| Primary Agriculture      |                                                                               |                                     |
| Crops                    | 0.025634836                                                                   | 16,770                              |
| Primary Agriculture      |                                                                               |                                     |
| Livestock                | 0.071911079                                                                   | 23,211                              |
| Forestry Inputs          | 0.000028466                                                                   | 2                                   |
| Mining                   | 0.005176815                                                                   | 4,528                               |
| Services                 | 0.000557495                                                                   | 38,204                              |
| Utilities                | 0.003344872                                                                   | 6,915                               |
| Water, Sewage, and Other |                                                                               |                                     |
| Systems                  | 0.004683563                                                                   | 350                                 |
| Construction             | 0.000485056                                                                   | 5,497                               |
| Secondary Agriculture    | 0.001492302                                                                   | 9,868                               |
| Manufacturing            | 0.001202521                                                                   | 48,039                              |
| Primary Forestry         | 0.000696798                                                                   | 160                                 |
| Secondary Forestry       | 0.000797290                                                                   | 1,213                               |
| Agriculture Inputs       | 0.000426895                                                                   | 11                                  |
| Wholesale Trade          | 0.000433562                                                                   | 4,709                               |
| Retail Trade             | 0.000773522                                                                   | 7,766                               |
| Transportation           | 0.001832937                                                                   | 11,614                              |
| Finance                  | 0.000267899                                                                   | 1,771                               |
| Insurance                | 0.000153025                                                                   | 939                                 |
| Real Estate              | 0.000166051                                                                   | 2,768                               |
| Government               | 0.155828018                                                                   | 2,159,287                           |
| Miscellaneous            | 0.001628775                                                                   | 2,540                               |

**Table 5. Lower TN River Region Water Use Coefficients by Aggregated Sector**

| <b>Sector</b>            | <b>Water Use Coefficient (Acre Feet per Dollar of Total Industry Output * 1,000)</b> | <b>Sector Water Withdrawal (Acre-Feet)</b> |
|--------------------------|--------------------------------------------------------------------------------------|--------------------------------------------|
| Primary Agriculture      |                                                                                      |                                            |
| Crops                    | 0.023613228                                                                          | 14,091                                     |
| Primary Agriculture      |                                                                                      |                                            |
| Livestock                | 0.045640353                                                                          | 21,512                                     |
| Forestry Inputs          | 0.000018613                                                                          | 1                                          |
| Mining                   | 0.017298130                                                                          | 4,351                                      |
| Services                 | 0.000787265                                                                          | 5,618                                      |
| Utilities                | 0.005059035                                                                          | 2,522                                      |
| Water, Sewage, and Other |                                                                                      |                                            |
| Systems                  | 0.002839798                                                                          | 29                                         |
| Construction             | 0.000526370                                                                          | 1,197                                      |
| Secondary Agriculture    | 0.010330638                                                                          | 30,689                                     |
| Manufacturing            | 0.007997434                                                                          | 93,812                                     |
| Primary Forestry         | 0.030095763                                                                          | 31,446                                     |
| Secondary Forestry       | 0.000852463                                                                          | 604                                        |
| Agriculture Inputs       | 0.001642809                                                                          | 35                                         |
| Wholesale Trade          | 0.000462792                                                                          | 702                                        |
| Retail Trade             | 0.000729339                                                                          | 1,482                                      |
| Transportation           | 0.000382066                                                                          | 341                                        |
| Finance                  | 0.000254190                                                                          | 261                                        |
| Insurance                | 0.000141863                                                                          | 85                                         |
| Real Estate              | 0.000132090                                                                          | 405                                        |
| Government               | 0.229920218                                                                          | 748,684                                    |
| Miscellaneous            | 0.001897505                                                                          | 634                                        |

**Table 6. Mississippi River Region Water Use Coefficients by Aggregated Sector**

| <b>Sector</b>            | <b>Water Use Coefficient (Acre Feet per Dollar of Total Industry Output * 1,000)</b> | <b>Sector Water Withdrawal (Acre-Feet)</b> |
|--------------------------|--------------------------------------------------------------------------------------|--------------------------------------------|
| Primary Agriculture      |                                                                                      |                                            |
| Crops                    | 0.02787266                                                                           | 41,368                                     |
| Primary Agriculture      |                                                                                      |                                            |
| Livestock                | 0.04748364                                                                           | 5,981                                      |
| Forestry Inputs          | 1.6025E-05                                                                           | 1                                          |
| Mining                   | 0.011243913                                                                          | 2,938                                      |
| Services                 | 0.000677498                                                                          | 26,366                                     |
| Utilities                | 0.002213891                                                                          | 944                                        |
| Water, Sewage, and Other |                                                                                      |                                            |
| Systems                  | 0.004141321                                                                          | 86                                         |
| Construction             | 0.000499568                                                                          | 3,268                                      |
| Secondary Agriculture    | 0.000822988                                                                          | 8,642                                      |
| Manufacturing            | 0.002139348                                                                          | 49,495                                     |
| Primary Forestry         | 0.004375917                                                                          | 15,679                                     |
| Secondary Forestry       | 0.000654083                                                                          | 1,083                                      |
| Agriculture Inputs       | 0.007724334                                                                          | 6,434                                      |
| Wholesale Trade          | 0.000491509                                                                          | 4,213                                      |
| Retail Trade             | 0.000803955                                                                          | 5,386                                      |
| Transportation           | 0.001676169                                                                          | 8,183                                      |
| Finance                  | 0.000348642                                                                          | 1,467                                      |
| Insurance                | 0.000201534                                                                          | 452                                        |
| Real Estate              | 0.000171691                                                                          | 1,754                                      |
| Government               | 0.034697735                                                                          | 530,115                                    |
| Miscellaneous            | 0.001079018                                                                          | 1,144                                      |

**Table 7. Upper TN River Region Water Use Coefficients by Aggregated Sector**

| <b>Sector</b>                    | <b>Water Use Coefficient (Acre Feet per Dollar of Total Industry Output * 1,000)</b> | <b>Sector Water Withdrawal (Acre-Feet)</b> |
|----------------------------------|--------------------------------------------------------------------------------------|--------------------------------------------|
| Primary Agriculture Crops        | 0.019337384                                                                          | 8,568                                      |
| Primary Agriculture Livestock    | 0.066221871                                                                          | 39,437                                     |
| Forestry Inputs                  | 0.000025304                                                                          | 1                                          |
| Mining                           | 0.006477823                                                                          | 5,564                                      |
| Services                         | 0.000784179                                                                          | 40,815                                     |
| Utilities                        | 0.002812343                                                                          | 2,785                                      |
| Water, Sewage, and Other Systems | 0.004843849                                                                          | 689                                        |
| Construction                     | 0.000541571                                                                          | 6,265                                      |
| Secondary Agriculture            | 0.002536292                                                                          | 23,147                                     |
| Manufacturing                    | 0.013402571                                                                          | 622,558                                    |
| Primary Forestry                 | 0.036417506                                                                          | 52,270                                     |
| Secondary Forestry               | 0.000623828                                                                          | 2,004                                      |
| Agriculture Inputs               | 0.004479949                                                                          | 2,585                                      |
| Wholesale Trade                  | 0.000501497                                                                          | 4,323                                      |
| Retail Trade                     | 0.000851312                                                                          | 9,095                                      |
| Transportation                   | 0.000537325                                                                          | 3,032                                      |
| Finance                          | 0.000372422                                                                          | 2,045                                      |
| Insurance                        | 0.000128579                                                                          | 556                                        |
| Real Estate                      | 0.000170184                                                                          | 2,640                                      |
| Government                       | 0.181642012                                                                          | 3,205,482                                  |
| Miscellaneous                    | 0.001434557                                                                          | 2,273                                      |

**Table 8. Summary of Regional Output and Withdrawals for 21 Aggregated Sectors**

| <b>Region</b> | <b>TIO</b>               | <b>% of Total TIO</b> | <b>Withdrawal (Acre Feet)</b> | <b>% of Total Withdrawal</b> |
|---------------|--------------------------|-----------------------|-------------------------------|------------------------------|
| Cumberland    | \$204,341,862,522        | 35%                   | 2,346,161                     | 29%                          |
| Mississippi   | \$140,726,719,028        | 24%                   | 714,999                       | 9%                           |
| Upper TN      | \$197,010,411,454        | 34%                   | 4,036,134                     | 50%                          |
| Lower TN      | \$40,506,677,489         | 7%                    | 958,501                       | 12%                          |
| <b>TOTAL</b>  | <b>\$582,585,670,494</b> | <b>100%</b>           | <b>8,055,795</b>              | <b>100%</b>                  |

## Figures

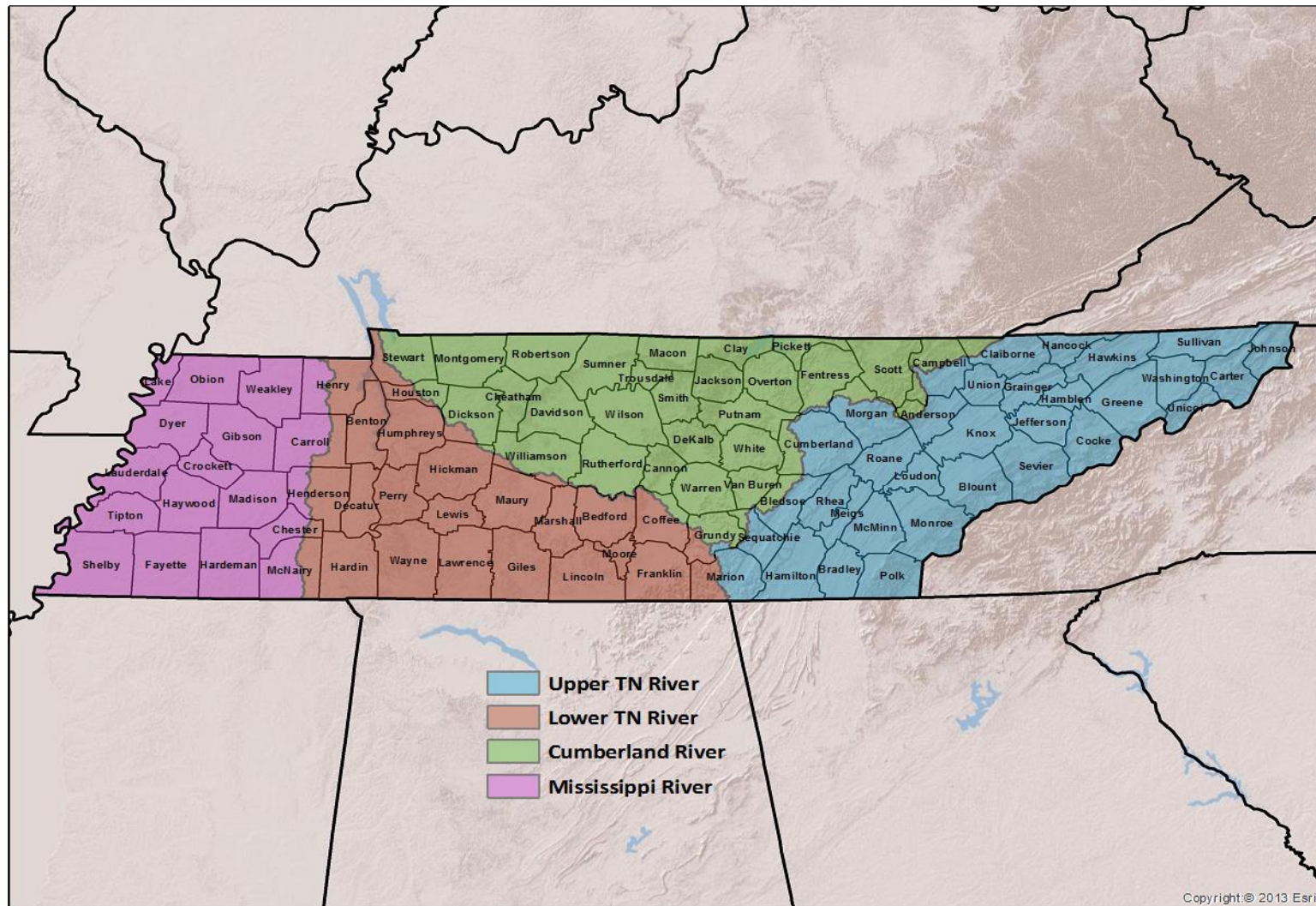


Figure 1. Hydrologic Unit Regions for the State of Tennessee

## **CHAPTER 3: Estimating Shadow Values for Water in Tennessee Using Linear Programming and Input-Output Analysis**

## **Abstract**

Understanding how industries contribute to the Tennessee economy is important to ensuring a resilient economy into the uncertain future. In addition, understanding the resource use associated with each industry is useful in developing a sustainable economy. This chapter applies an input-output linear programming model (IOLP) to quantify how much gross regional product varies with every one unit change in water availability. These aggregate and sector-level shadow values are useful for interpreting the possible effects climate change and other stressors could have on Tennessee's water resources and the economy. The model maximizes gross regional product subject to water and labor constraints using water use coefficients estimated in Chapter 2 and data from IMPLAN.

The results show that the real estate, insurance, and forestry inputs sectors have the highest shadow values for water and that the primary agriculture livestock, primary agriculture crops, and government sectors have the lowest shadow values for water. Shadow values do not change in most regions until an 80 to 90% decrease in water withdrawals is achieved relative to the current water withdrawal baseline. The Cumberland River region is contributing the most to the state's GRP. Further investigation into each region's sectors and constraints is needed to determine why abundant water resources, such as in the Upper Tennessee River region, does not necessarily translate into relatively higher economic activity compared to regions with less water withdrawals. A closer look at each region's primary economic sectors can help determine which sectors are the most impacted by changes in water withdrawal and which sectors have the most impact on the state economy.

## **Problem Identification and Explanation**

Water is essential to all facets of life, and the underlying question this study aims to answer is what are the shadow values for water among competing economic sectors. However, because water is valued by different people, industries, and regions in unique and dissimilar ways, determining shadow values for water becomes a hard problem to solve. While Tennessee is typically considered to have an abundant supply of water, the state is already experiencing the pressures of water scarcity. For example, Georgia has been battling with Tennessee for years in hopes of obtaining access to Tennessee's water resources (McWhirter, 2013). With the mounting evidence of climate change, increases in population growth, increases in irrigation, issues with water contamination, economic advancement, infrastructure depreciation, and inefficiencies and inequities in current water policies, these pressures on Tennessee's water resources can only be expected to rise. The current literature provides little information on the shadow value of water for individual sectors in Tennessee and does not provide information on the interconnected linkages between the state's competing sectors. This chapter focuses on determining the shadow value of water for Tennessee's industries by using an IOLP model.

The results of this analysis benefit the state by providing information useful in developing an Integrated Water Resource Management (IWRM) plan or other water resource plan by providing perspective on which sectors the state should promote in planning for the future if water efficiency and economic growth within the economy should be primary criterion (Griffin, 2006; Anisfield, 2010; Zetland, 2011). In addition, this model allows the user to observe the effects of changes in water withdrawals in one sector on the output and water use of connected sectors.

## **Research Objective**

The objective of this chapter is to determine the shadow value of water for each economic sector by maximizing gross regional product, subject to water resource constraints.

## **Literature Review**

The literature contains studies that determine industrial water footprints. A water footprint is the amount of water required by an economic sector to produce goods and services, including both the direct use plus the amount of water required to produce inputs required by that sector, or the indirect water use. The literature also contains methods that estimate the economic contributions of water, and how trade contributes to economies at the regional, interregional, and national scales.

In 1981, a study of 64 sectors in South Carolina used linear programming in conjunction with regional Input-Output analysis (IOA) as a way of estimating the shadow value of water to alternative uses while maximizing gross regional product (Henry and Bowen, 1981). Similarly, Hubacek and Sun (2005) linked a hydrological model with a regional IOA to look at 118 sectors and eight regions in China comparing water demand in 2025 with water supply. Other studies have also used optimization methods for similar analysis (Ward and Pulido-Velazquez, 2008; Rosegrant et al., 2000), and the last 15 years have provided several studies using IOA by industry sector (Lenzen and Foran, 2001; Duarte et al., 2002; Velazquez, 2006; Guan and Hubacek, 2007; Lenzen, 2009; Blackhurst et al., 2010; Feng et al., 2012; Mubako et al., 2013).

Lenzen and Foran (2001) evaluated the future of water use in Australia using IOA and calculated water multipliers for 118 industry sectors. Water multipliers show which sectors could be prioritized to achieve the highest economic output per unit of water (Feng et al., 2012).

Lenzen and Foran (2001) found that agriculture was not only the highest user, but also the most

sensitive to change in water pricing. Similarly, Duarte et al. (2002) evaluated the consumption of irrigation, drinking water, and waste water by sector in Spain to see how each sector affected water availability. The authors made an important observation that reducing agricultural activity could put other interconnected industries at risk. This is because sectors are interdependent and require both water and outputs from other sectors to thrive. If water availability is reduced in one sector, it may affect sectors that are dependent on its outputs and sectors that supply its inputs (Henry and Bowen, 1981). Velazquez (2006) took IOA a step further and combined it with a model of energy use to look at direct and indirect consumption, production potential, and to what extent water scarcity could limit some production sectors.

Cicas et al. (2007) used regional IOA based life cycle assessment (RIO-LCA) to determine economic multipliers for electricity, fuel use, and air emissions for eight U.S. regions and 491 sectors. Then Blackhurst et al. (2010) used the same approach on the national level for direct and indirect water multipliers examining 428 sectors from the 2002 U.S. economic input-output table. Both Blackhurst et al. (2010) and Cicas et al. (2007) recommend using hybrid LCA models to connect relationships between sectors. Several studies have applied principles from the studies mentioned and expanded them to models that look at virtual water, or the water embodied in traded products (Feng et al., 2012; Guan and Hubacek, 2007; Zhao et al., 2009; Zhang et al., 2011; Hoekstra and Chapagain, 2007). This chapter contributes to the literature by providing shadow values for water for economic sectors in Tennessee's economy.

Several economic modeling software packages exist that can calculate economic multipliers such as Regional Input Output Modeling System (RIMS II), Regional Economic Modeling, Inc. (REMI), and Impact Analysis for Planning (IMPLAN), but there is difficulty finding useful resource use data by region that can be used in the software because regional data

are limited (Cicas et al., 2007). McKean et al. (1998) notes that IMPLAN is the most versatile and complete software and provides some insight on the usefulness and limitations of the system.

## Methods

The data for this study consist of a combination of publicly available data from USGS (2010) and USDA (2007; 2013) as well as data purchased from IMPLAN Group, LLC (2013).

The IOLP model used for this analysis was developed by Henry and Bowen (1981):

$$\text{Maximize } Z = V_n * X_n \quad (1)$$

subject to

$$(I - A) * X \leq Y \quad (2)$$

$$\sum_{n=1}^N u_n * X_n \leq W^{Total} \quad [\lambda_w] \quad (3)$$

$$\sum_{n=1}^N l_n * X_n \leq L^{Total} \quad [\lambda_l] \quad (4)$$

where:  $Z$  is the total value added to the economy,  $V_n$  is value added per dollar of output for sector  $n$ , and  $X_n$  is the total industry output of sector  $n$ . The first constraint (equation (2)) is a final demand constraint including linkages between sectors where:  $I$  is an identity matrix,  $A$  is the direct requirements matrix,  $\lambda$  is the shadow value, and  $Y$  is the current final demand. The second constraint (equation (3)) is a resource constraint on water availability where:  $u_n$  is a water use coefficient of acre feet of water used per dollar of output for sector  $n$ , and  $W^{Total}$  is the total acre feet of water withdrawals in Tennessee. Equation (4) is also a resource constraint where:  $l$  are labor coefficients for number of employees per dollar of output, and  $L^{Total}$  is the total number of employees in Tennessee. This model was solved for the state of Tennessee. Then, constraints (3) and (4) were modified as:

$$u_n * X_n \leq W_n \quad [\lambda W_n] \forall n \quad (5)$$

$$l_n * X_n \leq L_n \quad [\lambda l_n] \forall n \quad (6)$$

where:  $W_n$  and  $L_n$  are now total water and labor availability for each sector instead of for the region as a whole. This is done so that the shadow value of water for each sector can be determined in addition to the shadow value of water for all of the sectors combined. The shadow value of water is the change in the objective function for every acre foot change in water withdrawal. The shadow value for water can be written as:

$$\frac{\Delta GRP}{\Delta W} = \lambda_w. \quad (7)$$

First, the state total water supply was decreased incrementally to determine how GRP would change (Figure 2) and to estimate the shadow value of water across all sectors. The total water withdrawal was reduced at the state level which means no particular sector was penalized, and the model could bring in the top GRP contributing sectors based on the water withdrawal. Then, the model was re-solved with decreases in water withdrawal for each individual sector.

## Results and Discussion

Five models were built – one at the state level and one for each of the four HUC regions. Baseline industry water withdrawals are shown in Table 9. The models were solved to determine the shadow value of water by state/region (Tables 10 - 15) and also the shadow value of water by industry for the state and each region (Tables 16-20).

### Regional Shadow Values

The average shadow value of water is zero at the water withdrawal baseline indicating that the water constraint is not binding. In most cases, the shadow value stays consistent until there has been an 80 – 90% decrease in the water withdrawal baseline. From the initial results, it

appears that the Cumberland River region is contributing most to the state's value added, or gross regional product (GRP), followed by the Upper Tennessee River region, then the Mississippi River region, and lastly by the Lower Tennessee River region. The largest baseline water withdrawal is in the Upper Tennessee River region in Eastern Tennessee, and baseline water withdrawals decrease with each region to the west. Interestingly, based on the averages, the Lower Tennessee River region is using the most acre-feet of water for every \$1 million of output, followed by the Upper Tennessee River region, the Cumberland River region, and lastly the Mississippi River region. This indicates that in general, the Lower and Upper Tennessee River regions generate less economic activity per acre-foot of water, and therefore, have a lower economic value of water than the Mississippi and Cumberland River regions. The relatively higher economic activity per acre-foot of water in the Mississippi and Cumberland River regions indicates that the western part of the state is using water more efficiently than the eastern part of the state. This may indicate that the Mississippi and Cumberland River regions are supported by less water-intensive industries than the Upper and Lower Tennessee River regions.

### **Sector Shadow Values**

To take a closer look at the economic sectors within each region, the models were re-solved to find the shadow value of water for each industry and to estimate how GRP will change when each sector receives the same percentage decrease (Figure 3-7). In this section, each sector's water withdrawals are simultaneously reduced by the same percentage to examine how each sector specifically is affected by water constraints.

At the state level baseline water withdrawal, the real estate and wholesale trade sectors have the largest shadow values indicating that those two sectors would benefit the economy the most from additional water under the specified water constrained scenarios. For all of the sectors,

the shadow values stay the same from a 10-90% decrease in water withdrawal, but GRP drops dramatically from \$292 million dollars at the baseline level to \$29 million dollars. The insurance and real estate sectors appear to have the highest shadow values of water on average across all water supply scenarios, and the government and primary agriculture livestock sectors have the lowest, indicating a low economic value of water for the latter two sectors and vice versa. This is of interest since the insurance sector is directly dependent on there being people and industries in need of insurance, and the real estate sector is directly dependent on there being industries to provide jobs for people to want to live in the area and an influx of businesses coming to the area in need of operational space. Therefore, though the insurance and real estate sectors have high shadow values for water, a reduction in water/output of the other sectors could greatly affect the economic contributions the high value sectors could have. For this reason, it would be important to look at how shadow values change under different scenarios and also what additional constraints may need to be considered.

In the four individual regions, the real estate, insurance, and forestry inputs sectors consistently have some of the highest shadow values across all scenarios, and the government, primary agricultural livestock, primary agricultural crops, and primary forestry sectors have the lowest shadow values consistently across all water withdrawal scenarios. The government and livestock sectors are the lowest two in most cases. This results correlate with the water use coefficients found in Chapter 2.

This information is useful in thinking about the future of the Tennessee economy in varying water availability scenarios. While agricultural and government entities are essential to the health and progression of the economy, their low values indicate the need for improvements where possible in water use. Operations such as a dairy farm will use more water, and

consequently, farmers benefit from staying proactive in implementing water reducing practices and technologies. The government sector includes water uses such as public schools, universities, the postal service, public transit, and utilities and could also benefit from incorporating water saving methods.

### **Application of Results**

The results of this chapter can be used in informing policy makers of the economic contributions made by individual sectors and of the resource use associated with each contribution. This is beneficial in developing medium to long term strategies that both strengthen the state economy and preserve natural resources. For example, policymakers could compare high and low water use sectors to determine which ones are contributing most to GRP and which ones are using the most water. Future policy may require water to be allocated or more stringently used, and the resulting data will be beneficial in comparing proposed policies.

Future studies could use methods or data from this analysis as guidance for other projects on related topics such as consumptive use, risk analysis, and trade flows or virtual water. It may be helpful to disaggregate the sectors and look at the specific activities within each one to gain more understanding of the resource use.

Further research can also look at the effects to the economy by altering water supply in each sector by varying percentages instead of by equivalent percentages. This is important because it is unlikely that each sector will be affected proportionally by water stress, and estimating how each sector will be affected will be essential in evaluating realistic scenarios. It is important to remember that a change in water availability in one sector impacts other sectors even if they do not also experience a change in water availability. Therefore, increasing or decreasing water supply in low shadow value sectors may either positively or adversely affect

the economy as a whole. Also, each region could be included in the model simultaneously to analyze how climate change or other water stress could affect different geographical areas. It is unlikely that each region would be affected the same by climate change so including each region in the same model could provide more insight on how allocation or limitation to sectors could affect the state as a whole when implemented uniformly across regions.

Lastly, a projection of final demand could be implemented into the model like Henry and Bowen (1981) shows to determine changes in TIO based on increases in final demand.. Implementing a projection of final demand allows the model to determine the shadow value of water under population growth scenarios.

## **Discussion**

The low agricultural shadow values estimated in this chapter correspond with previous studies found in the literature. In general, the insurance, real estate, and forestry input sectors contribute the most to the economy for each additional unit of water, and the livestock, crop, and government sectors contribute the least. More detail could be provided with consumptive versus withdrawal data, and the model can be expanded to include more constraints. To prepare for uncertain water scenarios there is a need for more detailed data collection, and there is a need for more cohesive data among providing agencies. Overall, what is provided in this chapter is a building block to future research and an overall representation of water withdrawals in relation to the economy.

## **Limitations of Results**

While the government and agricultural sectors may withdraw quite a bit of water, the withdrawals do not necessarily represent water that is consumed. Though the terms water “withdrawal” and water “use” have been used interchangeably throughout this study, this

analysis has utilized only water “withdrawal” data. Industries that withdraw water, for example, the thermoelectric industry, do not actually “use” or consume all of the water withdrawn, and how much of the water is considered “consumed” is controversial (Zetland, 2011). Therefore, the water withdrawn is actually put to multiple uses by different industries that are all providing value to the economy. This means that “it is not really possible to state any single value for water, but rather a water resource used within a watershed (or economy) results in a total increase of economic value or community welfare (Fadali et al., 2012).” Differentiating between consumptive and non-consumptive use would be useful in evaluating if sectors determined to have low shadow values in this study would intensify water stress situations or if they could continue to use water without affecting the overall sustainability of the resources and economy. Future studies may estimate water consumption by using water use coefficients from Chapter 1 in combination with adjustment factors similar to Smith et al. (2011).

The model presented also does not account for trade among regions. All of the interactions occur within the region itself, and the model does not provide information on where the water is coming from. With some changes though, a multiregional model can be built to address this issue (Leontief and Strout, 1963).

Another limitation of this study is the lack of harmonized data. Different agencies and regions use varying methods to estimate water use, the data are often from different years, and aggregation can often lead to overestimation. These results should be applied accounting for uncertainty.

It is also important to consider that this model is what is known as a “lumped parameter” model, meaning that it is focused on only one parameter, which in this case is water availability

(Griffin, 2006). This means other factors such as water quality, land availability, and location are not being considered. While this does not take away from the value of the information provided, the model could be enhanced to include more details. Because of the unique life cycle of water, it can be difficult to track such details; however, further research in topics such as the movement of water between geographical locations and through products would be beneficial in formulating dynamic water management strategies in years to come.

## References

- Anisfield, S.C. *Water Resources*. Washington D.C.: Island Press, 2010.
- Blackhurst, M., C. Hendrickson, and J.S. I Vidal. "Direct and Indirect Water Withdrawals for U.S. Industrial Sectors." *Environmental Science and Technology* 44(February 2010): 2126-2130.
- Cicas, G., C.T. Hendrickson, A. Horvath, and H.S. Matthews. "A Regional Version of a US Economic Input-Output Life-Cycle Assessment Model." *The International Journal of Life Cycle Assessment* 12(September 2007):365-372.
- Duarte, R., J. Sanchez-Choliz, and J. Bielsa. "Water Use in the Spanish Economy: an input-output approach." *Ecological Economics* 43(November 2002):71-85.
- Fadali, E., K. Rollins, and S. Stoddard. "Determining Water Values with Computable General Equilibrium Models." Paper presented at The Importance of Water to the U.S. Economy: Technical Workshop, Washington, D.C., September 19, 2012.
- Feng, K., Y.L. Siu, D. Gaun, and K. Hubacek. "Assessing Regional Virtual Water Flows and Water Footprints in the Yellow River Basin, China: A Consumption Based Approach." *Applied Geography* 32(March 2012):691-701.
- Griffin, Ronald C. *Water Resource Economics*. Cambridge, Massachusetts: The MIT Press, 2006.
- Guan, D., and K. Hubacek. "Assessment of Regional Trade and Virtual Water Flows in China." *Ecological Economics* 61(February 2007):159-170.
- Henry, M.S and E. Bowen. "A Method for Estimating the Value of Water Among Sectors of a Regional Economy." *Southern Journal of Agricultural Economics* 13(December 1981): 125-132.
- Hoekstra, A.Y., and A.K. Chapagain. "Water Footprints of Nations: Water Use by People as a Function of Their Consumption Pattern." *Water Resources Management* 21(January 2007):35-48.
- Hubacek, K. and L. Sun. "Economic and Societal Changes in China and their Effects on Water Use." *Journal of Industrial Ecology* 9(January 2005):187-200.
- IMPLAN Group, LLC, IMPLAN System (2013 data and software), 16740 Birkdale Commons Parkway, Suite 206, Huntersville, NC 28078 [www.IMPLAN.com](http://www.IMPLAN.com).
- Lenzen, M. "Understanding Virtual Water Flows: A Multiregion Input-Output Case Study of Victoria." *Water Resources Research* 45(September 2009):W09416.
- Lenzen, M., and B. Foran. "An Input-Output Analysis of Australian Water Usage." *Water Policy* 3(June 2001):321-340.

- Leontief, W. and A. Strout. "Multiregional Input-Output Analysis." *Structural Interdependence and Economic Development: Proceedings of an International Conference on Input-Output Techniques, Geneva, September 1961*. T. Barna, ed. New York, New York: St. Martin's Press Inc., 1963.
- McKean, J.R., R.G. Taylor, G. Alward, and R.A. Young. "Adapting Synthesized Input-Output Models for Small Natural Resource-Based Regions: A Case Study." *Society & Natural Resources: An International Journal* 11(1998):387-399.
- McWhirter, Cameron. "In Latest War Between the States, Georgia Says Tennessee Is All Wet – Wayward Surveyors Blocked River Access; Is Jack Daniel's Whiskey Next on the List?" *The Wall Street Journal* (April 10, 2013). Internet site: <http://www.wsj.com/articles/SB10001424127887324000704578388472029592836>
- Mubako, S., S. Lahin, and C. Lant. "Input-Output Analysis of Virtual Water Transfers: Case Study of California and Illinois." *Ecological Economics* 93(September 2013):230-238.
- Rosegrant, M.W., C. Ringler, D.C. McKinney, X. Car, A. Keller, and G. Donoso. "Integrated Economic-Hydrologic Water Modeling at the Basin Scale: The Maipo River Basin." *Agricultural Economics* 24(December 2000):33-46.
- Smith, C. A., A. J. Simon, A. J., and R. D. Belles. "Estimated Water Flows in 2005: United States." (LLNL-TR-475772). Livermore, CA (2011). Internet Site: [https://flowcharts.llnl.gov/content/water/water\\_flow\\_archive/2005USSateWater.pdf](https://flowcharts.llnl.gov/content/water/water_flow_archive/2005USSateWater.pdf) (Accessed May 16, 2016).
- U.S. Department of Agriculture (USDA) 2007 Census of Agriculture. Internet Site: [http://www.agcensus.usda.gov/Publications/2007/Full\\_Report/Volume\\_1,\\_Chapter\\_1\\_State\\_Level/Tennessee/](http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_1_State_Level/Tennessee/) (Accessed February 11, 2015).
- U.S. Department of Agriculture (USDA) 2013 Farm and Ranch Irrigation Survey. Internet Site: [http://www.agcensus.usda.gov/Publications/2012/Online\\_Resources/Farm\\_and\\_Ranch\\_Irrigation\\_Survey/](http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/) (Accessed June 9, 2015).
- U.S. Department of the Interior – U.S. Geological Survey (USGS) National Water Information System – 2010 Water Use Data for Tennessee. Internet site: [http://waterdata.usgs.gov/tn/nwis/water\\_use?format=html\\_table&rdb\\_compression=file&wu\\_area=County&wu\\_year=2010&wu\\_county=ALL&wu\\_category=ALL&wu\\_countynms=--ALL%2BCounties--](http://waterdata.usgs.gov/tn/nwis/water_use?format=html_table&rdb_compression=file&wu_area=County&wu_year=2010&wu_county=ALL&wu_category=ALL&wu_countynms=--ALL%2BCounties--) (Accessed June 9, 2015).
- Velazquez, E. "An Input-Output Model of Water Consumption: Analysing Intersectoral Water Relationships in Andalusia." *Ecological Economics* 56(February 2006):226-240.
- Ward, F.A., and M. Pulido-Velazquez. "Water Conservation in Irrigation Can Increase Water Use." *Proceedings of the National Academy of Sciences of the United States of America*, 2008, pp. 18215-18220.

Zetland, D. *The End of Abundance*. Mission Viejo, Amsterdam: Aguanomics Press, 2011.

Zhang, Z., H. Yang, and M. Shi. "Analyses of Water Footprint of Beijing in an Interregional Input-Output Framework." *Ecological Economics* 70(October 2011):2494-2502.

Zhao, X., B. Chen, and Z.F. Yang. "National Water Footprint in an Input-Output Framework – A Case Study of China 2002." *Ecological Modelling* 220 (January 2009):245-253.

## Appendix B: Tables and Figures used in the Manuscript

### Tables

**Table 9. Baseline Water Withdrawals for each Industry by State and Region**

| Sector                            | Baseline Water Withdrawals<br>(Acre-Feet) |                  |                |                |                  |
|-----------------------------------|-------------------------------------------|------------------|----------------|----------------|------------------|
|                                   | State                                     | Upper<br>TN      | Lower<br>TN    | Mississippi    | Cumberland       |
| Primary Ag Crops                  | 80,797                                    | 8,568            | 14,091         | 41,368         | 16,770           |
| Primary Ag Livestock              | 90,141                                    | 39,437           | 21,512         | 5,981          | 23,211           |
| Forestry Inputs                   | 7                                         | 1                | 1              | 1              | 2                |
| Mining                            | 17,381                                    | 5,564            | 4,351          | 2,938          | 4,528            |
| Services                          | 111,004                                   | 40,815           | 5,618          | 26,366         | 38,204           |
| Utilities                         | 13,166                                    | 2,785            | 2,522          | 944            | 6,915            |
| Water, sewage, & Other<br>Systems | 1,153                                     | 689              | 29             | 86             | 350              |
| Construction                      | 16,227                                    | 6,265            | 1,197          | 3,268          | 5,497            |
| Secondary Ag                      | 72,346                                    | 23,147           | 30,689         | 8,642          | 9,868            |
| Manufacturing                     | 813,903                                   | 622,558          | 93,812         | 49,495         | 48,039           |
| Primary Forestry                  | 99,555                                    | 52,270           | 31,446         | 15,679         | 160              |
| Secondary Forestry                | 4,903                                     | 2,004            | 604            | 1,083          | 1,213            |
| Ag Inputs                         | 9,066                                     | 2,585            | 35             | 6,434          | 11               |
| Wholesale trade                   | 13,947                                    | 4,323            | 702            | 4,213          | 4,709            |
| Retail Trade                      | 23,730                                    | 9,095            | 1,482          | 5,386          | 7,766            |
| Transportation                    | 23,170                                    | 3,032            | 341            | 8,183          | 11,614           |
| Finance                           | 5,543                                     | 2,045            | 261            | 1,467          | 1,771            |
| Insurance                         | 2,032                                     | 556              | 85             | 452            | 939              |
| Real Estate                       | 7,566                                     | 2,640            | 405            | 1,754          | 2,768            |
| Government                        | 6,643,568                                 | 3,205,482        | 748,684        | 530,115        | 2,159,287        |
| Miscellaneous                     | 6,590                                     | 2,273            | 634            | 1,144          | 2,540            |
| <b>Total</b>                      | <b>8,055,795</b>                          | <b>4,036,134</b> | <b>958,501</b> | <b>714,999</b> | <b>2,346,161</b> |

**Table 10. Shadow Value of Water for Tennessee at Alternative Withdrawal Levels.**

| Water<br>Withdrawal<br>(Acre-Feet) | Percentage of<br>Baseline<br>Water<br>Withdrawal (%) | Shadow Value<br>(Dollars per Acre Foot *<br>1,000,000) | Maximized Gross Regional<br>Product<br>(Millions of Dollars) |
|------------------------------------|------------------------------------------------------|--------------------------------------------------------|--------------------------------------------------------------|
| 8,055,795                          | 100%                                                 | N/A                                                    | \$292,119                                                    |
| 7,250,216                          | 90%                                                  | \$6,174                                                | \$287,145                                                    |
| 6,444,636                          | 80%                                                  | \$6,174                                                | \$282,172                                                    |
| 5,639,057                          | 70%                                                  | \$6,174                                                | \$277,198                                                    |
| 4,833,477                          | 60%                                                  | \$6,174                                                | \$272,224                                                    |
| 4,027,898                          | 50%                                                  | \$6,174                                                | \$267,250                                                    |
| 3,222,318                          | 40%                                                  | \$6,174                                                | \$262,277                                                    |
| 2,416,739                          | 30%                                                  | \$6,174                                                | \$257,303                                                    |
| 1,611,159                          | 20%                                                  | \$6,174                                                | \$252,329                                                    |
| 805,580                            | 10%                                                  | \$56,498                                               | \$227,201                                                    |

**Table 11. Shadow Value of Water for Mississippi River Region at Alternative Withdrawal Levels.**

| Water<br>Withdrawal<br>(Acre-Feet) | Percentage of<br>Baseline<br>Water<br>Withdrawal (%) | Shadow Value<br>(Dollars per Acre Foot<br>*1,000,000) | Maximized Gross Regional<br>Product<br>(Millions of Dollars) |
|------------------------------------|------------------------------------------------------|-------------------------------------------------------|--------------------------------------------------------------|
| 714,999                            | 100%                                                 | N/A                                                   | \$71,279                                                     |
| 643,499                            | 90%                                                  | \$22,349                                              | \$69,898                                                     |
| 571,999                            | 80%                                                  | \$22,349                                              | \$68,300                                                     |
| 500,499                            | 70%                                                  | \$22,349                                              | \$66,702                                                     |
| 429,000                            | 60%                                                  | \$22,349                                              | \$65,104                                                     |
| 357,500                            | 50%                                                  | \$22,349                                              | \$63,506                                                     |
| 286,000                            | 40%                                                  | \$22,349                                              | \$61,908                                                     |
| 214,500                            | 30%                                                  | \$22,349                                              | \$60,310                                                     |
| 143,000                            | 20%                                                  | \$22,349                                              | \$58,713                                                     |
| 71,500                             | 10%                                                  | \$178,679                                             | \$49,598                                                     |

**Table 12. Shadow Value of Water for Cumberland River Region at Alternative Withdrawal Levels.**

| Water<br>Withdrawal<br><br>(Acre-Feet) | Percentag<br>e of<br>Baseline<br>Water<br>Withdraw<br>al (%) | Shadow Value<br><br>(Dollars per Acre Foot *<br>1,000,000) | Maximized Gross Regional<br>Product<br><br>(Millions of Dollars) |
|----------------------------------------|--------------------------------------------------------------|------------------------------------------------------------|------------------------------------------------------------------|
| 2,346,161                              | 100%                                                         | N/A                                                        | \$108,747                                                        |
| 2,111,545                              | 90%                                                          | \$5,638                                                    | \$107,425                                                        |
| 1,876,929                              | 80%                                                          | \$5,638                                                    | \$106,102                                                        |
| 1,642,312                              | 70%                                                          | \$5,638                                                    | \$104,779                                                        |
| 1,407,696                              | 60%                                                          | \$5,638                                                    | \$103,456                                                        |
| 1,173,080                              | 50%                                                          | \$5,638                                                    | \$102,134                                                        |
| 938,464                                | 40%                                                          | \$5,638                                                    | \$100,811                                                        |
| 703,848                                | 30%                                                          | \$5,638                                                    | \$99,488                                                         |
| 469,232                                | 20%                                                          | \$5,638                                                    | \$98,165                                                         |
| 234,616                                | 10%                                                          | \$5,638                                                    | \$96,843                                                         |

**Table 13. Shadow Value of Water for Lower TN River Region at Alternative Withdrawal Levels.**

| Water<br>Withdrawal<br><br>(Acre-Feet) | Percentag<br>e of<br>Baseline<br>Water<br>Withdraw<br>al (%) | Shadow Value<br><br>(Dollars per Acre Foot *<br>1,000,000) | Maximized Gross Regional<br>Product<br><br>(Millions of Dollars) |
|----------------------------------------|--------------------------------------------------------------|------------------------------------------------------------|------------------------------------------------------------------|
| 958,501                                | 100%                                                         | N/A                                                        | \$18,012                                                         |
| 862,651                                | 90%                                                          | \$3,552                                                    | \$17,671                                                         |
| 766,801                                | 80%                                                          | \$3,552                                                    | \$17,331                                                         |
| 670,951                                | 70%                                                          | \$3,552                                                    | \$16,990                                                         |
| 575,101                                | 60%                                                          | \$3,552                                                    | \$16,650                                                         |
| 479,251                                | 50%                                                          | \$3,552                                                    | \$16,309                                                         |
| 383,401                                | 40%                                                          | \$3,552                                                    | \$15,969                                                         |
| 287,550                                | 30%                                                          | \$3,552                                                    | \$15,628                                                         |
| 191,700                                | 20%                                                          | \$10,521                                                   | \$15,166                                                         |
| 95,850                                 | 10%                                                          | \$40,525                                                   | \$12,667                                                         |

**Table 14. Shadow Value of Water for Upper TN River Region at Alternative Withdrawal Levels.**

| Water<br>Withdrawal<br><br>(Acre-Feet) | Percentage of<br>Baseline<br>Water<br>Withdrawal (%) | Shadow Value<br><br>(Dollars per Acre Foot *<br>1,000,000) | Maximized Gross Regional<br>Product<br><br>(Millions of Dollars) |
|----------------------------------------|------------------------------------------------------|------------------------------------------------------------|------------------------------------------------------------------|
| 4,036,134                              | 100%                                                 | N/A                                                        | \$94,081                                                         |
| 3,632,521                              | 90%                                                  | \$4,337                                                    | \$92,331                                                         |
| 3,228,907                              | 80%                                                  | \$4,337                                                    | \$90,581                                                         |
| 2,825,294                              | 70%                                                  | \$4,337                                                    | \$88,830                                                         |
| 2,421,680                              | 60%                                                  | \$4,337                                                    | \$87,080                                                         |
| 2,018,067                              | 50%                                                  | \$4,337                                                    | \$85,330                                                         |
| 1,614,454                              | 40%                                                  | \$4,337                                                    | \$83,580                                                         |
| 1,210,840                              | 30%                                                  | \$4,337                                                    | \$81,829                                                         |
| 807,227                                | 20%                                                  | \$7,219                                                    | \$80,026                                                         |
| 403,613                                | 10%                                                  | \$27,729                                                   | \$70,089                                                         |

**Table 15. Shadow Value of Water for Mississippi River Region at Alternative Withdrawal Levels.**

| Water<br>Withdrawal<br><br>(Acre-Feet) | Percentag<br>e of<br>Baseline<br>Water<br>Withdraw<br>al (%) | Shadow Value<br><br>(Dollars per Acre Foot *<br>1,000,000) | Maximized Gross Regional<br>Product<br><br>(Millions of Dollars) |
|----------------------------------------|--------------------------------------------------------------|------------------------------------------------------------|------------------------------------------------------------------|
| 714,999                                | 100%                                                         | N/A                                                        | \$71,279                                                         |
| 643,499                                | 90%                                                          | \$22,349                                                   | \$69,898                                                         |
| 571,999                                | 80%                                                          | \$22,349                                                   | \$68,300                                                         |
| 500,499                                | 70%                                                          | \$22,349                                                   | \$66,702                                                         |
| 429,000                                | 60%                                                          | \$22,349                                                   | \$65,104                                                         |
| 357,500                                | 50%                                                          | \$22,349                                                   | \$63,506                                                         |
| 286,000                                | 40%                                                          | \$22,349                                                   | \$61,908                                                         |
| 214,500                                | 30%                                                          | \$22,349                                                   | \$60,310                                                         |
| 143,000                                | 20%                                                          | \$22,349                                                   | \$58,713                                                         |
| 71,500                                 | 10%                                                          | \$178,679                                                  | \$49,598                                                         |

**Table 16. Shadow Values of Water for Tennessee by Sector.**

| Sector                         | Percentage of Baseline Water Supply (%)          |          |          |          |          |          |          |          |          |          |
|--------------------------------|--------------------------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
|                                | 100                                              | 90       | 80       | 70       | 60       | 50       | 40       | 30       | 20       | 10       |
|                                | Shadow Values (in Dollars per Acre Foot * 1,000) |          |          |          |          |          |          |          |          |          |
| Primary Ag Crops               | \$0                                              | \$18     | \$18     | \$18     | \$18     | \$18     | \$18     | \$18     | \$18     | \$18     |
| Primary Ag Livestock           | \$8                                              | \$7      | \$7      | \$7      | \$7      | \$7      | \$7      | \$7      | \$7      | \$7      |
| Forestry Inputs                | \$0                                              | \$26,657 | \$26,657 | \$26,657 | \$26,657 | \$26,657 | \$26,657 | \$26,657 | \$26,657 | \$26,657 |
| Mining                         | \$0                                              | \$83     | \$83     | \$83     | \$83     | \$83     | \$83     | \$83     | \$83     | \$83     |
| Services                       | \$0                                              | \$915    | \$915    | \$915    | \$915    | \$915    | \$915    | \$915    | \$915    | \$915    |
| Utilities                      | \$0                                              | \$101    | \$101    | \$101    | \$101    | \$101    | \$101    | \$101    | \$101    | \$101    |
| Water, Sewage, & Other Systems | \$189                                            | \$172    | \$172    | \$172    | \$172    | \$172    | \$172    | \$172    | \$172    | \$172    |
| Construction                   | \$0                                              | \$671    | \$671    | \$671    | \$671    | \$671    | \$671    | \$671    | \$671    | \$671    |
| Secondary Ag                   | \$0                                              | \$102    | \$102    | \$102    | \$102    | \$102    | \$102    | \$102    | \$102    | \$102    |
| Manufacturing                  | \$0                                              | \$40     | \$40     | \$40     | \$40     | \$40     | \$40     | \$40     | \$40     | \$40     |
| Primary Forestry               | \$0                                              | \$20     | \$20     | \$20     | \$20     | \$20     | \$20     | \$20     | \$20     | \$20     |
| Secondary Forestry             | \$566                                            | \$384    | \$384    | \$384    | \$384    | \$384    | \$384    | \$384    | \$384    | \$384    |
| Ag Inputs                      | \$0                                              | \$45     | \$45     | \$45     | \$45     | \$45     | \$45     | \$45     | \$45     | \$45     |
| Wholesale trade                | \$1,666                                          | \$1,359  | \$1,359  | \$1,359  | \$1,359  | \$1,359  | \$1,359  | \$1,359  | \$1,359  | \$1,359  |

**Table 16. Continued Shadow Values of Water for Tennessee by Sector.**

| <b>Sector</b>                  | Percentage of Baseline Water Supply (%)          |                  |                  |                  |                  |                  |                  |                 |                 |                 |
|--------------------------------|--------------------------------------------------|------------------|------------------|------------------|------------------|------------------|------------------|-----------------|-----------------|-----------------|
|                                | 100                                              | 90               | 80               | 70               | 60               | 50               | 40               | 30              | 20              | 10              |
|                                | Shadow Values (in Dollars per Acre Foot * 1,000) |                  |                  |                  |                  |                  |                  |                 |                 |                 |
| Retail Trade                   | \$946                                            | \$786            | \$786            | \$786            | \$786            | \$786            | \$786            | \$786           | \$786           | \$786           |
| Transportation                 | \$0                                              | \$315            | \$315            | \$315            | \$315            | \$315            | \$315            | \$315           | \$315           | \$315           |
| Finance                        | \$0                                              | \$1,342          | \$1,342          | \$1,342          | \$1,342          | \$1,342          | \$1,342          | \$1,342         | \$1,342         | \$1,342         |
| Insurance                      | \$0                                              | \$3,019          | \$3,019          | \$3,019          | \$3,019          | \$3,019          | \$3,019          | \$3,019         | \$3,019         | \$3,019         |
| Real Estate                    | \$5,010                                          | \$4,491          | \$4,491          | \$4,491          | \$4,491          | \$4,491          | \$4,491          | \$4,491         | \$4,491         | \$4,491         |
| Government                     | \$0                                              | \$5              | \$5              | \$5              | \$5              | \$5              | \$5              | \$5             | \$5             | \$5             |
| Miscellaneous                  | \$521                                            | \$433            | \$433            | \$433            | \$433            | \$433            | \$433            | \$433           | \$433           | \$433           |
| <b>GRP (in millions of \$)</b> | <b>\$292,119</b>                                 | <b>\$262,907</b> | <b>\$233,695</b> | <b>\$204,483</b> | <b>\$175,271</b> | <b>\$146,060</b> | <b>\$116,848</b> | <b>\$87,636</b> | <b>\$58,424</b> | <b>\$29,212</b> |

**Table 17. Shadow Values of Water for the Cumberland River Region by Sector.**

| Sector                         | Percentage of Baseline Water Supply (%)          |          |          |          |          |          |          |          |          |          |
|--------------------------------|--------------------------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
|                                | 100                                              | 90       | 80       | 70       | 60       | 50       | 40       | 30       | 20       | 10       |
|                                | Shadow Values (in Dollars per Acre Foot * 1,000) |          |          |          |          |          |          |          |          |          |
| Primary Ag Crops               | \$22.46                                          | \$21     | \$21     | \$21     | \$21     | \$21     | \$21     | \$21     | \$21     | \$21     |
| Primary Ag Livestock           | \$6                                              | \$6      | \$6      | \$6      | \$6      | \$6      | \$6      | \$6      | \$6      | \$6      |
| Forestry Inputs                | \$0                                              | \$18,497 | \$18,497 | \$18,497 | \$18,497 | \$18,497 | \$18,497 | \$18,497 | \$18,497 | \$18,497 |
| Mining                         | \$0                                              | \$119    | \$119    | \$119    | \$119    | \$119    | \$119    | \$119    | \$119    | \$119    |
| Services                       | \$1,231                                          | \$1,155  | \$1,155  | \$1,155  | \$1,155  | \$1,155  | \$1,155  | \$1,155  | \$1,155  | \$1,155  |
| Utilities                      | \$102                                            | \$98     | \$98     | \$98     | \$98     | \$98     | \$98     | \$98     | \$98     | \$98     |
| Water, Sewage, & Other Systems | \$0                                              | \$170    | \$170    | \$170    | \$170    | \$170    | \$170    | \$170    | \$170    | \$170    |
| Construction                   | \$0                                              | \$756    | \$756    | \$756    | \$756    | \$756    | \$756    | \$756    | \$756    | \$756    |
| Secondary Ag                   | \$0                                              | \$215    | \$215    | \$215    | \$215    | \$215    | \$215    | \$215    | \$215    | \$215    |
| Manufacturing                  | \$0                                              | \$209    | \$209    | \$209    | \$209    | \$209    | \$209    | \$209    | \$209    | \$209    |
| Primary Forestry               | \$0                                              | \$282    | \$282    | \$282    | \$282    | \$282    | \$282    | \$282    | \$282    | \$282    |
| Secondary Forestry             | \$0                                              | \$343    | \$343    | \$343    | \$343    | \$343    | \$343    | \$343    | \$343    | \$343    |
| Ag Inputs                      | \$636                                            | \$592    | \$592    | \$592    | \$592    | \$592    | \$592    | \$592    | \$592    | \$592    |
| Wholesale trade                | \$1,575                                          | \$1,488  | \$1,488  | \$1,488  | \$1,488  | \$1,488  | \$1,488  | \$1,488  | \$1,488  | \$1,488  |

**Table 17. Continued. Shadow Values of Water for the Cumberland River Region by Sector.**

| <b>Sector</b>                  | Percentage of Baseline Water Supply (%)          |                |                |                 |                 |                 |                 |                 |                 |                 |
|--------------------------------|--------------------------------------------------|----------------|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                                | 100                                              | 90             | 80             | 70              | 60              | 50              | 40              | 30              | 20              | 10              |
|                                | Shadow Values (in Dollars per Acre Foot * 1,000) |                |                |                 |                 |                 |                 |                 |                 |                 |
| Retail Trade                   | \$919                                            | \$827          | \$827          | \$827           | \$827           | \$827           | \$827           | \$827           | \$827           | \$827           |
| Transportation                 | \$232                                            | \$212          | \$212          | \$212           | \$212           | \$212           | \$212           | \$212           | \$212           | \$212           |
| Finance                        | \$0                                              | \$1,647        | \$1,647        | \$1,647         | \$1,647         | \$1,647         | \$1,647         | \$1,647         | \$1,647         | \$1,647         |
| Insurance                      | \$3,307                                          | \$3,168        | \$3,168        | \$3,168         | \$3,168         | \$3,168         | \$3,168         | \$3,168         | \$3,168         | \$3,168         |
| Real Estate                    | \$0                                              | \$4,526        | \$4,526        | \$4,526         | \$4,526         | \$4,526         | \$4,526         | \$4,526         | \$4,526         | \$4,526         |
| Government                     | \$5                                              | \$5            | \$5            | \$5             | \$5             | \$5             | \$5             | \$5             | \$5             | \$5             |
| Miscellaneous                  | \$0                                              | \$379          | \$379          | \$379           | \$379           | \$379           | \$379           | \$379           | \$379           | \$379           |
|                                |                                                  | <b>\$97,87</b> | <b>\$86,99</b> |                 |                 |                 |                 |                 |                 |                 |
| <b>GRP (in millions of \$)</b> | <b>\$108,747</b>                                 | <b>3</b>       | <b>8</b>       | <b>\$76,123</b> | <b>\$65,248</b> | <b>\$54,374</b> | <b>\$43,499</b> | <b>\$32,624</b> | <b>\$21,749</b> | <b>\$10,875</b> |

**Table 18. Shadow Values of Water for the Upper TN River Region by Sector.**

| Sector                                           | Percentage of Baseline Water Supply (%) |          |          |          |          |          |          |          |          |          |
|--------------------------------------------------|-----------------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
|                                                  | 100                                     | 90       | 80       | 70       | 60       | 50       | 40       | 30       | 20       | 10       |
| Shadow Values (in Dollars per Acre Foot * 1,000) |                                         |          |          |          |          |          |          |          |          |          |
| Primary Ag Crops                                 | \$0                                     | \$31     | \$31     | \$31     | \$31     | \$31     | \$31     | \$31     | \$31     | \$31     |
| Primary Ag Livestock                             | \$7                                     | \$6      | \$6      | \$6      | \$6      | \$6      | \$6      | \$6      | \$6      | \$6      |
| Forestry Inputs                                  | \$0                                     | \$21,802 | \$21,802 | \$21,802 | \$21,802 | \$21,802 | \$21,802 | \$21,802 | \$21,802 | \$21,802 |
| Mining                                           | \$102                                   | \$100    | \$100    | \$100    | \$100    | \$100    | \$100    | \$100    | \$100    | \$100    |
| Services                                         | \$752                                   | \$728    | \$728    | \$728    | \$728    | \$728    | \$728    | \$728    | \$728    | \$728    |
| Utilities                                        | \$137                                   | \$122    | \$122    | \$122    | \$122    | \$122    | \$122    | \$122    | \$122    | \$122    |
| Water, Sewage, & Other Systems                   | \$0                                     | \$164    | \$164    | \$164    | \$164    | \$164    | \$164    | \$164    | \$164    | \$164    |
| Construction                                     | \$678                                   | \$592    | \$592    | \$592    | \$592    | \$592    | \$592    | \$592    | \$592    | \$592    |
| Secondary Ag                                     | \$117                                   | \$96     | \$96     | \$96     | \$96     | \$96     | \$96     | \$96     | \$96     | \$96     |
| Manufacturing                                    | \$0                                     | \$20     | \$20     | \$20     | \$20     | \$20     | \$20     | \$20     | \$20     | \$20     |
| Primary Forestry                                 | \$0                                     | \$8      | \$8      | \$8      | \$8      | \$8      | \$8      | \$8      | \$8      | \$8      |
| Secondary Forestry                               | \$0                                     | \$415    | \$415    | \$415    | \$415    | \$415    | \$415    | \$415    | \$415    | \$415    |
| Ag Inputs                                        | \$0                                     | \$61     | \$61     | \$61     | \$61     | \$61     | \$61     | \$61     | \$61     | \$61     |
| Wholesale trade                                  | \$0                                     | \$1,253  | \$1,253  | \$1,253  | \$1,253  | \$1,253  | \$1,253  | \$1,253  | \$1,253  | \$1,253  |
| Retail Trade                                     | \$760                                   | \$736    | \$736    | \$736    | \$736    | \$736    | \$736    | \$736    | \$736    | \$736    |

**Table 18. Continued. Shadow Values of Water for the Upper TN River Region by Sector.**

| <b>Sector</b>                  | Percentage of Baseline Water Supply (%)          |                |                |                 |                 |                 |                 |                 |                 |                |
|--------------------------------|--------------------------------------------------|----------------|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|----------------|
|                                | 100                                              | 90             | 80             | 70              | 60              | 50              | 40              | 30              | 20              | 10             |
|                                | Shadow Values (in Dollars per Acre Foot * 1,000) |                |                |                 |                 |                 |                 |                 |                 |                |
| Transportation                 | \$863                                            | \$784          | \$784          | \$784           | \$784           | \$784           | \$784           | \$784           | \$784           | \$784          |
| Finance                        | \$0                                              | \$1,000        | \$1,000        | \$1,000         | \$1,000         | \$1,000         | \$1,000         | \$1,000         | \$1,000         | \$1,000        |
| Insurance                      | \$3,562                                          | \$3,483        | \$3,483        | \$3,483         | \$3,483         | \$3,483         | \$3,483         | \$3,483         | \$3,483         | \$3,483        |
| Real Estate                    | \$4,454                                          | \$4,368        | \$4,368        | \$4,368         | \$4,368         | \$4,368         | \$4,368         | \$4,368         | \$4,368         | \$4,368        |
| Government                     | \$0                                              | \$4            | \$4            | \$4             | \$4             | \$4             | \$4             | \$4             | \$4             | \$4            |
| Miscellaneous                  | \$447                                            | \$419          | \$419          | \$419           | \$419           | \$419           | \$419           | \$419           | \$419           | \$419          |
| <b>GRP (in millions of \$)</b> |                                                  | <b>\$84,67</b> | <b>\$75,26</b> |                 |                 |                 |                 |                 |                 |                |
|                                | <b>\$94,081</b>                                  | <b>3</b>       | <b>5</b>       | <b>\$65,857</b> | <b>\$56,449</b> | <b>\$47,041</b> | <b>\$37,633</b> | <b>\$28,224</b> | <b>\$18,816</b> | <b>\$9,408</b> |

**Table 19. Shadow Values of Water for the Lower TN River Region by Sector.**

| Sector                         | Percentage of Baseline Water Supply (%)          |          |         |          |          |          |          |          |          |          |
|--------------------------------|--------------------------------------------------|----------|---------|----------|----------|----------|----------|----------|----------|----------|
|                                | 100                                              | 90       | 80      | 70       | 60       | 50       | 40       | 30       | 20       | 10       |
|                                | Shadow Values (in Dollars per Acre Foot * 1,000) |          |         |          |          |          |          |          |          |          |
| Primary Ag Crops               | \$0                                              | \$20     | \$20    | \$20     | \$20     | \$20     | \$20     | \$20     | \$20     | \$20     |
| Primary Ag Livestock           | \$11                                             | \$9      | \$9     | \$9      | \$9      | \$9      | \$9      | \$9      | \$9      | \$9      |
| Forestry Inputs                |                                                  |          | \$32,10 |          |          |          |          |          |          |          |
|                                | \$0                                              | \$32,108 | 8       | \$32,108 | \$32,108 | \$32,108 | \$32,108 | \$32,108 | \$32,108 | \$32,108 |
| Mining                         | \$0                                              | \$39     | \$39    | \$39     | \$39     | \$39     | \$39     | \$39     | \$39     | \$39     |
| Services                       | \$0                                              | \$716    | \$716   | \$716    | \$716    | \$716    | \$716    | \$716    | \$716    | \$716    |
| Utilities                      | \$0                                              | \$71     | \$71    | \$71     | \$71     | \$71     | \$71     | \$71     | \$71     | \$71     |
| Water, Sewage, & Other Systems | \$298                                            | \$278    | \$278   | \$278    | \$278    | \$278    | \$278    | \$278    | \$278    | \$278    |
| Construction                   | \$0                                              | \$523    | \$523   | \$523    | \$523    | \$523    | \$523    | \$523    | \$523    | \$523    |
| Secondary Ag                   | \$0                                              | \$30     | \$30    | \$30     | \$30     | \$30     | \$30     | \$30     | \$30     | \$30     |
| Manufacturing                  | \$0                                              | \$32     | \$32    | \$32     | \$32     | \$32     | \$32     | \$32     | \$32     | \$32     |
| Primary Forestry               | \$14                                             | \$9      | \$9     | \$9      | \$9      | \$9      | \$9      | \$9      | \$9      | \$9      |
| Secondary Forestry             | \$390                                            | \$288    | \$288   | \$288    | \$288    | \$288    | \$288    | \$288    | \$288    | \$288    |
| Ag Inputs                      | \$0                                              | \$198    | \$198   | \$198    | \$198    | \$198    | \$198    | \$198    | \$198    | \$198    |
| Wholesale trade                | \$0                                              | \$1,313  | \$1,313 | \$1,313  | \$1,313  | \$1,313  | \$1,313  | \$1,313  | \$1,313  | \$1,313  |
| Retail Trade                   | \$951                                            | \$836    | \$836   | \$836    | \$836    | \$836    | \$836    | \$836    | \$836    | \$836    |

**Table 19. Continued. Shadow Values of Water for the Lower TN River Region by Sector.**

| <b>Sector</b>                  | Percentage of Baseline Water Supply (%)          |                 |                |                 |                 |                |                |                |                |                |
|--------------------------------|--------------------------------------------------|-----------------|----------------|-----------------|-----------------|----------------|----------------|----------------|----------------|----------------|
|                                | 100                                              | 90              | 80             | 70              | 60              | 50             | 40             | 30             | 20             | 10             |
|                                | Shadow Values (in Dollars per Acre Foot * 1,000) |                 |                |                 |                 |                |                |                |                |                |
| Transportation                 | \$0                                              | \$1,113         | \$1,113        | \$1,113         | \$1,113         | \$1,113        | \$1,113        | \$1,113        | \$1,113        | \$1,113        |
| Finance                        | \$0                                              | \$1,463         | \$1,463        | \$1,463         | \$1,463         | \$1,463        | \$1,463        | \$1,463        | \$1,463        | \$1,463        |
| Insurance                      | \$3,152                                          | \$2,871         | \$2,871        | \$2,871         | \$2,871         | \$2,871        | \$2,871        | \$2,871        | \$2,871        | \$2,871        |
| Real Estate                    | \$5,990                                          | \$5,560         | \$5,560        | \$5,560         | \$5,560         | \$5,560        | \$5,560        | \$5,560        | \$5,560        | \$5,560        |
| Government                     | \$0                                              | \$3             | \$3            | \$3             | \$3             | \$3            | \$3            | \$3            | \$3            | \$3            |
| Miscellaneous                  | \$0                                              | \$310           | \$310          | \$310           | \$310           | \$310          | \$310          | \$310          | \$310          | \$310          |
| <b>GRP (in millions of \$)</b> |                                                  |                 | <b>\$14,40</b> |                 |                 |                |                |                |                |                |
|                                | <b>\$18,012</b>                                  | <b>\$16,210</b> | <b>9</b>       | <b>\$12,608</b> | <b>\$10,807</b> | <b>\$9,006</b> | <b>\$7,205</b> | <b>\$5,403</b> | <b>\$3,602</b> | <b>\$1,801</b> |

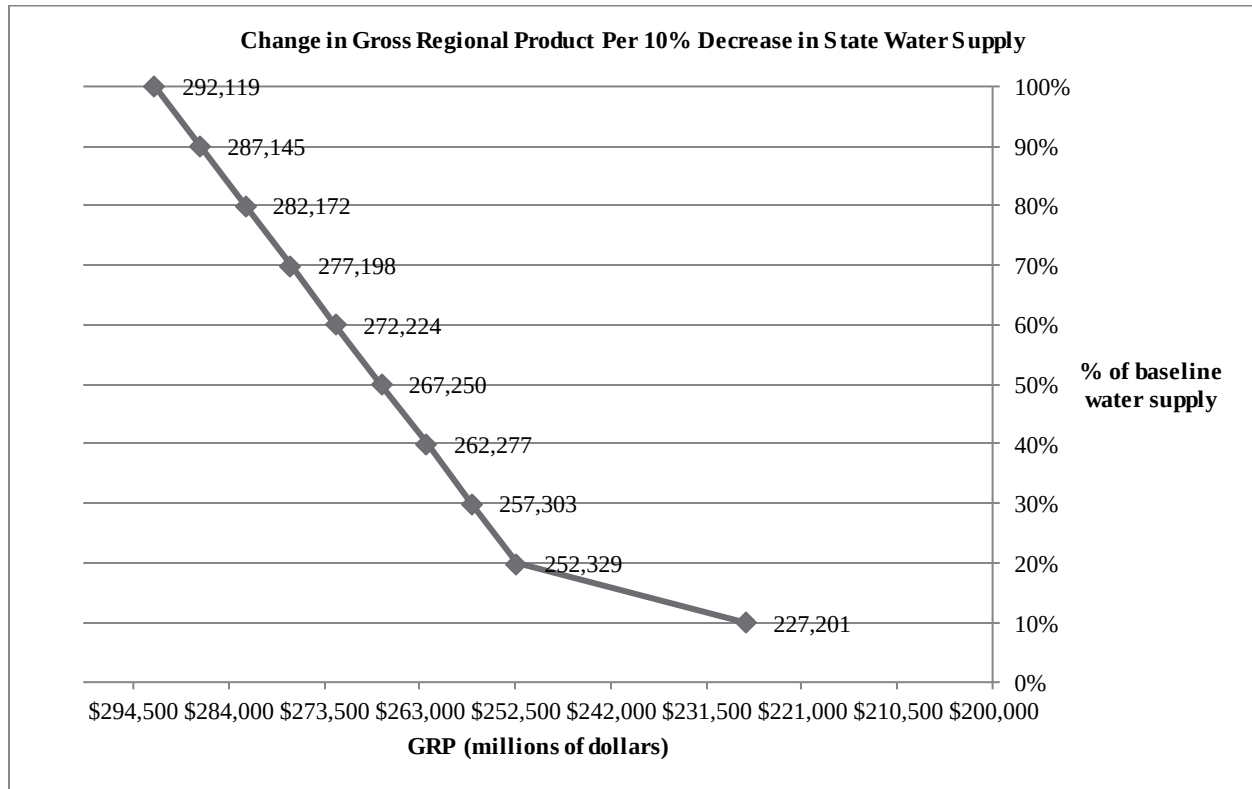
**Table 20. Shadow Values of Water for the Mississippi River Region by Sector.**

| Sector                            | Percentage of Baseline Water Supply (%)          |          |         |          |          |          |          |          |          |          |
|-----------------------------------|--------------------------------------------------|----------|---------|----------|----------|----------|----------|----------|----------|----------|
|                                   | 100                                              | 90       | 80      | 70       | 60       | 50       | 40       | 30       | 20       | 10       |
|                                   | Shadow Values (in Dollars per Acre Foot * 1,000) |          |         |          |          |          |          |          |          |          |
| Primary Ag Crops                  | \$16                                             | \$14     | \$14    | \$14     | \$14     | \$14     | \$14     | \$14     | \$14     | \$14     |
| Primary Ag Livestock              | \$11                                             | \$10     | \$10    | \$10     | \$10     | \$10     | \$10     | \$10     | \$10     | \$10     |
| Forestry Inputs                   |                                                  |          | \$40,39 |          |          |          |          |          |          |          |
|                                   | \$41,900                                         | \$40,395 | 5       | \$40,395 | \$40,395 | \$40,395 | \$40,395 | \$40,395 | \$40,395 | \$40,395 |
| Mining                            | \$0                                              | \$58     | \$58    | \$58     | \$58     | \$58     | \$58     | \$58     | \$58     | \$58     |
| Services                          | \$928                                            | \$899    | \$899   | \$899    | \$899    | \$899    | \$899    | \$899    | \$899    | \$899    |
| Utilities                         | \$0                                              | \$145    | \$145   | \$145    | \$145    | \$145    | \$145    | \$145    | \$145    | \$145    |
| Water, Sewage, &<br>Other Systems | \$214                                            | \$209    | \$209   | \$209    | \$209    | \$209    | \$209    | \$209    | \$209    | \$209    |
| Construction                      | \$0                                              | \$735    | \$735   | \$735    | \$735    | \$735    | \$735    | \$735    | \$735    | \$735    |
| Secondary Ag                      | \$320                                            | \$249    | \$249   | \$249    | \$249    | \$249    | \$249    | \$249    | \$249    | \$249    |
| Manufacturing                     | \$0                                              | \$137    | \$137   | \$137    | \$137    | \$137    | \$137    | \$137    | \$137    | \$137    |
| Primary Forestry                  | \$0                                              | \$78     | \$78    | \$78     | \$78     | \$78     | \$78     | \$78     | \$78     | \$78     |
| Secondary Forestry                | \$551                                            | \$427    | \$427   | \$427    | \$427    | \$427    | \$427    | \$427    | \$427    | \$427    |
| Ag Inputs                         | \$0                                              | \$37     | \$37    | \$37     | \$37     | \$37     | \$37     | \$37     | \$37     | \$37     |
| Wholesale trade                   | \$0                                              | \$1,332  | \$1,332 | \$1,332  | \$1,332  | \$1,332  | \$1,332  | \$1,332  | \$1,332  | \$1,332  |
| Retail Trade                      | \$821                                            | \$798    | \$798   | \$798    | \$798    | \$798    | \$798    | \$798    | \$798    | \$798    |

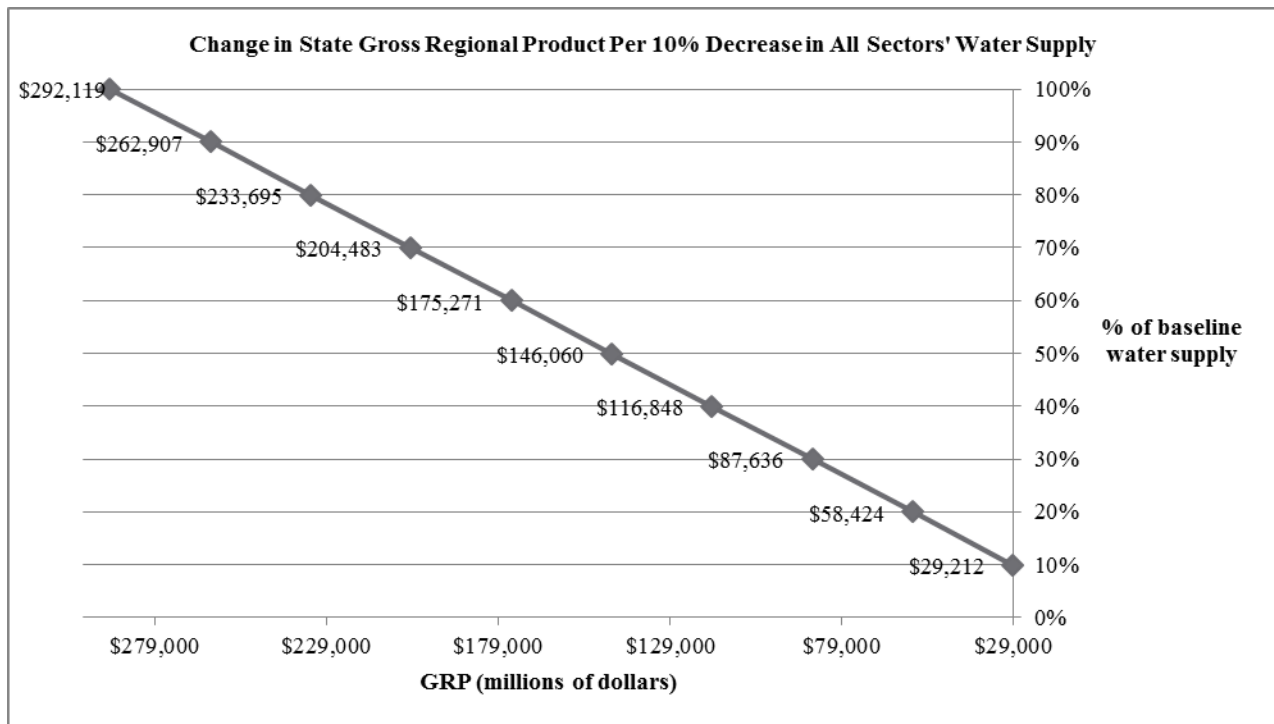
**Table 21. Continued. Shadow Values of Water for the Mississippi River Region by Sector.**

| <b>Sector</b>                  | Percentage of Baseline Water Supply (%)          |          |         |          |          |          |          |          |          |         |
|--------------------------------|--------------------------------------------------|----------|---------|----------|----------|----------|----------|----------|----------|---------|
|                                | 100                                              | 90       | 80      | 70       | 60       | 50       | 40       | 30       | 20       | 10      |
|                                | Shadow Values (in Dollars per Acre Foot * 1,000) |          |         |          |          |          |          |          |          |         |
| Transportation                 | \$279                                            | \$254    | \$254   | \$254    | \$254    | \$254    | \$254    | \$254    | \$254    | \$254   |
| Finance                        | \$0                                              | \$1,431  | \$1,431 | \$1,431  | \$1,431  | \$1,431  | \$1,431  | \$1,431  | \$1,431  | \$1,431 |
| Insurance                      | \$2,233                                          | \$2,165  | \$2,165 | \$2,165  | \$2,165  | \$2,165  | \$2,165  | \$2,165  | \$2,165  | \$2,165 |
| Real Estate                    | \$4,591                                          | \$4,377  | \$4,377 | \$4,377  | \$4,377  | \$4,377  | \$4,377  | \$4,377  | \$4,377  | \$4,377 |
| Government                     | \$20                                             | \$18     | \$18    | \$18     | \$18     | \$18     | \$18     | \$18     | \$18     | \$18    |
| Miscellaneous                  | \$689                                            | \$648    | \$648   | \$648    | \$648    | \$648    | \$648    | \$648    | \$648    | \$648   |
| <b>GRP (in millions of \$)</b> |                                                  |          | \$57,02 |          |          |          |          |          |          |         |
|                                | \$71,279                                         | \$64,151 | 3       | \$49,895 | \$42,767 | \$35,639 | \$28,512 | \$21,384 | \$14,256 | \$7,128 |

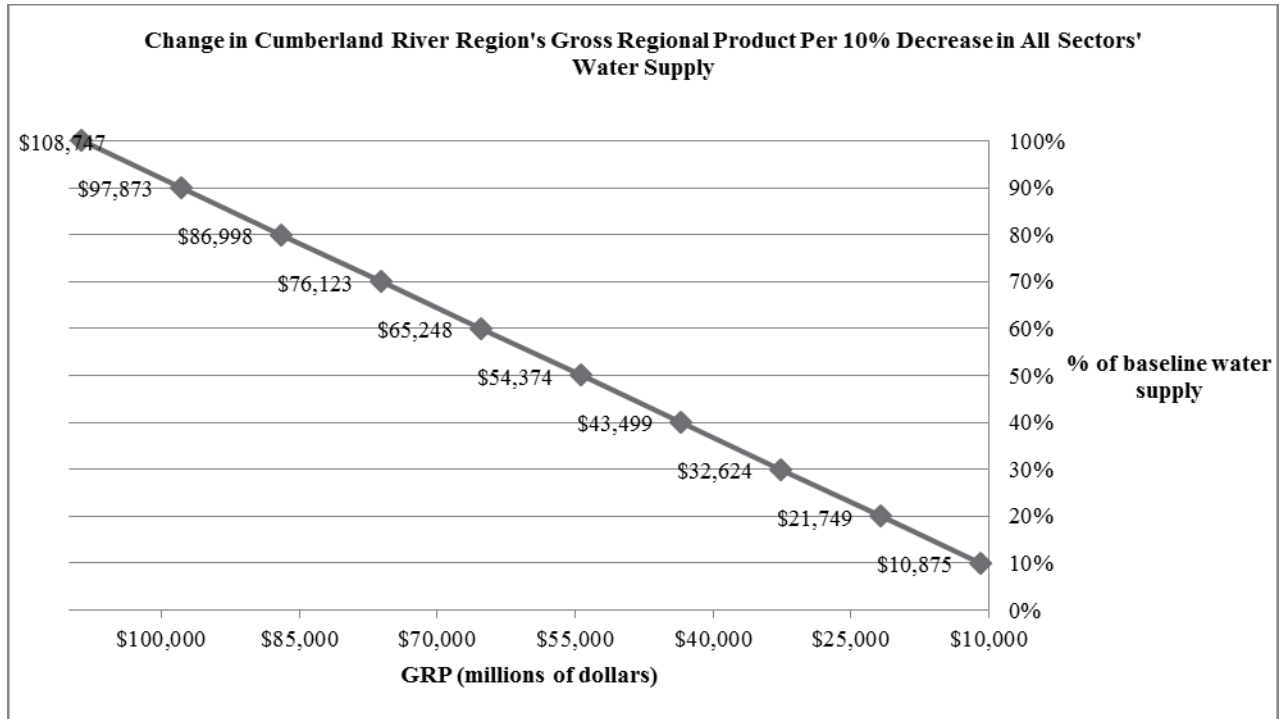
## Figures



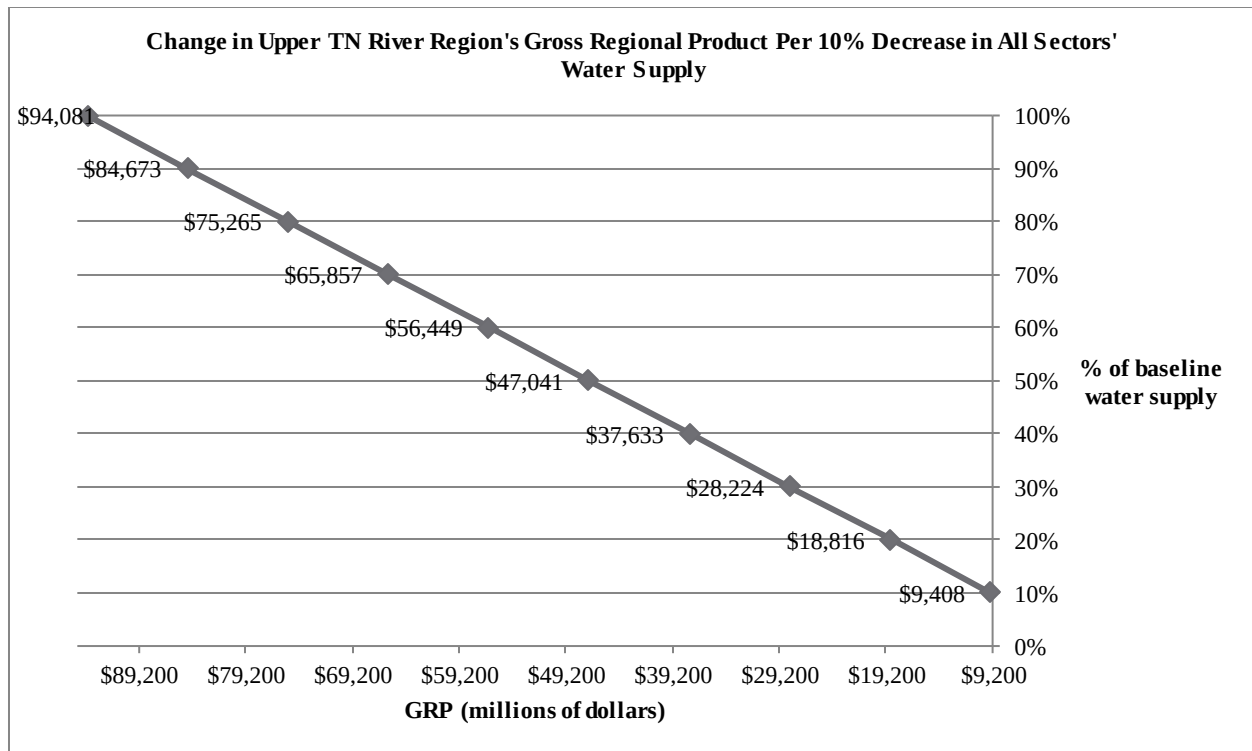
**Figure 2. Change in State Gross Regional Product Resulting from a Decrease in State Water Supply at 10% Increments**



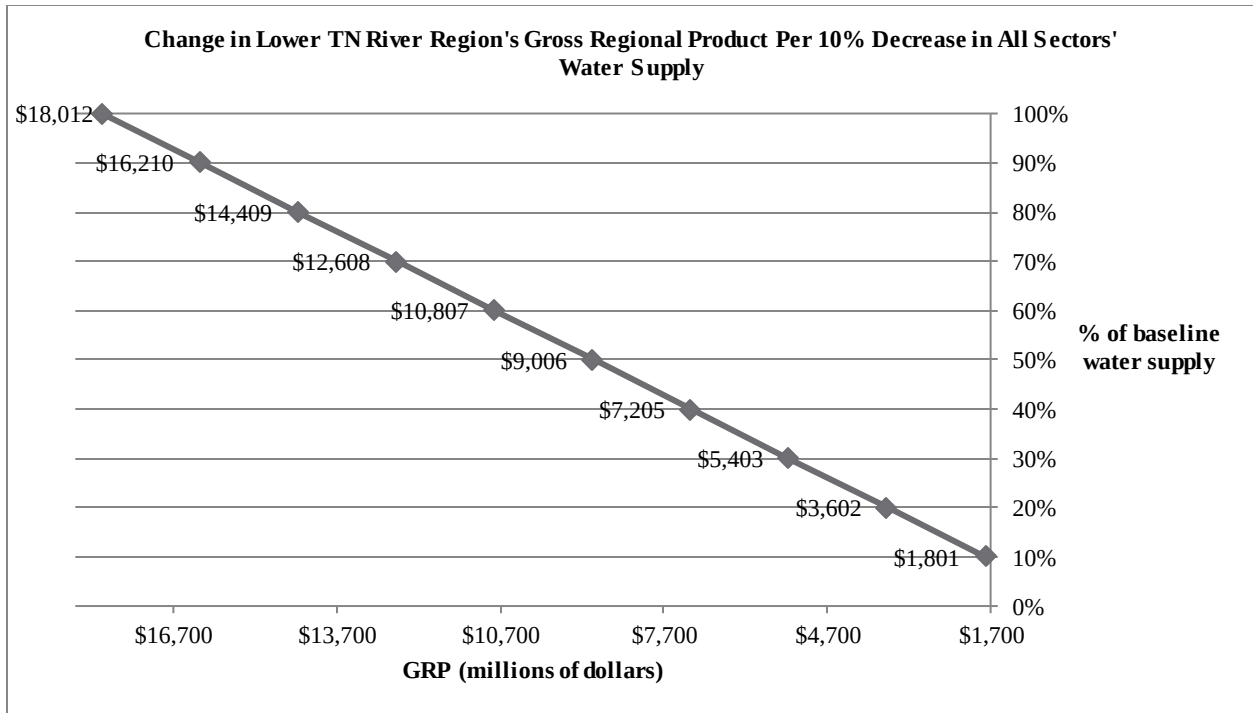
**Figure 3. Change in State Gross Regional Product Resulting from a Decrease in All Sectors' Water Supply at 10% Increments**



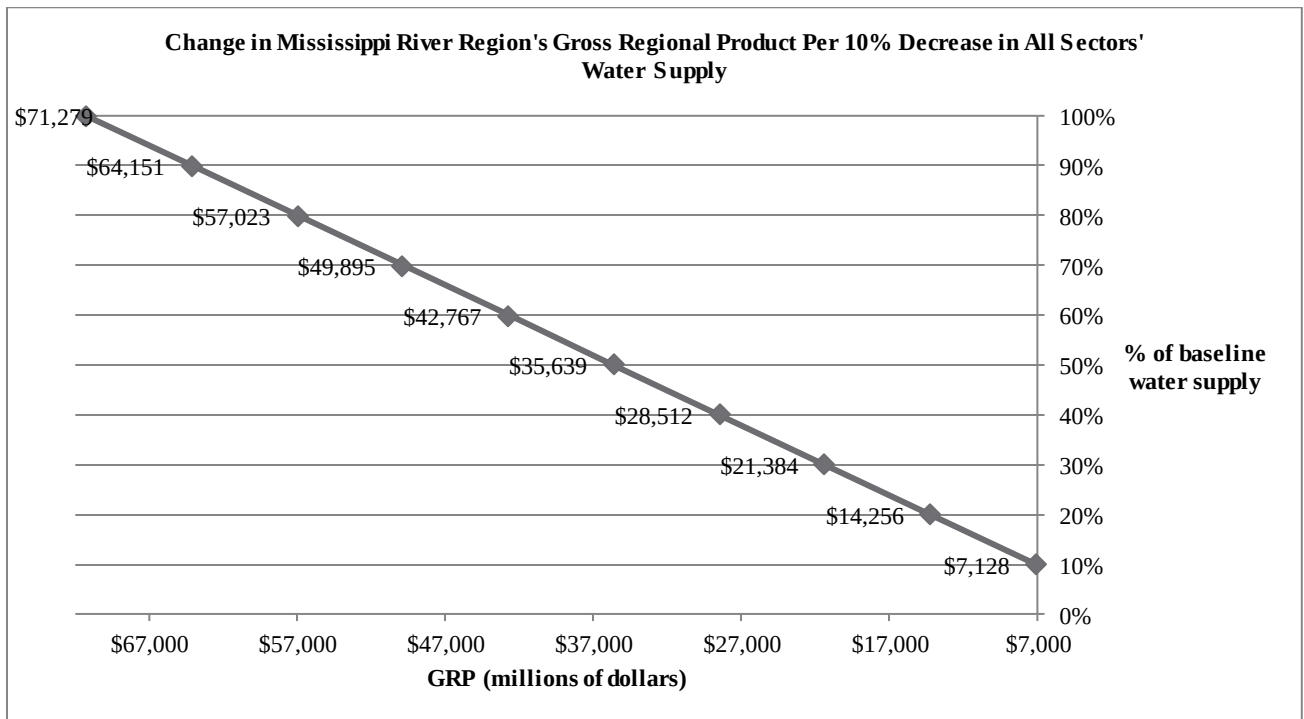
**Figure 4. Change in the Cumberland River Region's Gross Regional Product Resulting from a Decrease in All Sectors' Water Supply at 10% Increments**



**Figure 5. Change in the Upper TN River Region's Gross Regional Product Resulting from a Decrease in All Sectors' Water Supply at 10% Increments**



**Figure 6. Change in the Lower TN River Region's Gross Regional Product Resulting from a Decrease in All Sectors' Water Supply at 10% Increments**



**Figure 7. Change in the Mississippi River Region's Gross Regional Product Resulting from a Decrease in All Sectors' Water Supply at 10% Increments**

## **CHAPTER 4: Conclusion**

The future of Tennessee's water resources is uncertain, and Tennessee does not currently have a plan to deal with strained water resources. However, with the right tools and research, the state can be proactive in preparation for a variety of outcomes and benefit from creating a dynamic and resilient plan applicable to a range of possibilities. Water withdrawal coefficients for 536 economic sectors by county were estimated, and shadow values of water were provided for the state and 4 hydrologic regions on average and by sector. Though there are limitations to the data, the results can be used to identify new possibilities in resource use and economic activity, and the continuation of this research can detail more about the interconnectedness of industries and flow of water through the economy.

## **Vita**

Stephanie Owen was born in Knoxville, TN to Steven and Marie Owen in 1992. She has one older sister, Ashley. Stephanie grew up in Newport, TN where she attended Newport Grammar School and Cocke County High School. After high school graduation, she headed to Knoxville to study at the University of Tennessee where she obtained her Bachelors of Science in May of 2014 with a degree in Agricultural and Resource Economics. Her major was Food and Agricultural Business and her minor was Natural Resources and Environmental Economics. In August of 2014, she started her Masters of Science program also at the University of Tennessee in Agricultural and Resource Economics. Her major was Natural Resources and Environmental Economics and her minor was Watershed. She graduated with her Masters of Science in August of 2016. Upon commencement, she went to work with the United States Army Corps of Engineers in Nashville, TN as their Economist.