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

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To the Graduate Council:

I am submitting herewith a thesis written by Stephanie Michaela Owen entitled "Estimating the Economic Value of Water for Agriculture and Other Industries in Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Economics.

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

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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.

Table of Contents

List of Tables

List of Figures

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 (Siikamaki, 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 Tennesseeans 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:

$$T_j^{Cen} - \sum_i P_{ij} = N_{\square} \tag{1}$$

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:

$$\frac{P_{jr}}{F_{jr}} = B_r \tag{2}$$

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:

$$B_r \cdot F_{ij}^{NAICS} = N_{ij} \tag{3}$$

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:

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

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:

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

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 inputed using:

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

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:

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

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:

$$Min_{\lambda}\, Z = 0$$

Subject to:

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

where: Z is the difference between the USGS water withdrawal estimate and the estimate calculated in the second part of the constraint $\sum_{j=1}^{j} \exp(-1 - \lambda \cdot A_j^{Irr\cdot}) \cdot A_j^{Irr\cdot}$, 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, $exp(-1 - \lambda * A_J^{Irr\cdot})$ is the calculated weight for each crop j in county i, λ is a proportional weighting factor, and $A_j^{Irr\cdot}$ is a weight that can be used for each crop sector. In the case of the Irrigation sector calculations, $A_j^{Irr\cdot}$ 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 $exp(-1 - \lambda \cdot A_J^{Irr\cdot})$ 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:

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

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:

$$\frac{W_n^B}{E_n^B} = u_n^B \tag{13}$$

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:

$$u_{ni} = \frac{W_{ni}}{Z_{ni}} \tag{17}$$

where: u_{1i} 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.

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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)

[a] 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

USGS Sector	Water Withdrawals (000s of Acre Feet Per Year)	% of Total Water Withdrawal
Public Supply ł	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%

ł "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 - Miscellaneious 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

Sector	Water Use Coefficient (Acre Feet per Dollar of Total Industry Output * 1,000)	Sector Water Withdrawal (Acre-Feet)
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

Sector	Water Use Coefficient (Acre Feet per Dollar of Total Industry Output * 1,000)	Sector Water Withdrawal (Acre-Feet)
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

Sector	Water Use Coefficient (Acre Feet per Dollar of Total Industry Output * 1,000)	Sector Water Withdrawal (Acre-Feet)
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

Region	TIO	% of Total TIO	Withdrawal (Acre Feet)	%of Total Withdrawal
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%
TOTAL	**$582,585,670,494**	**100%**	**8,055,795**	**100%**

Figures

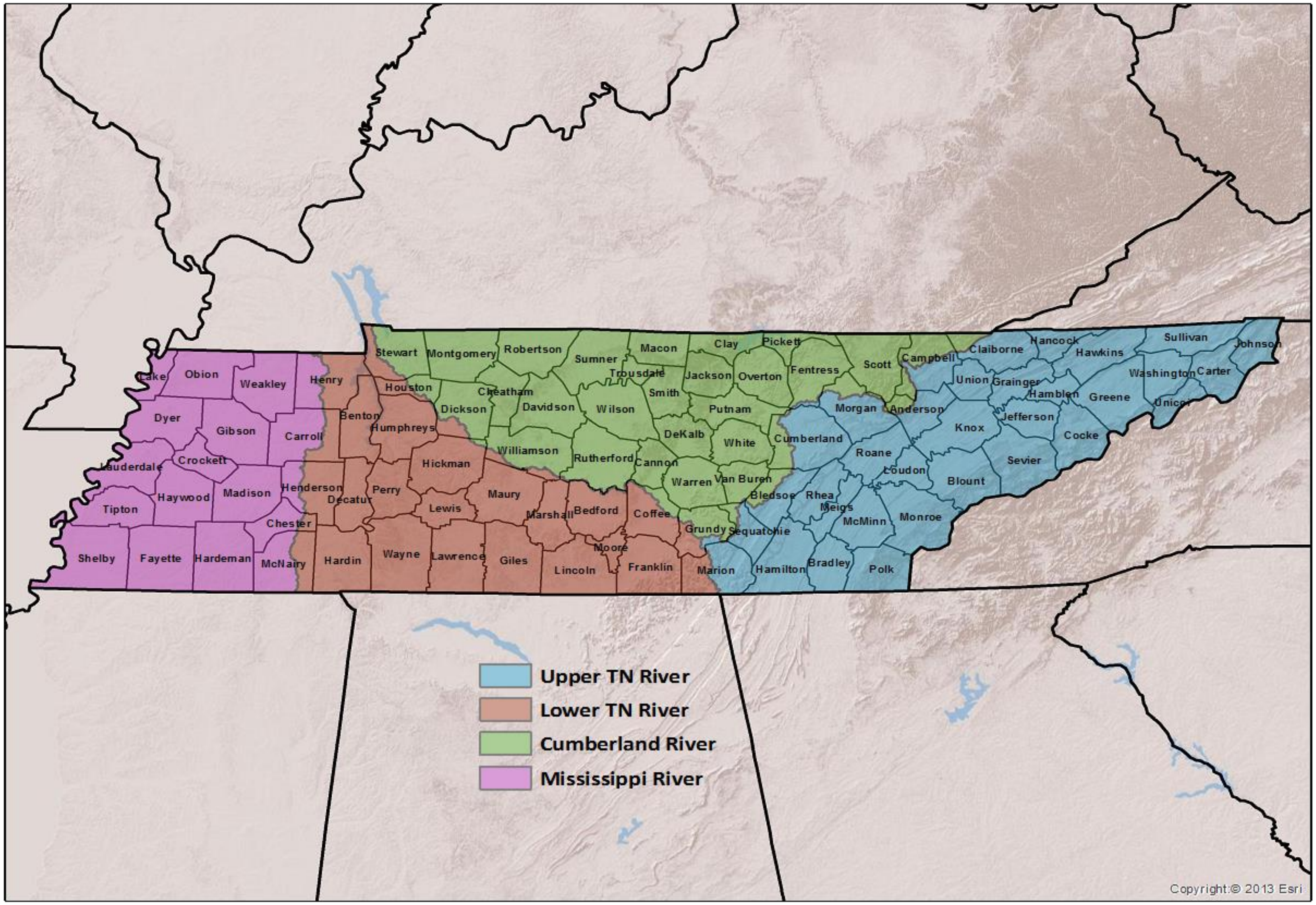

Figure 1. Hydrologic Unit Regions for the State of Tennessee

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 polices, 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):

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

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, λ 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:

$$u_n * X_n \leq W_n \quad [\lambda W_n] \; \forall \; n \tag{5}$$

$$l_n * X_n \leq L_n \quad [\lambda l_n] \; \forall \; n \tag{6}$$

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:

$$\frac{\Delta GRP}{\Delta W} = \lambda\text{w.} \tag{7}$$

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.

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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 (Acre-Feet)				
	State	**Upper TN**	**Lower 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 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
Total	**8,055,795**	**4,036,134**	**958,501**	**714,999**	**2,346,161**

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

Water Withdrawal (Acre-Feet)	Percentage of Baseline Water Withdrawal (%)	Shadow Value (Dollars per Acre Foot * 1,000,000)	Maximized Gross Regional Product (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 Withdrawal (Acre-Feet)	Percentage of Baseline Water Withdrawal (%)	Shadow Value (Dollars per Acre Foot *1,000,000)	Maximized Gross Regional Product (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 Withdrawal (Acre-Feet)	Percentage of Baseline Water Withdrawal (%)	Shadow Value (Dollars per Acre Foot * 1,000,000)	Maximized Gross Regional Product (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 Withdrawal (Acre-Feet)	Percentage of Baseline Water Withdrawal (%)	Shadow Value (Dollars per Acre Foot * 1,000,000)	Maximized Gross Regional Product (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 Withdrawal (Acre-Feet)	Percentage of Baseline Water Withdrawal (%)	Shadow Value (Dollars per Acre Foot * 1,000,000)	Maximized Gross Regional Product (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 Withdrawal (Acre-Feet)	Percentage of Baseline Water Withdrawal (%)	Shadow Value (Dollars per Acre Foot * 1,000,000)	Maximized Gross Regional Product (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.

	Percentage of Baseline Water Supply (%)									
	100	90	80	70	60	50	40	30	20	10
Sector	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.

	Percentage of Baseline Water Supply (%)									
	100	90	80	70	60	50	40	30	20	10
Sector	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
GRP (in millions of $)	**$292,119**	**$262,907**	**$233,695**	**$204,483**	**$175,271**	**$146,060**	**$116,848**	**$87,636**	**$58,424**	**$29,212**

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

	Percentage of Baseline Water Supply (%)									
	100	90	80	70	60	50	40	30	20	10
Sector	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.

	Percentage of Baseline Water Supply (%)									
	100	90	80	70	60	50	40	30	20	10
Sector	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
GRP (in millions of $)	**$108,747**	**$97,873**	**$86,998**	**$76,123**	**$65,248**	**$54,374**	**$43,499**	**$32,624**	**$21,749**	**$10,875**

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

	Percentage of Baseline Water Supply (%)									
	100	90	80	70	60	50	40	30	20	10
Sector	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.

	Percentage of Baseline Water Supply (%)									
	100	90	80	70	60	50	40	30	20	10
Sector	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
GRP (in millions of $)	**$94,081**	**$84,673**	**$75,265**	**$65,857**	**$56,449**	**$47,041**	**$37,633**	**$28,224**	**$18,816**	**$9,408**

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

	Percentage of Baseline Water Supply (%)									
	100	90	80	70	60	50	40	30	20	10
Sector	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	$0	$32,108	$32,10 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.

	Percentage of Baseline Water Supply (%)									
	100	90	80	70	60	50	40	30	20	10
Sector	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
GRP (in millions of $)	**$18,012**	**$16,210**	**$14,409**	**$12,608**	**$10,807**	**$9,006**	**$7,205**	**$5,403**	**$3,602**	**$1,801**

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

	Percentage of Baseline Water Supply (%)									
	100	90	80	70	60	50	40	30	20	10
Sector	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	$41,900	$40,395	$40,395	$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, & 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.

	Percentage of Baseline Water Supply (%)									
	100	90	80	70	60	50	40	30	20	10
Sector	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
GRP (in millions of $)	$71,279	$64,151	$57,023	$49,895	$42,767	$35,639	$28,512	$21,384	$14,256	$7,128

Figures

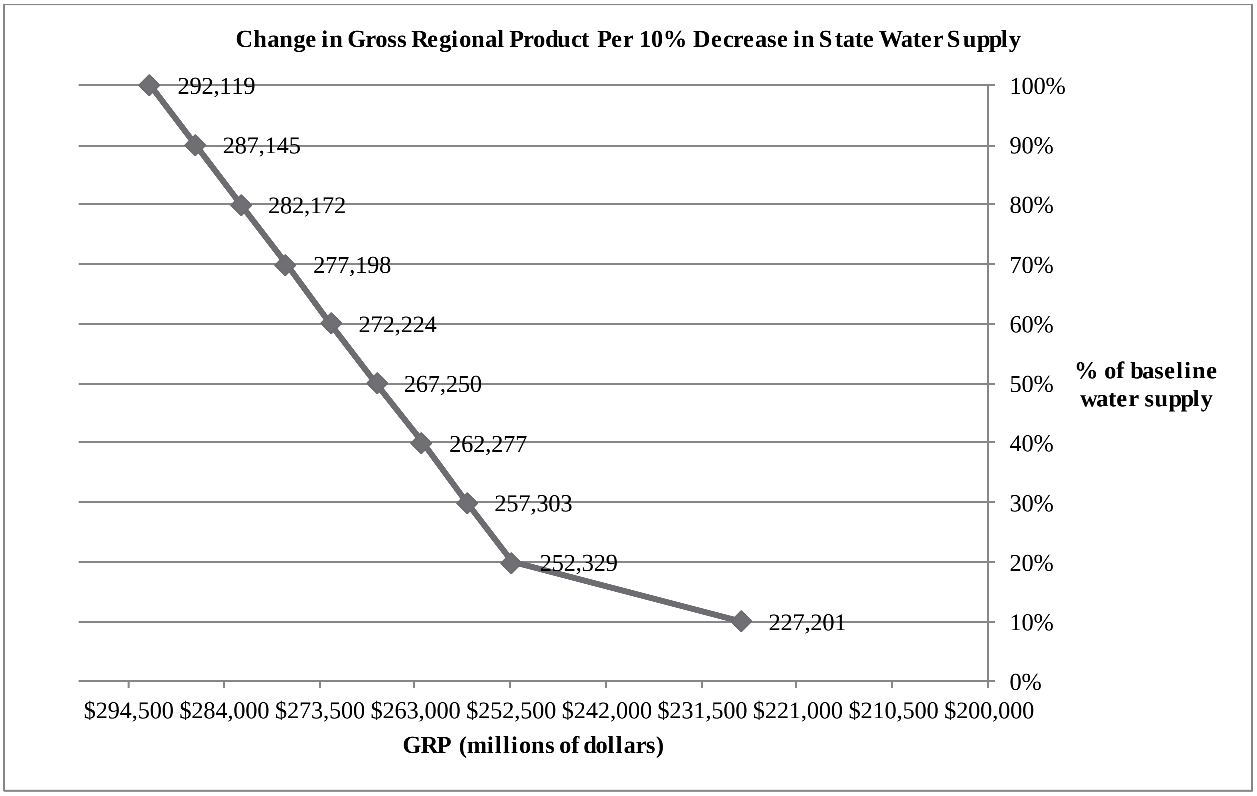

Figure 2. Change in State Gross Regional Product Resulting from a Decrease in State Water Supply at 10% Increments

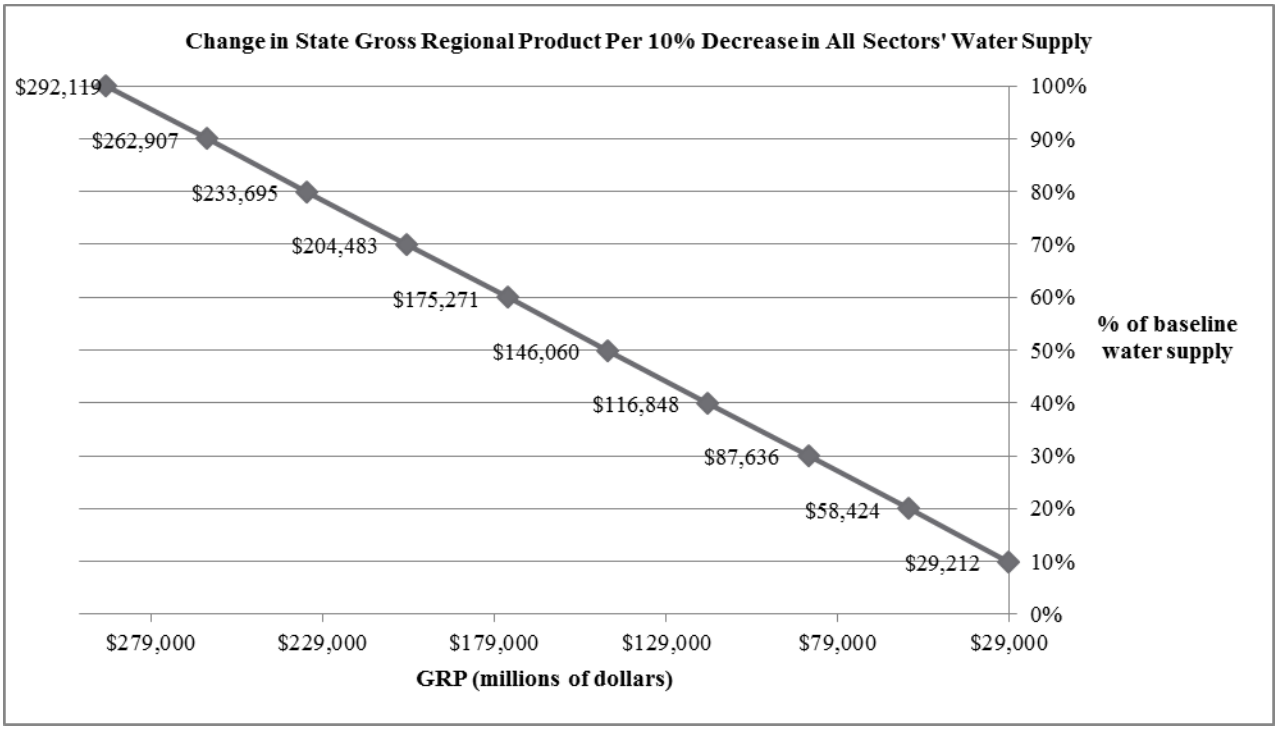

Figure 3. Change in State Gross Regional Product Resulting from a Decrease in All Sectors' Water Supply at 10% Increments

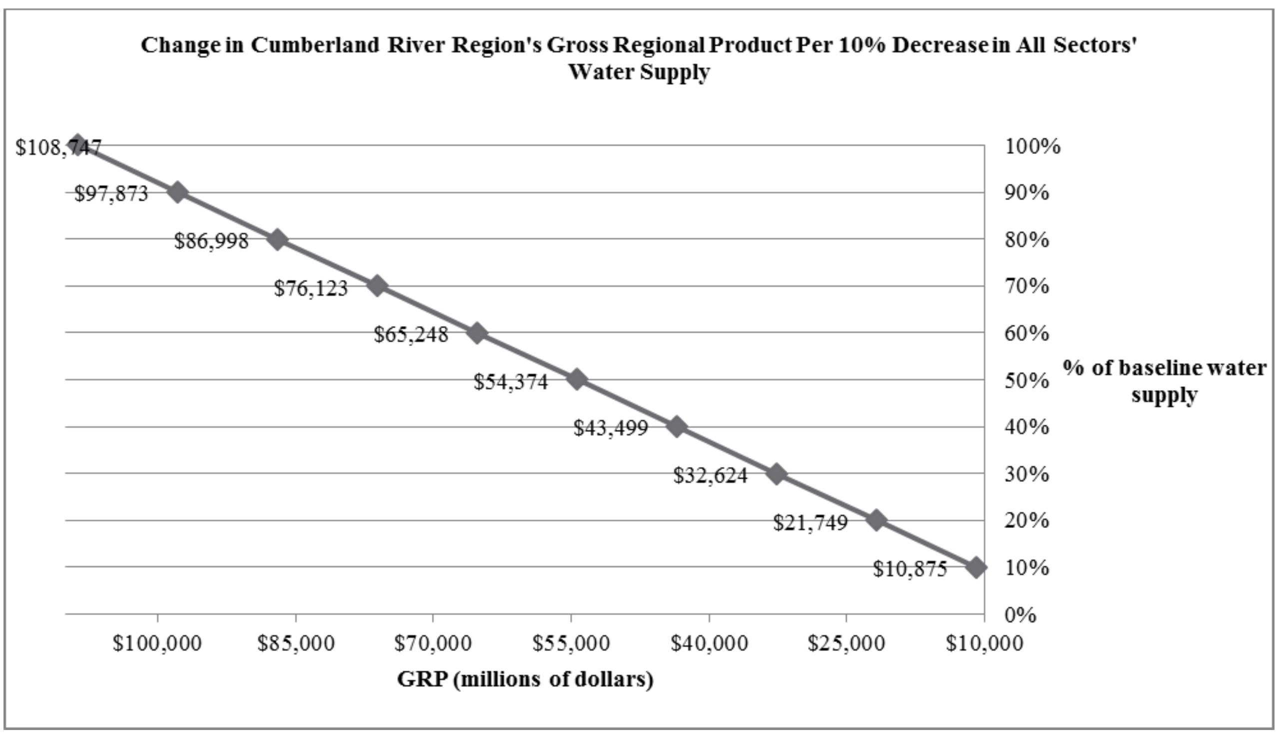

Figure 4. Change in the Cumberland River Region's Gross Regional Product Resulting from a Decrease in All Sectors' Water Supply at 10% Increments

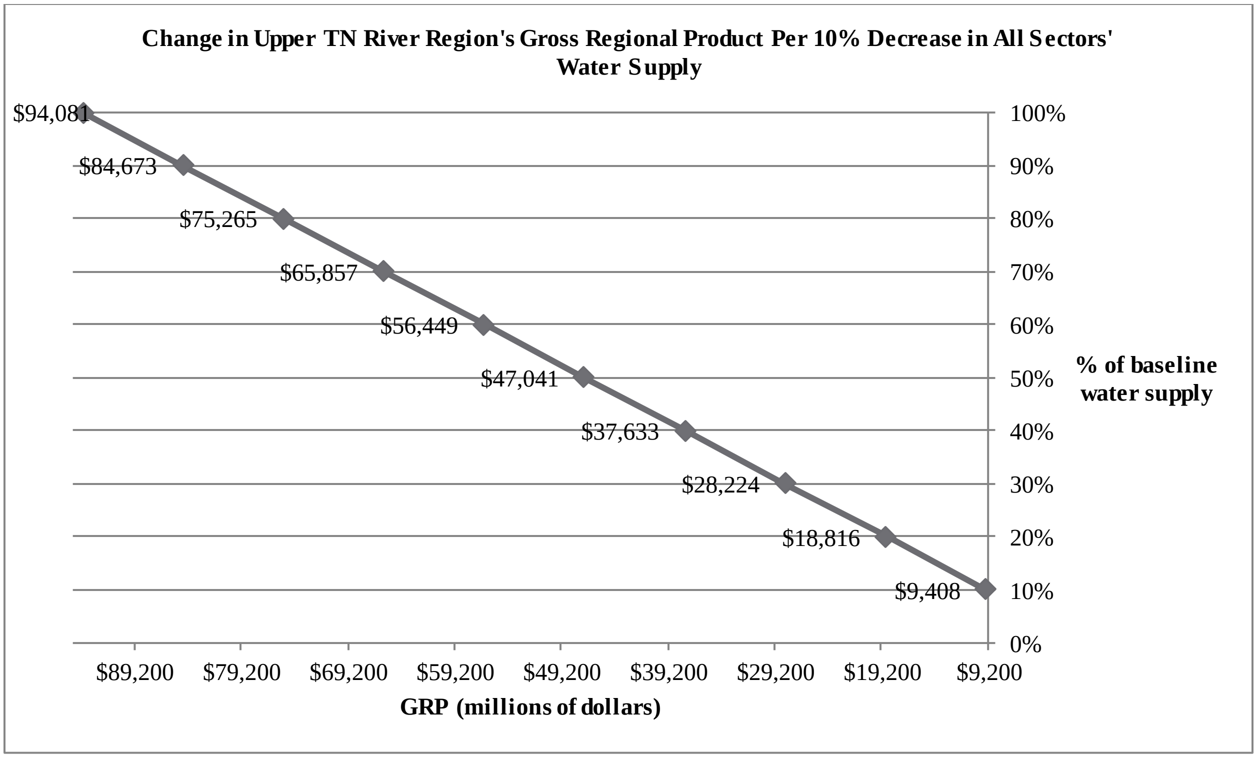

Figure 5. Change in the Upper TN River Region's Gross Regional Product Resulting from a Decrease in All Sectors' Water Supply at 10% Increments

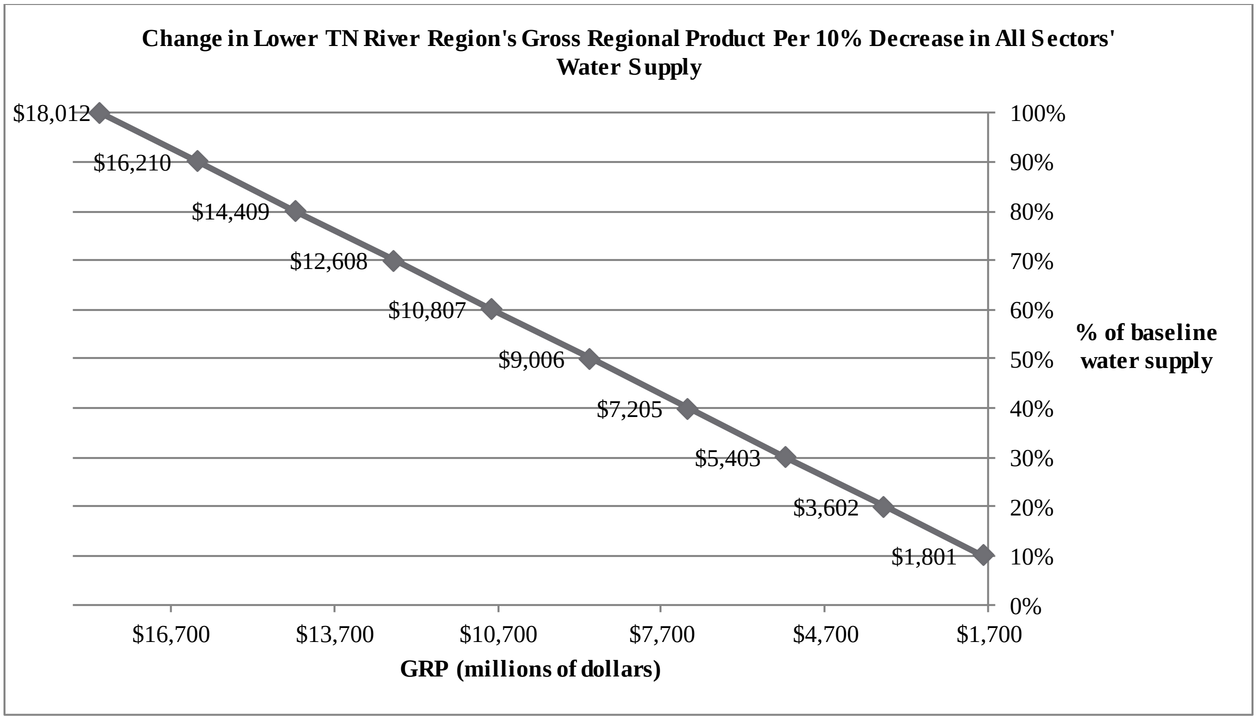

Figure 6. Change in the Lower TN River Region's Gross Regional Product Resulting from a Decrease in All Sectors' Water Supply at 10% Increments

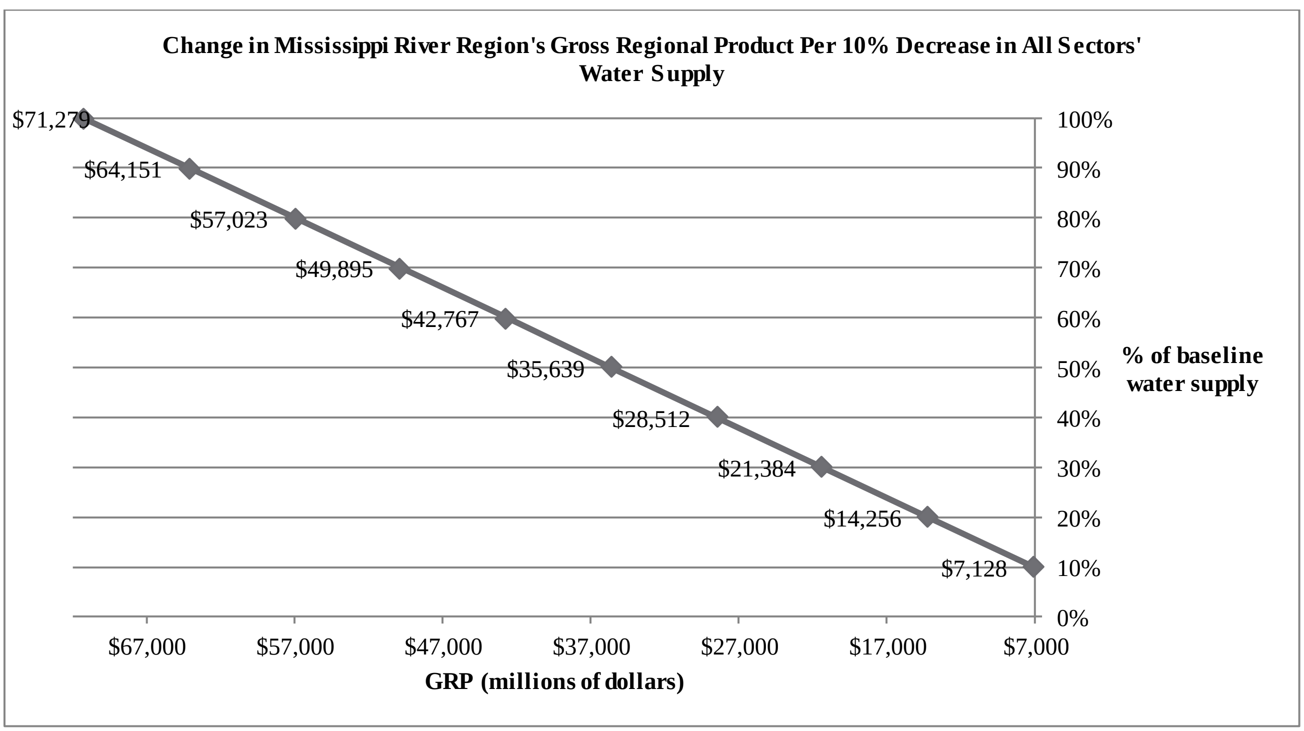

Figure 7. Change in the Mississippi River Region's Gross Regional Product Resulting from a Decrease in All Sectors' Water Supply at 10% Increments

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.