ASSESSING THE SOCIAL AND ECONOMIC IMPACTS OF HYDROLOGIC EXTREMES

by

LIAN ZHU

GLENN TOOTLE, COMMITTEE CHAIR
ANDREW N. S. ERNEST
BENNETT L. BEARDEN
PAULINE JOHNSON
THOMAS G. JOHNSON

A DISSERTATION

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Civil, Construction, and Environmental Engineering
in the Graduate School of
The University of Alabama

TUSCALOOSA, ALABAMA

2017

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ABSTRACT

Disaster impact assessments are crucial for understanding disasters and effective disaster prevention. Deciding how to respond to disasters cannot be efficient without considering the disaster's social and economic impacts. Among all types of disasters, drought and flood induce the largest human and economic cost. Interbasin transfer is a commonly used strategy to overcome the mismatch between water availability and water demand, and enhance economic development. The researches present within this dissertation discuss how can we develop an efficient economic impact model or models which can take into consideration sector vulnerability and resiliency strategies in response to extreme climate events, to assist decision makers in devising response strategies.

The first and second studies in this dissertation investigate methods to assess the economic consequences of drought induced water restriction and the economic consequences of flood impact in public water supply systems. Drought and flood induce water outage, and cause substantial impacts in public water supply systems. However, researches and tools which assess drought and flood impact in water supply systems are uncommon. We adapt previous work on economic consequence assessment in the event of water services disruption to evaluate the economic impact of water restrictions resulting from extended drought conditions, and water contamination and outage resulting from flood conditions. These two models focus on all commercial and industrial economic sectors across multiple basins using a continuous dynamic social accounting matrix approach.The third study in this dissertation investigates the interbasin transfer impact to the basin(s), with a focus on agriculture production, and discusses the necessity to establish a state-level interbasin transfer regulation in Alabama. A framework for comprehensive impact assessment of interbasin transfer is developed in this dissertation. The interbasin transfer research reviews four representative interbasin transfer projects, concludes the triggers of interbasin transfer projects and impacts in economic, hydrologic, ecological, and social systems. The relation between irrigation and agriculture production is simulated with AquaCrop. Three states' interbasin transfer regulations and acts are studied. Results indicate the required processes to establish a state-level interbasin transfer regulation and the focuses of future researches.

DEDICATION

I dedicate this research to everyone who helped me and guided to the degree of Doctor of Philosophy.

LIST OF ABBREVIATIONS AND SYMBOLS

m	Number of alternative actions modeled
j	Day of the disruption event (from 1 to n), up to 365
k	IMPLAN sector type
i	Type of business (1=Accommodation and Services, 2= Extractive, utilities, construction, manufacturing, 3=Trade and Transportation, 4=Services, 5=Education and Day Care, 6=Health Care and Social Assistance, 7=Government)
ΔB_{mjk}	Change of expenditures for sector k at day j
β_i	Average expenditures per employee-hour by type of business i, obtained from the businesses survey
α_{ij}	Probability of implementing businesses actions day j by business type i
γ_{ij}	Indicator equal to 1 if the action is implemented on day j, obtained from survey
θ_k	Number of employees per business type k, obtained from the IMPLAN database
δ_k	Number of businesses of type k, obtained from the IMPLAN database
ΔH_j	Change in expenditures for action m on day j
ρ_m	Expenditures per person-day for action m, derived from the household surveys
τ	Population in the modeled area, obtained from IMPLAN database
φ	Percentage of population served by the water utility, obtained from USGS (2010)
π_j	Percentage of residential customers affected by the disruption on day j
τ and π_j	Data provided by the user
AWAWG	Alabama Water Agencies Working Group

CAP	Central Arizona Project
CGE	Computable General Equilibrium
CPIC	Consumer Price Index
DWR	Department of Water Resource, California
ECAT	Economic Consequence Assessment Tool
EPA	United States Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
FEMA-Hazus	Federal Emergency Management Agency United States Hazard – Multi Hazard
GDP	Gross Domestic Product
HEC-FDA	Hydrologic Engineering Center Flood Damage Analysis
HEC-FIA	Hydrologic Engineering Center Flood Impact Analysis
IBT	Interbasin transfer
IBWA	International Bottled Water Association
IMPLAN	IMpact analysis for PLANning
I-O model	input-output model
MGD	Million gallon per day
NAICS	North American Industry Classification System
NCDC	National Climatic Data Center
PyWREM	Python based Water Restriction Economic Model
PyFECA	Python based Flood Economic Consequence Assessment Tool
SAM	Social Accounting Matrix
USGS	United States Geological Survey

ACKNOWLEDGMENTS

Firstly, I would like to express my sincere gratitude to my advisor, Andrew Ernest, for his continual support and guidance of me over the better part of four years. I am proud to call him my mentor, and friend. Besides my advisor, I would like to thank the rest of my thesis committee: Glenn Tootle, Bennett L. Bearden, Pauline Johnson, and Thomas G. Johnson, for their insightful comments and encouragement. I am also indebted to parents, Xiaoping Zhu and Shuqin Jin, who raised me to work hard in whatever I pursue and provide much need encouragement. I would like to thank my friends Jodi Lees and Betty Zhang for their words of encouragement over the years. I would also like to thank Joseph L. Gutenson and Leah Gutenson, who helped me edit the content presented here and all my publications. I would also like to acknowledge all my colleagues that I have had the privilege to work with throughout my career: Abdoul A. Oubeidillah, Xiaoyin Zhang, Sahar T. Sadeghi, Cheryl Y. Clifton, and Phillip Grammer. Further, I thank the National Flood Interoperability Experiment project, which gives me a change to work on the flood forecasting with students, professors and scientists from all over the world.

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CHAPTER 1 INTRODUCTION AND HYPOTHESIS

In this chapter, the researcher introduces the needs for research in this area. Following a summary of the background information, this chapter presents the research design and a list of research questions to be answered by the dissertation. This chapter also presents the structure of the dissertation manuscript.

Background and Motivation

Disaster impact assessments are crucial for understanding disasters and effective disaster prevention. Deciding how to respond to disasters cannot be efficient without considering the disaster's social and economic impacts. Social and economic disaster impact assessments help manage the limited resources efficiently and reduce the impact of such events (Laugé, 2013).

Among all types of disasters, drought and flood induce the largest human and economic cost (Dilley, et al., 1995). Interbasin transfer is a commonly used strategy to overcome the mismatch between water availability and water demand. It can transfer water from flood-plagued regions to drought regions, reduce the impacts of floods and droughts (Gupta and Zaag, 2008; Cummings, 1974). Drought can be an economically disastrous natural hazard, where exacerbated impacts lack the abrupt onset and offset that define tornados and hurricanes. Driven by a variety of factors including climate change, population growth, increased water demands, and alterations to land cover, drought occurs widely all over the world.

The literature on current drought economic impact modeling methods indicates that most of these models deal with the impact in the agricultural sector with a focus on a single basin, and almost all of the drought models in United States are state level. However, drought impacts are rarely restricted to basin boundaries, and cascading economic impacts are likely to be significant. A holistic approach to county-level, multi-sector drought economic impact assessment is needed.

Flooding is one of the most economically disastrous natural hazards and occur frequently throughout both the United States and the world at large. Floods occur with little or no advanced warning, and cause immense devastation to both the built environment and the economy of an impacted region.

The literature on flood damage assessment tools indicates that the Federal Emergency Management Agency United States Hazard – Multi Hazard (FEMA-Hazus), Hydrologic Engineering Center's Flood Damage Reduction Analysis (HEC-FDA), and Flood Impact Assessment (HEC-FIA) are the most commonly used flood impact assessment models in the United States. All of these tools focus on assessing the floods direct damage, with FEMA-Hazus providing the only rudimentary indirect economic impact assessment (HAZUS-MH & F. E. M. A., 2003).

Interbasin transfer (IBT) is a strategy which allocates water resources to locations where people need it to meet growing water demands and reduce the impacts of drought. Driven by the increasing pressure on water supply, interbasin transfer is becoming a hot topic and has been receiving increasing attention and controversy. Interbasin transfer projects are large-scale, costly, and unchangeable in a short time. A necessary and proper assessment of water transfer will allow decision makers and local, state, and federal governments to gain insight into the water transfer project and make more reasonable decisions. Currently, there is a lack of comprehensive interbasin transfer impacts assessment methods.

Dissertation Research Questions

In the research presented within this dissertation, we adapt previous work on economic consequence assessment in the event of water services disruption to evaluate the economic impact of water restrictions resulting from extended drought conditions, and water contamination and outage resulting from flood conditions. These two models focus on all commercial and industrial economic sectors across multiple basins using a continuous dynamic social accounting matrix approach, coupled with calculation of the indirect consequences for the local and regional economies and the various resilience and other strategies implemented. A framework for comprehensive impact assessment of interbasin transfer is developed in this dissertation. The interbasin research considers the impacts in economic, hydrologic, ecological, and social systems. Also, the necessity of a state-level IBT regulation is discussed.

- How can we assess the economic consequences of drought induced water restriction?
- How can we assess the economic consequences of flood impacts in public water supply systems?
- How can we assess the interbasin transfer impacts to the basin(s), with a focus on agriculture production?

In summary, how can we to develop an efficient economic impact model or models which can take into consideration sector vulnerability and resiliency strategies in response to extreme climate events, to assist decision makers in devising response strategies?

Outline of Dissertation

This dissertation consists of three articles, each building toward the support of a singular goal, a method of assessing the economic benefit of water resources and providing analytical supports to water resources management. These articles compose Chapters 2, 3, and 4, respectively.

Chapter 2 introduces the method to develop a model to assess economic impact of drought induced water restriction based on previous work on economic consequence assessment on water disruption events. The model is applied in nine counties in Alabama to simulate the economic impact of county-level water restriction.

Chapter 3 introduces how to assess flood impact in public water supply system and the economic impact of flood induced water service closure. This research indicates the economic loss caused by flood in public water supply system is considerable. The research applies the methodology in Tuscaloosa County, Alabama, and Montgomery County, Alabama.

Chapter 4 analyzes IBT impact, discusses the cost-benefit of IBT with a focus on agriculture production. The study highlights a state-level IBT regulation is necessary to guide the existing and future IBT projects in Alabama. Three crops in eight northern Alabama counties, Colbert, Jackson, Lauderdale, Lawrence, Limestone, Madison, Marshall, and Morgan Counties, are studied to estimate the agricultural production increase from irrigation.

Chapter 5 highlights the results of these researches, summarizes the results, and provides recommendation for future work.

CHAPTER 2 DEVELOPING AN ECONOMIC ASSESSMENT TOOL FOR DROUGHT INDUCED WATER RESTRICTION BASED ON THE ECONOMIC CONSEQUENCE ASSESSMENT TOOL - ECAT

Introduction

Drought can be an economically disastrous natural hazard, one whose impacts are exacerbated by the lack of abrupt onset and offset that define other disasters such as tornados and hurricanes. Driven by a variety of factors including climate change, population growth, increased water demands, and alterations to land cover, the severity and frequency of drought is increasing all over the world.

Decision support systems for drought management and response are needed to allow decision makers and stakeholders to anticipate and respond effectively. In this study, the researchers review current drought economic impact modeling methods. Most of these models deal with the impact of drought on the agricultural sector with a focus on a single basin, and almost all of the drought models in United States are at the state level. However, drought impacts are rarely restricted to basin boundaries, and cascading economic impacts are likely to be significant. A holistic approach to county-level, multi-sector drought economic impact assessment is needed.

In this work, we adapt previous work on economic consequence assessment in the event of water service disruptions to evaluate the economic impact of water restrictions resulting from extended drought conditions. This model focuses on all economic sectors across multiple basins using a continuous dynamic social accounting matrix approach, coupled with calculation of the indirect consequences for the local and regional economies and the various resilience and other strategies implemented. The research is part of an overarching effort to develop an efficient economic impact model which can take into consideration sector vulnerability and resiliency strategies in response to extreme climate events, to assist decision makers in devising response strategies. This model was applied to the entire State of Alabama to test its feasibility. The results of this research indicate that while the economic losses in high-GDP counties were correspondingly higher, the percentage of loss was less. Excluding the impact in agriculture sector, most of the economic losses were in the manufacturing sector. The sensitivity analysis indicates that the most significant losses were due to extra household expenses.

Literature Review

Drought can be defined as a deficiency in precipitation over an extended period, usually a season or more, resulting in water shortages which affect human activities, and fail to meet ecologic and environmental requirements (National Weather Service, 2008; Wilhite, 2005). Climate change, together with population growth, urban expansion, increasing water demands and requirements for environmental protection can increase the frequency and intensity of drought, and lead to increasingly serious impacts (Young, 1995; Dai, 2013; IPCC, 2007). Given these trends, drought impact models which inform water allocation policies and drought response plans will become particularly needed (Booker, 2005).

The human and economic costs of drought are among the highest of all types of natural disasters (Dilley, et al., 1995). The National Mitigation Strategy (Witt, 1997) points out that drought directly causes 6 to 8 billion dollars in annual damages in the Unites States. Drought produces a complex web of impacts and has ripple effects in many sectors of the economy

(Wilhite et al. 2007). There have been 13 droughts over the past 15 years (2000-2015) that exceeded a billion dollars in losses each (billion-dollar droughts), totaling more than 109 billion dollars in losses, excluding the cost of the 2015 western drought for which estimates of costs are not yet available (National Climatic Data Center (NCDC), 2016). The effects of droughts begin in natural systems and extend into society. Besides impacts on agriculture, drought impacts public water supply systems, recreation, public utilities and services, and water-consuming industries and businesses (Ding, et al. 2011; DOW, 2010). Among these non-agriculture impacts, the impacts on public water supply systems are the most obvious and relevant to residents' life and as a result have the most significant socioeconomic impact.

Drought can impact public water supply systems by reducing the water availability, causing water scarcity, as well as deteriorating water quality (Ding, et al., 2011). Water restrictions are a strategy governors and water resources managers commonly choose under serious drought conditions. Consider the following examples. In 2015, a drought caused a serious water shortage in San Juan., Puerto Rico. In response, decision makers issued water restrictions. More than 160,000 residences and businesses on the island lost water service for anywhere from several hours to several days. Most people in Puerto Rico reported a five day period without water service (Janssen, 2015; Lee, 2015; Bury, 2015; Suarez, 2015). During June 2015, Mountain House, California, faced a serious water shortage. News reports suggested that if no action was taken, the county would have no water for the 15,000 residents to drink (Hernandez-Zarate, 2015; Kasler, 2015; Medina, 2015). In Sao Paulo, Brazil, an extended extreme drought caused the Cantareira reservoirs to cut operational capacity to 12% in October, 2015. Many residents of Sao Paulo suffered 12-hour water cutoffs daily for over one year (Gerberg, 2015; Zerkel 2014). In southwestern China, the severe 2009-2010 drought placed approximately 21 million people under water restriction, and cost nearly $30 billion in economic losses (Yang, et al., 2012). Drought can cause both long- and short-term, direct and indirect economic consequences.

A number of tools exist which estimate the impact that potential droughts may have on economic systems. For instance, Wu and Wilhite (2003) study agricultural drought risk in Nebraska. They incorporate multivariate techniques in this research, and study the potential agricultural risks on dryland crops, specifically focusing on corn and soybeans. Kirby et al. (2012) research how irrigation changed during drought in the Murray-Darling Basin. Kirby et al. review the published research literature for evidence of the impacts of drought induced by water shortage in agriculture production and food industries. Gil Sevilla et al. (2013) research the direct and indirect economic impact of drought in the Ebro River basin in Spain. Booker (2005) develop an integrated hydrologic, economic and institutional model to evaluate the economic impact of institutional adjustments during a drought period in the Rio Grande Basins, and note that 33% of drought damages per year are reducible through interstate water markets. Howitt et al. (2014) study the economic analysis for California drought in 2014 and 2015. They use C2VISim (the California Department of Water Resources groundwater model for California's Central Valley) and SWAP (an economic model of agricultural production and water use in California) to assess drought economic impact in agriculture and incorporate the IMPLAN model to estimate the state-level multiplier effects and job losses.

The research literature focuses primarily on drought impacts in the agricultural sectors or sub-sectors in a single basin or at a low resolution state level. Agriculture activities are highly sensitive to weather variability and the data for other economic sectors are not easy to obtain in comparison to necessary agricultural data (Ding et al., 2011, Ya et al., 2011).

Little research has a focus on the indirect impact of drought. However, in those cases where the research considers indirect impacts, they often exceed the magnitude of direct impacts (Wilhite et al., 2007). Thus, we identify a need for a more detailed socioeconomic drought analysis model which identifies who and what is at risk during droughts and which investments might decrease the resulting economic loss (Dow 2009; Wilhite and Pulwarty, 2005; IPCC 2007; Karl et al. 2009). A socioeconomic drought analysis model can improve the management of water, inform water allocation decisions in times of drought, and design adequate drought mitigation and prevention measures that help minimize the impact of drought on regional economies (Gil Sevilla, 2013).

This research is part of an overarching effort to develop an efficient economic impact model which can take into consideration sector vulnerability and resiliency strategies in response to extreme climate events, and to assist decision makers in devising response strategies. In this paper we discuss the development of a Python based Water Restriction Economic Model (PyWREM) based on the Economic Consequence Assessment Tool (ECAT), developed at the University of Missouri-Columbia (Alva-Lizarragga, 2012a; Alva-Lizarraga and Johnson, 2012b). PyWREM is a multi-sector, county-level socioeconomic assessment tool that models the economic consequences of extended water restrictions, such as those resulting from droughts. ECAT is a dynamic demand driven social accounting matrix based model with supply constraints that incorporates resilience strategies of both consumers and producers. This model has the advantage of managing the discrepancy between the time intervals involved in water disruption events and the typical observation interval of the data used for modeling purposes. The tool is capable of analyzing other drought related issues such as, the socioeconomic impact of drought-driven food shortages, and limited recreational access to water. Thus, PyWREM can determine the comprehensive socioeconomic impacts of drought.

In PyWREM, all industry sectors in the IMPLAN database are consolidated into 13 categories based on the North American Industry Classification System (NAICS). The details of the consolidation are shown in Table 1. In addition, we divide households into two sectors: employees and household expenditures.

Table 1. Detail descriptions of the 13 businesses categories in PyWREM.

PyWREM Description	NAICS Sector	NAICS Description
Agriculture	11	Agriculture, Forestry, Fishing and Hunting
Mining	21	Mining, Quarrying, and Oil and Gas Extraction
Utilities	22	Utilities
Construction	23	Construction
Manufacturing	31-33	Manufacturing
Wholesale	42	Wholesale Trade
Retail	44-45	Retail Trade
Transportation and Warehousing	48-49	Transportation and Warehousing
Education	61	Educational Services
Health	62	Health Care and Social Assistance
Service	72	Accommodation and Food Services
Others	51-56, 71, 81	Information; Finance and Insurance; Real Estate and Rental and Leasing; Professional, Scientific, and Technical Services; Management of Companies and Enterprises; Administrative and Support and Waste Management and Remediation Services; Arts, Entertainment, and Recreation; Other Services (except Public Administration)
Government	92	Public Administration

Methods and Materials

Survey

In the original ECAT model (Alva-Lizarraga, et al., 2011; Alva-Lizarraga and Johnson, 2012a; Alva-Lizarraga and Johnson, 2012b), a residential survey of recent water disruption events provides information on direct impacts, and resiliency strategies taken by residential consumers (Jensen et al., 2011a; Jensen et al., 2011b). This survey information reflects not only economic losses but also resiliency responses and changes in preparedness for future events.

Additionally, ECAT incorporates data from a survey of 288 business affected by water disruptions. The business survey provides information on the businesses income distribution, the percentage of businesses prepared before the water disruption, and average financial and temporal costs of various responses to drought. Logit regressions were estimated to obtain the probability that businesses of particular types would implement a particular action. These estimated regression results are included in the basic ECAT model. The user inputs the percentage of population affected by the disruption in the industrial sector and other baseline data. ECAT then predicts the probabilities of implementing a particular action by businesses and residents in the study area (α_{ij}). These probabilities vary by type of event, business type and the proportion of the businesses within the sector.

Ultimately, ECAT multiplies the probability of implementing each resiliency action by the average revenue loss or the expenditures incurred as a result of these activities and the time these activities were implemented in order to obtain the direct economic consequences for businesses.

The equations used to estimate the direct economic consequences for each business sector took the form:

$$\Delta B_{mjk} = \alpha_{ij} * \beta_i * \gamma_{ij} * \theta_k * \delta_k * \frac{1}{365} \qquad \text{for i=1…7, j=1…..n, k=1…536, m=1…13}$$

Where:

m is the number of alternative actions modeled.

j is the day of the disruption event (from 1 to n), up to 365.

k is the IMPLAN sector type.

i represents the type of business (1=Accommodation and Services, 2= Extractive, utilities, construction, manufacturing, 3=Trade and Transportation, 4=Services, 5=Education and Day Care, 6=Health Care and Social Assistance, 7=Government).

ΔB_{mjk} is the change of expenditures for sector k at day j

β_i is the average expenditures per employee-hour by type of business i, obtained from the businesses survey.

α_{ij} is the probability of implementing businesses actions day j by business type i, calculated from the probability estimated using the logit regressions.

γ_{ij} is an indicator equal to 1 if the action is implemented on day j, obtained from survey.

θ_k is the number of employees per business type k, obtained from the IMPLAN database.

δ_k is the number of businesses of type k, obtained from the IMPLAN database.

Average expenditure estimates are based on data collected from the residential surveys. These actions vary according to the average household size, the population of the region and the day of the disruption. Previous studies (Harrington et al., 2016) and official statistics (U.S. Geological Survey (USGS), 2010) were used in some cases to supplement the estimates. The daily expenditures incurred by households follow the following formula:

$$\Delta H_{mj} = \rho_m * \tau * \varphi * \pi_j \qquad \text{for j= 1…..n and m=1…}$$

j is the day of the disruption event (from 1 to n), up to 365.

m are the alternative actions modeled.

ΔH_j is the change in expenditures for action m on day j.

ρ_m is the expenditures per person-day for action m, derived from the household surveys.

τ is the total population in the modeled area, obtained from IMPLAN database.

φ is the percentage of population served by the water utility, obtained from USGS (2010).

π_j is the percentage of residential customers affected by the disruption on day j.

τ and π_j are data provided by the user.

The proportion of the population which boils water in response to potential bacterial contamination is from the survey and adjusted by the percentage of residential customers affected by the disruption on day j. Using water needs by person from the (USGS, 2010) and the formula in (Harrington et al., 2016) to estimate boiling costs, we obtain the energy and time spent per day boiling water.

Economic Principles

The social accounting matrix was built using an input-output model (I-O model) to reflect the interindustry relationships. The I-O modeling approach was first developed by Wassily W. Leontief. He describes it as "a method of analysis that takes advantage of the relatively stable pattern of the flow of goods and services among the elements of our economy to bring a much more detailed statistical picture of the system into the range of manipulation by economic theory" (Leontief, 1986). The regional I-O multipliers are calculated based on a detailed set of industry accounts that measure the production in each industry and the intermediate demand by other industries and the final user demand. In I-O models each industry's production impact in the economy is described by a system of linear equations. With the assumption that prices of products remain the same, and incorporated with inter-industry relationships information, I-O models can estimate the economy-wide effects that an initial change in economic activity has on the aggregate economy of a region. (Leontief, 1963; Bess, et al., 2011; Miller, 2009; Haimes, 2005).

I-O models are often employed to evaluate direct and indirect impacts of drought. Gunter et al. combined an I-O model and an Equilibrium Displacement Mathematical Programming

Model to analyze the Southeast Colorado drought (Gunter, 2012). Kulshreshtha and Klein use an I-O model to determine drought impacts on agricultural (Kulshreshtha, 1989). Gil Sevilla et al. (2013) use an I-O model to measure the direct and indirect economic impact of drought in agriculture.

Compared to the Computable General Equilibrium (CGE) model, I-O models are easier to implement, maintain, and merge with existing spatial and engineering models (Okuyama, 2007). Gutenson merged an I-O model with EPANET and QGIS for assessing economic consequences (Gutenson, et al., 2014).

In this study, the Social Accounting Matrix (SAM) is built around an I-O model to gain insight into the social and economic structure of impacts. A SAM is an extension of an I-O model. It is a summary table recording the inter-relationships between sectors, which includes production processes, income distribution and redistribution, in the whole regional economic system (Pyatt, et al., 1985; Keuning and Ruuter, 1988; Bellú, 2012).

The I-O model took the form:

$$x_i = \sum_{j=1}^{j=n} a_{ij} * x_{ij} + y_i$$

where a_{ij} is the technical coefficient. IMPLAN supplies the original technical coefficients. During water restriction periods, the original technical coefficients are replaced by modified technical coefficients, which are derived from survey based indexes and user inputs.

Data

IMPLAN is a widely-used data resource for undertaking input-output analysis at the U.S. sub-regional level. It was first developed by the US Forest Service and subsequently managed by the Minnesota IMPLAN Group (Ding, Ya, et al., 2011).1 I-O tables are highly specific to the economy of a particular geographical area. IMPLAN contains I-O Model tables, and is highly specific for the economy of a particular geographical area. IMPLAN is popular among government and industry economists who investigate the economic impacts of natural disaster and governmental policy changes (McKean and Spencer, 2003). IMPLAN allows the user to modify the base data to suit their needs.

In this study, we use the original Social Accounting Matrix from IMPLAN Version 3. In addition to the I-O tables, IMPLAN provides tables detailing the margins used in order to convert expenditures at purchaser prices to expenditures at producer prices, and each sector's production levels, employment levels, payments to employees and returns to capital.

The USGS (2014) provides statistics describing the estimated use of water in the United States on a per-county basis. Based on the water demand data, population served by each utility data from USGS and population data from IMPLAN, we determine the average daily domestic consumption of water per capita. FCWA (US Census, 2011) provides water price data, average wage rate comes from 2010 U.S. national averages (US Census Bureau, 2010). The International Bottled Water Association (IBWA) provides the estimate of average bottled water price. EPA (2008) provides detailed information about common household uses of drinking water. The cost of electricity per kWh is from Alabama Power (2008), Alabama's power supply company. The Consumer Price Index (CPI) adjusts all economic data to reflect price levels in the modeled year, 2013 (BLS, 2016).

[1] IMPLAN is currently offered by IMPLAN Group LLC, Huntersville, NC 28078.

Adaptation

The household survey based indexes in the original ECAT can be summarized as: water storage and bottled water consumption, illness expenditures, daycare and babysitting and other household expenditures (cooking, food, overnight stay, etc.). Indexes were adapted when developing PyWREM from ECAT. The adaptations come from a literature review, experiences, and assumptions.

To prepare the model for simulation of drought conditions, several changes were made to the basis data in the ECAT model. Droughts are slow-onset natural disasters (Laczko, 2009; Svoboda, 2002). This temporal characteristic of droughts makes the afflicted area dry for an extended period before a water restriction event. In this case, residents in the drought afflicted area would have more time to prepare for drought-induced water restrictions than in the case of a water disruption event. To reflect this situation, the water storage index in PyWREM was increased by 20% from the levels assumed in ECAT. During droughts, water and air are more susceptible to contamination, which will increase the illness rate. And there is higher prevalence of heat stroke and dehydration (Konkel, 2009). According to Sauerborn (1996), the illness cost in the dry season was 2.3 times the cost in the rainy season. Thus, the index for illness expenditure in original ECAT was multiplied by 2.3 to get the new index for PyWREM. The literature on daycare expenditures during drought indicates that the care expenditure in the dry season was 6 times the expenditures during normal weather patterns (Sauerborn, 1996). Since childcare expenses are likely to rise relative to water outages, child care expenses in the original ECAT was multiplied by 3 to get the index in PyWREM. Though drought always leads to some price increases for agriculture products, research shows that customers pay 1-2% more on food due to drought (USDA, 2015) so PyWREM uses the same index of other household expenditures used in the original ECAT. The original ECAT was developed in 2011, and all the dollar value in the model were in 2010 dollars. All dollar values were therefore inflated using the Consumer Price Index (CPI).

In PyWREM, the CPI and survey based indexes, together with other user input information, are read from a csv file. Users can modify the indexes in the csv file easily based upon the study area and/or specific model requirement.

Study area

In this research, the study area covers the whole state of Alabama. However, the methodology and model presented here can be applied to other states and regions that are affected by drought. Alabama is very vulnerable to drought. During 2007, 37 counties in Alabama were under drought warnings, and the drought lasted more than one year. And in 2012, more than 90 percent of the state suffered abnormally dry conditions (Seager, et al., 2009; NOAA, 2008; Freedman, 2012). According to the Water Supply Sustainability Index (2050) With Climate Change report, (NRDC, 2010) 12 counties (18%) in Alabama will face high risks of water shortages by mid-century, and 36 counties (54%) in Alabama will face moderate risks of water shortages by mid-century as the result of global warming.

According to the Alabama Drought Declaration (2016), the state is divided into nine regions. This research presents and discusses detailed economic consequences of one representative county from each region. These counties are Colbert County, Bibb County, Clarke County, Mobile County, Conecuh County, Coffee County, Montgomery County, Chilton County, and Shelby County.

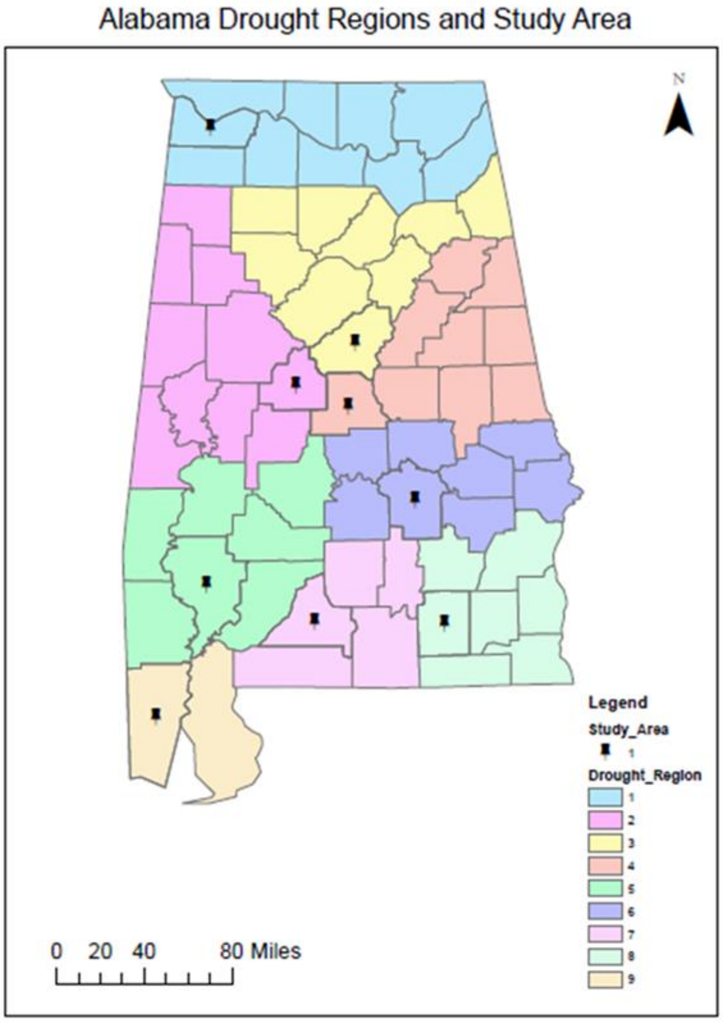

Figure 1. Study area of PyWREM, 9 counties in Alabama.

Results and Discussion

County-Level Economic Impacts

The researchers simulate a three-week drought induced water restriction in nine counties in Alabama. From Figures 4, 5, and 6, we conclude that counties with higher GDP always experience larger economic losses, but the economic loss as a percentage of total GDP is smaller. Among the nine counties studied, Clarke County and Chilton County experience similar losses of GDP in the modeled year, 2013, ($846 million and $843 million respectively). But the economic loss as a percentage of GDP in these two counties is quite different, 0.032% in Clarke County compared to 0.059% in Chilton County. The major difference between Clarke County and Chilton County, was the percentage of population served by a water utility, which was 73% and 79%, respectively. The populations of Clarke and Chilton counties were also quite different, 25,207 and 43,951, respectively. In addition, Chilton County had a higher percentage of its employment in manufacturing sectors and a lower percentage in government, recreation and service sectors. From Figure 7, we see that the manufacturing sector has the highest economic loss among the 15 sectors, which is another reason that the percentage of economic loss in Chilton is higher.

It is clear that most of the economic impact occurred in the manufacturing sector, the transportation and warehousing sector, primarily because of closures during the period of water shortages, and to households due to unexpected expenses and additional time requirements. In each county under investigation, the mining sector had some positive impact primarily because of additional demand for aggregates during construction of water related facilities.

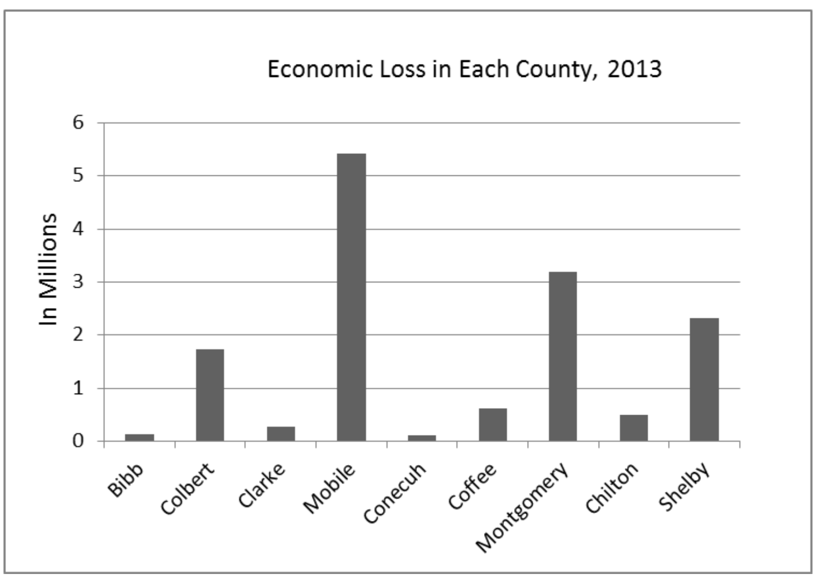

Figure 2. Economic loss in nine studied counties, all numbers are in million dollar, 2013 value.

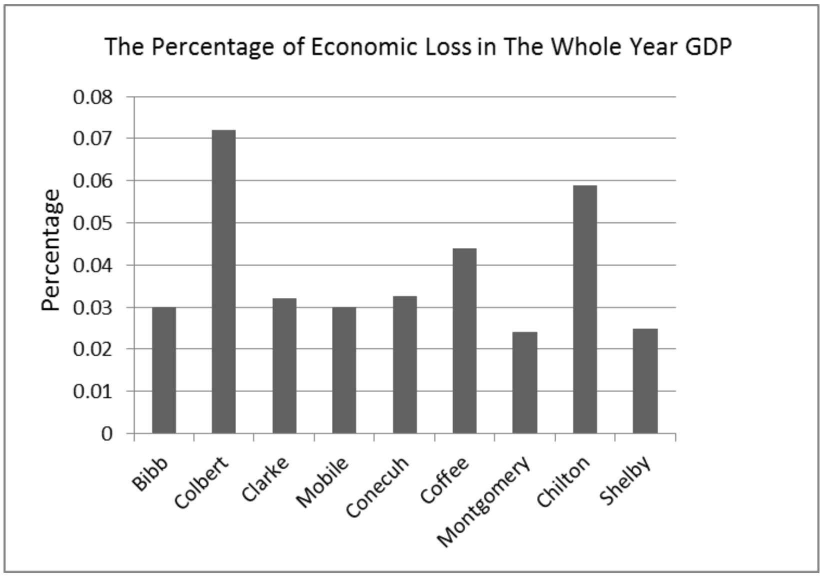

Figure 3. The percentage of three-week water restriction economic loss in the whole year's GDP

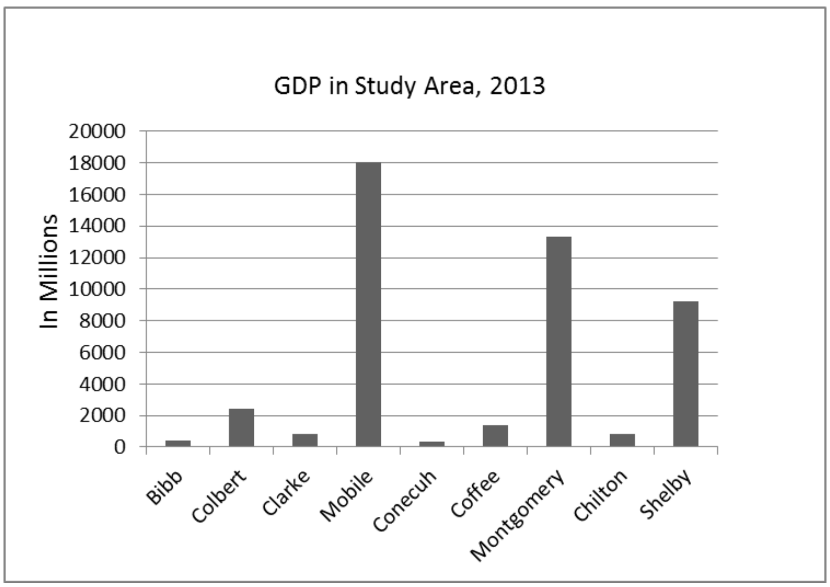

Figure 4. GDP of nine studied counties in 2013. Date source: IMPLAN.

Drought Impacts on Manufacturing

Drought and water shortage impacts in manufacturing originate from difficulties in input allocation and reductions in demand. Water is an important input for manufacturing, especially for low-technology manufacturing (Benson and Clay, 1998; Ridoutt and Pfister, 2010). In addition, during the drought period, agriculture output, which is an important contribution to manufacturing input, always decreases (Howitt, et al., 2014; Wu &Wilhite, 2003). Both survey results and previous research shows that the manufacturing sector always ceases or limits production when water is restricted (Benson and Clay, 1998, Alva-Lizarraga, 2011). Additionally, low-technology manufacturing is time-consuming and highly dependent on labor. During drought periods, people spend more time acquiring water, storing water and driving to purchase bottled water. The demand for manufacturing declines during drought periods, partly due to the reduced income and loss of jobs, and also due to the extra expenditures on illness, child care and other drought-related costs. The original ECAT survey data shows that 19% of manufacturers choose to shut down during water restrictions or water outage events rather than coping with the water disruption. This result is consistent with previous research, which indicated that over one-third of economic loss during water utility damage in the manufacturing sector (Chang, et al., 1996; Bram, Orr, and Rappaport, 2002; Rose and Liao, 2005).

Drought Impacts on Transportation and Warehousing

Of the NAICS industries examined, the transportation and warehousing sector includes pipeline transportation; rail transportation; water transportation; truck transportation etc., and warehousing and storage. Transportation is closely associated with agriculture and manufacturing. The reduction in agriculture outputs, manufacturing inputs and outputs lead to reduced demand for transportation (Cohen and Moon, 1990; Krugman, 1990; Fogel, 1994; Pretty, et al., 2005). Another main cause of the reduction in warehousing sector is that, during drought periods, industries and businesses usually depend on their inventory of products and inputs, which leads to the smaller demand for warehousing.

Drought Impacts on Education and Day Care Services

The previous ECAT survey shows that during water disruptions, Education and Day Care services typically close which leads to increased demand for babysitting. In addition, boiling water increases the electric expenditures and bottled water consumption increases the expenditures on grocery shopping and gasoline due to increased travel. During the drought period, the expenditures due to illness increase, which also contributes to the increase in household expenditure.

Drought Impacts on Health Care and Social Assistance

Expenditure due to illness increased but there was no significant positive impact on the Health Care and Social Assistance sector as a result. This lack of net profit impact for the Healthcare and Social Assistance sector is probably because the increases in revenues were approximately offset by increases in expenditures to meet their water quality and quantity requirements. In addition, labor cost during the drought period also increase.

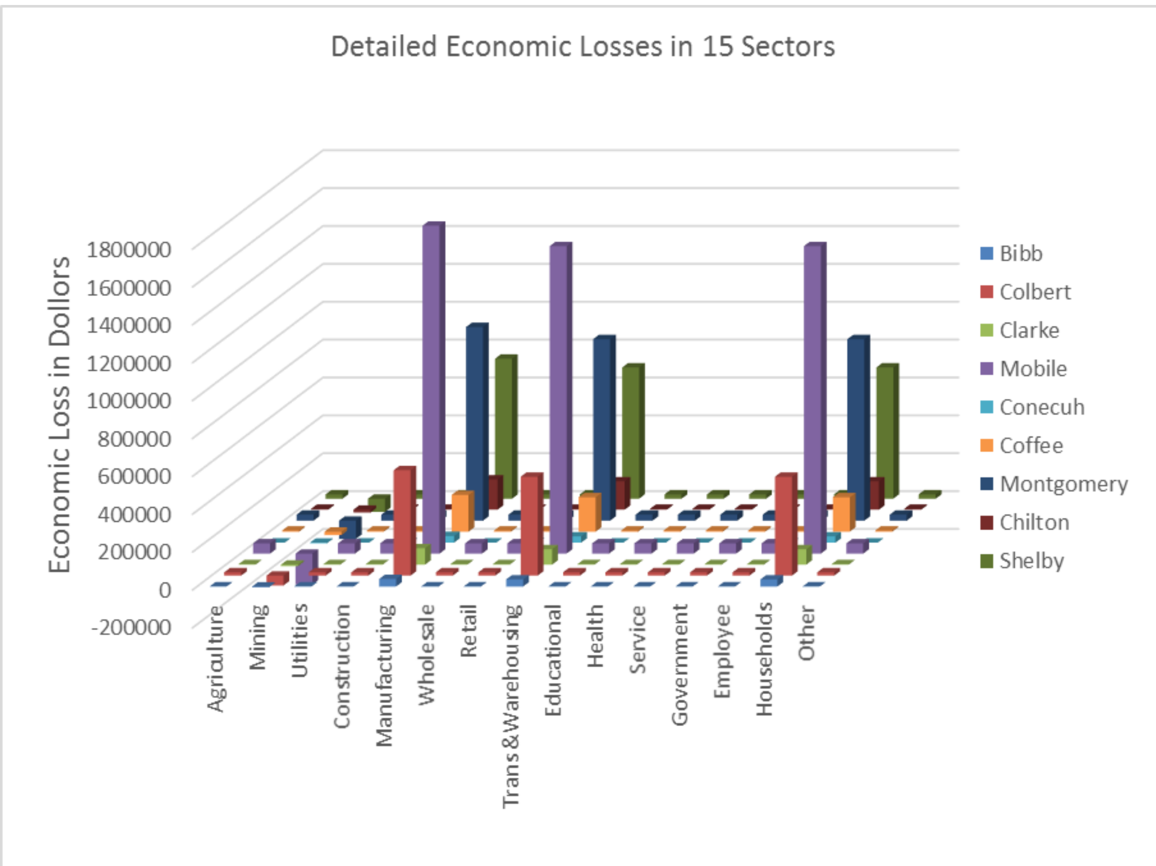

Figure 5. Detailed economic loss in 15 sector in nine studied counties, in dollar, 2013 value.

Sensitivity Analysis

This study uses sensitivity analysis to determine which of the survey-based indexes have the largest total economic impact. The researchers reduced the indexes by 50% and recalculated the total economic losses. From Table 2, we conclude that, the 50% reduction in drought-related household costs has the most significant impact on the reduction of total economic losses. During periods of drought, households must spend more money on food due to price increases (USDA, 2015) and unusual purchases such as bottled water. Additional costs occur during overnight stays in temporary housing if water becomes contaminated. These additional costs are necessary to maintain the household's economic welfare. To cope with these extra household expenditures, households must cut their consumption of other goods such as clothing, and recreation reducing economic welfare. Thus finding ways of reducing these unusual household expenditures would directly reduce the estimated economic losses due to drought.

Preparedness, like increasing water storage and thereby reducing the need for emergency purchases of bottle water also has some impact on reducing the total economic impact. Increasing water storage not only reduces the need for emergency purchases of bottled water but it also reduces the cost of traveling to purchase bottle water or boiling water (if water becomes contaminated). In PyWREM, time was a significant factor associated with economic losses. Reducing the necessary responses to drought reduces the time costs to individuals. Reducing expenditures on daycare and babysitting by 50% would lead to 16.9% reduction in the total economic losses.

Compared with the previous three factors, the impact of changing illness costs to the total economic loss was very small. This is partially due to the illness caused by drought being relatively insignificant.

Table 2. Sensitive analysis of four indexes in PyWREM.

Index	Change in Total Economic Impact
50% reduction in water storage and bottle water consumption	-18.1%
50% reduction in illness rate and cost	-0.0%
50% reduction in child care and babysitting	-16.9%
50% reduction in additional household expenditures (food, overnight stay, etc.)	-25.0%
50% reduction in all four indexes	-59.2%

Future Work

To increase the accuracy of PyFECA, future research will require a new drought based survey, in order to understand the impact of long term water restrictions and the specific resilience of drought.

Conclusion

Driven by population growth, climate change, urban expansion and other factors, more regions of the world are experiencing drought and drought severity continues to increase. Decision makers cannot ignore the socioeconomic impact of drought.

This study demonstrates that the water disruption event model (ECAT) can be transformed into a drought event economic analysis tool (PyWREM). Using customers' behavior under drought-caused water disruption periods as an example and the inter-industry relationships between each industry sector, PyWREM quantitatively assesses drought impact on regional socioeconomic systems. The primary mechanism for quantitative assessment is through IO modeling and social accounting matrices. Counties chosen from each of Alabama's nine regions were studied to gain insight into the socioeconomic characteristics of drought. In addition, Montgomery County was chosen to conduct a sensitivity analysis of survey based customer behavior indexes.

This study demonstrates that regions with higher GDP experience a higher magnitude of economic loss but that the size of economic loss relative to the region's total GDP was usually smaller. The majority of droughts' socioeconomic impacts occur in the manufacturing sector, households sector, and transportation and warehousing sectors. Drought had some positive, revenue generating impact in the mining sector.

The sensitivity analysis of household behaviors under water restriction events indicates that socioeconomic impact of drought is most sensitive to the extra household costs caused by drought induced water restrictions. In addition, increasing water storage has a significant effect on reducing the economic impact of drought. The sensitivity analysis provides guidance for a future survey that the researchers plan to conduct with businesses and households affected by drought. The sensitivity analysis also provides analytical support to policy makers and water resource managers so that they may better focus their efforts to reduce economic loss before droughts occur.

Additional research is needed to improve the accuracy of PyWREM. As mentioned, a survey of business and household responses to drought-induced water outages is necessary to refine PyWREM estimates. The sensitivity analysis within this research indicates that the survey should focus on household expenditure, water storage activities, and child care usage. To achieve a comprehensive drought socioeconomic impact model, additional research should investigate the impacts of drought on other non-agriculture sectors, such as tourism and recreation, and plant nurseries.

This study offers a method, using I-O models and social accounting matrices, to analyze water restriction events. This method can be adapted for analysis of drought impacts in other sectors, and even for buildings and infrastructures damage during floods, earthquake, hurricanes, and tornadoes (Wein and Rose, 2011; Rose, et al., 2011; Rose and Oladosu, 2008).

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CHAPTER 3 DEVELOPING A NATIONAL-SCALE, MULTI-BASIN FLOOD DECISION SUPPORT SYSTEM INCORPORATING ECONOMIC CONSEQUENCE ASSESSMENT

Introduction

Flooding is one of the most economically disastrous natural hazards. In the United States, floods account for nearly two-thirds of all presidential disaster declarations from 1953 to 2010 (Michel-Kerjan, et al. 2011), resulting in widespread economic impacts for societies, industries, agriculture, and recreation. Approximately 365 deaths were caused by flood from 2010 to 2014 (NWS 2015). Driven by a variety of factors including climate change, population growth and increased urbanization, and alteration to land cover, flood occurs widely all over the world and has increased significantly (Ashley et al., 2005).

Damage assessments of flood supply crucial information to decision support and policy development in flood management and emergency response. A Decision Support System (DSS) for flood management and response would allow decision makers and stakeholders to allocate resources for recovery and reconstruction effectively. Banks et al. (2014) and Ding et al. (2008) reviewed the functionality of several existing tools. The conclusion reached by these assessments is that FEMA's United States Hazard Multi-Hazard (Hazus) is among the more robust. This study aimed to develop a national-scale, multi-sector flood economic impact assessment and to overcome the problem of the spatial and temporal boundaries in almost all current flood impact assessment tools, such as those in Hazus.

In this work, the researchers developed a new tool for flood economic impact assessment, Python based Flood Economic Consequence Assessment Tool (PyFECA). PyFECA was based on previous efforts done on economic consequence assessment in the event of a disruption in water services. Different from other models which only focus on direct impact, this model deals with both direct and indirect impact. PyFECA focuses on all economic sectors using a continuous dynamic social accounting matrix approach, coupled with calculation of the indirect consequences for the local and regional economies and the various resilience and other strategies implemented. PyFECA was integrated with HEC-RAS, Hazus, ArcGIS and near-real-time hydrologic modeling methods. This model was able to provide a comprehensive flood impact assessment, including hazard assessment, damage assessment, and socio-economic assessment. Additionally, PyFECA can simulate flood impact in water contamination and drinking water systems.

PyFECA considers hydrologic data, IMPLAN, economic statistical data, and people's behavior as they respond to flood. All economic sectors were classified into 13 categories based on The North American Industry Classification System (NAICS, 2015). In this way, the detail of flood economic impact in all 13 categories can be achieved. Combined with ArcGIS for Desktop, PyFECA enables flood plain managers to notice the most susceptive area easily and then manage their limited resources efficiently. This paper presents a new method to use hydrology and hydrologic data to get flood economic consequence assessment and improve current emergency response plans. The detail of PyFECA development, and the application of PyFECA based on a case study in Montgomery, and Tuscaloosa, AL is discussed in this paper.

Literature Review

Driven by a variety of factors including climate change, population growth, increased urbanization, and alteration to land cover, floods occur widely all over the world and flood prevalence is increasing significantly (Jain, 2001; Ashley et al. 2005; IPCC, 2007). In the United

States, floods account for nearly two-thirds of all presidential disaster declarations from 1953 to 2010 (Michel-Kerjan et al. 2011), resulting in widespread economic impacts for societies, industries, agriculture, and recreation. Approximately 365 deaths were caused by flood from 2010 to 2014 (NWS 2015). There have been 11 floods over the past 15 years (2000-2015) that exceeded a billion dollars in losses each (billion-dollar floods), totaling more than 27.9 billion dollars in losses (National Climatic Data Center, 2016).

Besides damage to the built environment, floods impact water quality and induce water outage. Veldhuis' (2010) study on urban flood water shows that flood water is vulnerable to microbial contamination, and thus poses potential health risks to residents supplied by these waters. Research on New Zealand floods show that the E. coli bacterial concentration increased by more than two orders of magnitude during flood events (Nagels et al., 2002). Similar flood water contamination and drinking water sources contamination events occurred in Bangladesh and Indonesia (Phanuwan et al., 2006; Islam et al., 2007). During the 2015 flood of South Carolina and other locations along the east coast of the United States, damage to public water supply systems caused serious water outages. 40,000 residents of this area were without water service (Kalsi, 2015; SCEMD, 2015). Water contamination is worse in rural area, where tube-well are widely used. According to Shimi's (2010) research on floods in Bangladesh, floods left two-thirds of tube-well and toilet water compromised.

Currently, most of flood impact assessments studies and tools only focus on direct damage for buildings and infrastructure using damage functions or damage curves. HEC-FDA, HEC-FIA, and Hazus-MH are the most commonly used flood impact assessment models in the United States and are freely accessible. All of these three models use depth-damage functions to assess direct damage to residential, commercial, agricultural, and industrial structures. Das and

Lee (1988) present a nontraditional flood stage-damage assessment method with the depth-damage functions, flood elevation, and economic data. Yang and Tsai (2000) used the survey based empirical stage-damage curves to calculate the flood damages in anthropogenic structures. Though other methods are used to assess flood impacts, but almost all studies consider the damage of infrastructure. Merz et al. (2004) study the uncertainty of flood damage to buildings and conclude that the uncertainty of damage estimates depended on the number and distribution of flooded building, not the depth-damage function (Merz et al., 2004). Ding et al. (2008) study the Hazus-MH (Hazards United States Multi-Hazard) flood model with other programs, and pointed out that Hazus-MH Level 2 analysis appears to be favorable to HEC-FDA based on the man hours spent constructing the HEC-FDA model.

Though floods deteriorate water quality and the water supply system (Nagels et al., 2002; Veldhuis et al., 2010; Kalsi, 2015; SCEMD, 2015), little research focuses on assessing the flood impact on public water supply systems. Furthermore, indirect damage is as important as direct damage to the economy, but many assessments do not include indirect losses. The indirect economic assessment in Hazus-MH and HEC-FIA is based on loss of building function (Penning-Rowsell and Green, 2000; HAZUS-MH & F. E. M. A., 2003). There is a need to make impact assessment more comprehensive, and to supply the crucial information to decision support and policy development in flood management and emergency response scenarios. In contrast to previous research, this research assesses the indirect impacts based on household and businesses responses to flood with a focus on the loss of water services.

The research on flood economic impact presented within this paper is part of an overarching effort to develop an efficient economic impact model which can take into consideration sector vulnerability and resiliency strategies in response to extreme climate events, to assist decision makers in devising response strategies. In this paper we discuss the development of a Python based Flood Economic Consequence Assessment Tool (PyFECA) based on the Economic Consequence Assessment Tool (ECAT), developed by the University of Missouri-Columbia (Alva-Lizarragga, 2012). PyFECA are multi-sector, county-level socioeconomic assessment tools. PyFECA focuses on modeling the direct and indirect economic consequences of extended water contamination and outage, such as those resulting from flood. ECAT is a dynamic demand driven social accounting matrix based model with supply constraints that incorporates resilience strategies of both consumers and producers. This model has the advantage of managing the discrepancy between the time intervals involved in water disruption events and the typical observation interval of the data used for modeling purposes. The methodology can analyze other flood related issues such as, the socioeconomic impact of resulting flood-driven food shortages, and limited recreational access to water. PyFECA can describe the direct and indirect economic impacts that water supply restrictions have during flood events by focusing on resiliency actions by household and business and the cost of their implementation, instead of direct building damage losses that contemporary modeling software analyzes. Thus, PyFECA attempts to capture comprehensive socioeconomic impacts of flood based on water supply losses during such flood events. In PyFECA, all industry sectors in IMPLAN database consolidate into 13 categories based on the North American Industry Classification System (NAICS), the details of the consolidation are shown in Table 3. In addition, households are divided into two sectors: employee and household.

Table 3. Detail descriptions of the 13 businesses categories in PyFECA.

PyFECA Description	NAICS Sector	NAICS Description
Agriculture	11	Agriculture, Forestry, Fishing and Hunting
Mining	21	Mining, Quarrying, and Oil and Gas Extraction
Utilities	22	Utilities
Construction	23	Construction
Manufacturing	31-33	Manufacturing
Wholesale	42	Wholesale Trade
Retail	44-45	Retail Trade
Transportation and Warehousing	48-49	Transportation and Warehousing
Education	61	Educational Services
Health	62	Health Care and Social Assistance
Service	72	Accommodation and Food Services
Others	51-56, 71, 81	Information; Finance and Insurance; Real Estate and Rental and Leasing; Professional, Scientific, and Technical Services; Management of Companies and Enterprises; Administrative and Support and Waste Management and Remediation Services; Arts, Entertainment, and Recreation; Other Services (except Public Administration)
Government	92	Public Administration

Methods and Materials

Survey

In the original ECAT model (Alva-Lizarraga et al., 2011; Alva-Lizarraga and Johnson, 2012a; Alva-Lizarraga and Johnson, 2012b), a residential survey of recent water disruption events provided information on resiliency strategies taken by residential consumers (Jensen et al., 2011a; Jensen et al., 2011b). This survey information reflects not only economic losses but also resiliency responses and changes in preparedness for future events.

Additionally, ECAT incorporates data from a survey of 288 business affected by water disruptions. The business survey provides information on the businesses income distribution, the percentage of businesses prepared before the water disruption, and average financial and temporal costs of various responses to drought. Logit regressions were estimated to obtain the probability that businesses of particular types would implement a particular action. These estimated regression results are included in the basic ECAT model. The percentage of population affected by the disruption in the industrial sector and other baseline data are entered into ECAT by the user. ECAT then predicts the probabilities of implementing a particular action by businesses and residents in the study area (α_{ij}). These probabilities varied by type of event, business type and the proportion of the businesses within their respective sector.

Ultimately, they are multiplied by the average revenue loss or the expenditures incurred as a result of these activities and the time these activities were implemented in order to obtain the direct economic consequences for businesses.

The equations used to estimate the direct economic consequences for each business sector took the form:

$$\Delta B_{mjk} = \alpha_{ij} * \beta_i * \gamma_{ij} * \theta_k * \delta_k * \frac{1}{365}$$

for i=1…7, j=1…..n, k=1…536, m=1…13

Where:

m is the number of alternative actions modeled.

j is the day of the disruption event (from 1 to n), up to 365.

k is the IMPLAN sector type.

i represents the type of business (1=Accommodation and Services, 2= Extractive, utilities, construction, manufacturing, 3=Trade and Transportation, 4=Services, 5=Education and Day Care, 6=Health Care and Social Assistance, 7=Government).

ΔB_{mjk} is the change of expenditures for sector *k* at day *j*

β_i is the average expenditures per employee-hour by type of business i, obtained from the businesses survey.

α_{ij} is the probability of implementing businesses actions day *j* by business type i, calculated from the probability estimated using the logit regressions.

γ_{ij} is an indicator equal to 1 if the action is implemented on day j, obtained from survey.

θ_k is the number of employees per business type k, obtained from the IMPLAN database.

δ_k is the number of businesses of type k, obtained from the IMPLAN database.

Average expenditure estimates are based on data collected from the residential surveys. These actions vary according to the average household size, the population of the region and the day of the disruption. Previous studies (Harrington et al., 2016) and official statistics (e.g. Maupin, et al., 2014) were used in some cases to supplement the estimates. The daily expenditures incurred by households follow the following formula:

$$\Delta H_{mj} = \rho_m * \tau * \varphi * \pi_j$$

for j= 1…..n and m=1…

j is the day of the disruption event (from 1 to n), up to 365.

m are the alternative actions modeled.

ΔH_j is the change in expenditures for action m on day j.

ρ_m is the expenditures per person-day for action m, derived from the household surveys.

τ is the total population in the modeled area, obtained from IMPLAN database.

φ is the percentage of population served by the water utility, obtained from USGS (2010)

π_j is the percentage of residential customers affected by the disruption on day j.

τ and π_j are data provided by the user.

The proportion of population who boil water is obtained from the survey and adjusted by the percentage of residential customers affected by the disruption on day j. Using water needs by person from the USGS (Maupin et al., 2014) and the formula in (Harrington et al., 2016) to estimate boiling costs, we obtain the energy and time spent per day boiling water.

Economic Principles

The social accounting matrix was built using an input-output model (I-O model) to reflect the interindustry relationships. The I-O modeling approach was first developed by Wassily W. Leontief. He describes it as "a method of analysis that takes advantage of the relatively stable pattern of the flow of goods and services among the elements of our economy to bring a much more detailed statistical picture of the system into the range of manipulation by economic theory" (Leontief, 1986). The regional I-O multipliers are calculated based on a detailed set of industry accounts that measure the production in each industry and the intermediate demand by other industries and the final user demand. In I-O models each industry's production impact in the economy is described by a system of linear equations. With the assumption that prices of products remain the same, and incorporated with inter-industry relationships information, I-O models can estimate the economy-wide effects that an initial change in economic activity has on the aggregate economy of a region. (Leontief, 1963; Bess, et al., 2011; Miller, 2009; Haimes, 2005).

I-O models are often chosen to evaluate direct and indirect impacts of drought. Gunter et al. combined an I-O model and an Equilibrium Displacement Mathematical Programming Model to analysis the Southeast Colorado drought (Gunter, 2012). Kulshreshtha and Klein use an I-O model to determine drought impacts on agricultural (Kulshreshtha, 1989). Gil Sevilla et al., (2013) use an I-O model to measure the direct and indirect economic impact of drought in agriculture.

Compared to the Computable General Equilibrium (CGE) model, I-O models are easier to implement, maintain, and merge with existing spatial and engineering models (Okuyama, 2007). Gutenson merged an I-O model with EPANET and QGIS for assessing economic consequences (Gutenson et al. 2014).

In this study, the Social Accounting Matrix (SAM) is built around an I-O model to gain insight into the social and economic structure of impacts. A SAM can be considered as an extension of an I-O model. It is a summary table recording the inter-relationships between sectors, which includes production processes, income distribution and redistribution, in the whole regional economic system (Pyatt et al., 1985; Keuning and Ruuter, 1988; Bellú, 2012).

The I-O model took the form:

$$x_i = \sum_{j=1}^{j=n} a_{ij} * x_{ij} + y_i$$

where a_{ij} is the technical coefficient. The original technical coefficients are obtained from the IMPLAN database. During water restriction periods, the original technical coefficients are replaced by modified technical coefficients, which are derived from survey based indexes and user inputs.

Data

IMPLAN is a widely-used data resource for undertaking input-output analysis at the U.S. sub-regional level. It was first developed by the US Forest Service and subsequently managed by the Minnesota IMPLAN Group (Ding et al., 2011). I-O tables are highly specific for the economy of a particular geographical area and widely used in determining economic impacts. IMPLAN contains I-O Model tables, and is highly specific for the economy of a particular geographical area. IMPLAN is popular among government and industry economists who investigate the economic impacts of natural disaster and governmental policy changes (McKean, 2003). IMPLAN allows the user to modify the base data to suit their needs.

In this study, we use the original Social Accounting Matrix from IMPLAN Version 3. In addition to the I-O tables, IMPLAN provides tables detailing the margins used in order to convert expenditures at purchaser prices to expenditures at producer prices, and each sector's production levels, employment levels, payments to employees and returns to capital.

The USGS (2010) provides statistics describing the estimated use of water in the United States on a per-county basis. Based on the water demand data, population served by each utility data from USGS and population data from IMPLAN, we determine the average daily domestic consumption of water per capita. FCWA (US Census, 2011) provides water price data, average wage rate comes from 2010 U.S. national averages (US Census, 2011). The International Bottled Water Association (IBWA) provides the estimate of average bottled water price. EPA (2008) provides detailed information about common household uses of drinking water. The cost of electricity per kWh is from the power supply company (Alabama Power, 2008). All economic data was adjusted to reflect price levels in the modeled year (2013) using the Consumer Price Index (CPI) (BLS, 2016).

Adaptation

The household survey based indexes in the original ECAT can be summarized as: water storage and bottle water consumption, illness expenditures, daycare and babysitting and other household expenditures (cooking, food, overnight stay, etc.). The survey from the original ECAT model did not include flood induced water outages. Indexes were adapted when developeing PyFECA from ECAT. The adaptations come from a literature review, experiences, and assumptions.

To prepare the model for simulation of flood conditions, several changes were made to the basis data in the ECAT model. The water outages during flood events are typically caused by the damage to the public water supply system and water contamination (Krüger, et al., 2005; Taylor, et al., 2011; Ten Veldhuis., 2010), to reflect this situation, PyFECA was developed based on water contamination events in ECAT. Flood generally cause damage to transportation systems, this causes extra time for travelling during flood period. Based on research on transportation under flood condition (Faisal, et al., 2003; Doyle and Ketcheson, 2007; Proverbs and Soetanto, 2008; Collins et al., 2010), the travel time for purchasing, eating and other activities in PyFECA was increased by 50%. Restaurants and other food services usually shut down during flood events (Nagels et al., 2002; Phanuwan et al., 2006; Islam et al., 2007; Tapley, 2014; NRA, 2015; Parpal, 2015; Christinas, 2016). Additionally, considering the transportation difficulties, we assume the percentage of population eating in restaurants decreased by 80%. Previous research indicates that flood events increase the risk of disease and human health problems significantly. The percent increase in disease and human health risk varies from 8.6% to 53% and depends on factors like geographic and socio-economic conditions (Euripidou and Murray, 2004; Ahern et al., 2005; Alderman et al., 2012). The illness rate used in PyFECA was 0.35 instead of the original 0.11 in ECAT based on previous research on flood induced illness in United States (McMillen et al., 2002; Gaynor et al., 2007; Sharma et al., 2008). Power outages commonly occur during flood periods, which make it difficult to boil water with electricity. In this case, we reduced the percentage of population boiling water by 20% (Tierney, 1995; Scherp et al., 2009; Kwasinski et al., 2009). Since no prior research was found quantifying other factors, PyFECA uses the original indexes in the original ECAT. The original ECAT was developed in 2011, and all the dollar value in the model was in 2010. In order to achieve a more reasonable result, the dollar value now reflects the modeled year of this research using the Consumer Price Index (CPI).

In PyFECA, the CPI and survey based indexes, together with other user input information, are read from a csv file. Users can modify the indexes in the csv file easily based on the study area and/or specific model requirement.

Study area

In this study, PyFECA was applied in Montgomery and Tuscaloosa County, Alabama. However, the methodology and model presented here can be applied to other states and regions that are affected by flooding. To highlight the needs of comprehensive impact assessment, the flood induced water outage economic loss in Montgomery County are compared with the building damage loss caused by a 10-year return period flood in a Hazus-MH Level 1 simulation.

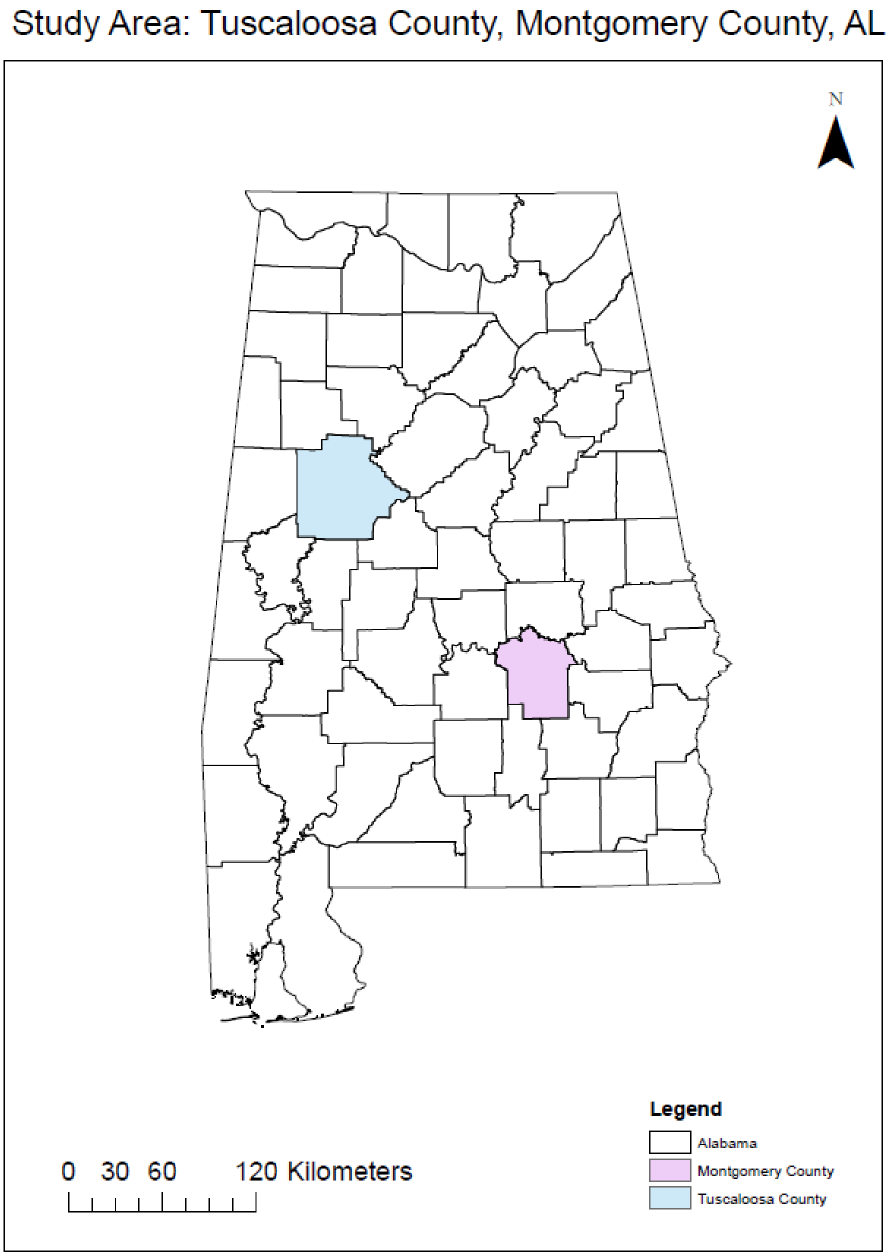

Figure 6. Study area of PyFECA, Tuscaloosa County, and Montgomery County, Alabama.

Results and discussions

County-Level Economic Impacts

This study simulated, 2-day, 5-day, and 10-day duration flood induced water outage events in Montgomery and Tuscaloosa County, Alabama. From Figure 7, under each simulated scenario, we see that the transportation and warehousing sector has the highest economic loss among the 15 sectors, and retail sector is the second highest. Additionally, results show the 5-day duration flood induced water outage causes a socioeconomic loss of $6.43 million (2013 value) in Montgomery County directly and indirectly. It is nearly 10% of the building damage loss caused by a 10-year return period flood in Montgomery County, as estimated by a Level 1 Hazus-MH simulation. Hazus-MH Flood Technical Manual (2003) mentions that Hazus-MH overestimates building damage commonly, which indicates the economic loss from loss water service can be more than 10% of the real building damage. The initial results indicate that most of the economic impact occurred in the retail, manufacturing, transportation and warehousing, and household economic sectors.

Flood Impacts on Transportation and Warehousing

The transportation and warehousing sector has the most significant economic loss. Transportation is very vulnerable to flood events, the infrastructure damage caused by flood and the road closures due to flood waters obstructs transportation (Dutta et al, 2003; Charles et al., 2006; Proverbs and Soetanto, 2008; Merz et al., 2010; Collins et al., 2010). Transportation is associated with both agriculture and manufacturing. The reduction in agricultural outputs, manufacturing inputs and outputs lead to demand reduction for transportation (Cohen and Moon, 1990; Krugman, 1990; Fogel, 1994; Morton, 2007; Pretty, 2005). Flood usually causes structural damage, the damage of warehouse and the flood inundation leads to the closure of warehouses, and then leads to economic loss in the warehousing sector (Smith, 1994; Scawthorn, 2006).

Flood Impacts on Manufacturing

Flood impacts in the manufacturing sector originate from infrastructure damage and difficulties in input acquisition. The damage to the manufacturing leads to the shutdown of production. Water is an important input for manufacturing, especially for low-technology manufacturing, the water outage reduces the water input and leads to the reduction of production (Benson and Clay, 1998; Ridoutt and Pfister, 2010). Additionally, low-technology manufacturing is time-consuming and highly dependent on labor. During a flood period, the difficulties in transporting goods and services makes the suppliers and employers unable to reach manufacturers, and leads to the reduction in production (MRl & H. M. 2003; Faisal et al., 2003; Merz et al., 2004; Doyle and Ketcheson, 2007). In addition, people spend more time acquiring water through boiling water, storing water and driving to purchase bottled water, which reduces the labor input into manufacturing, and consequently, reduces the production (Ehrenberg and Smith, 1985; Bentolila and Saint-Paul, 1994; Hamermesh, 1996).

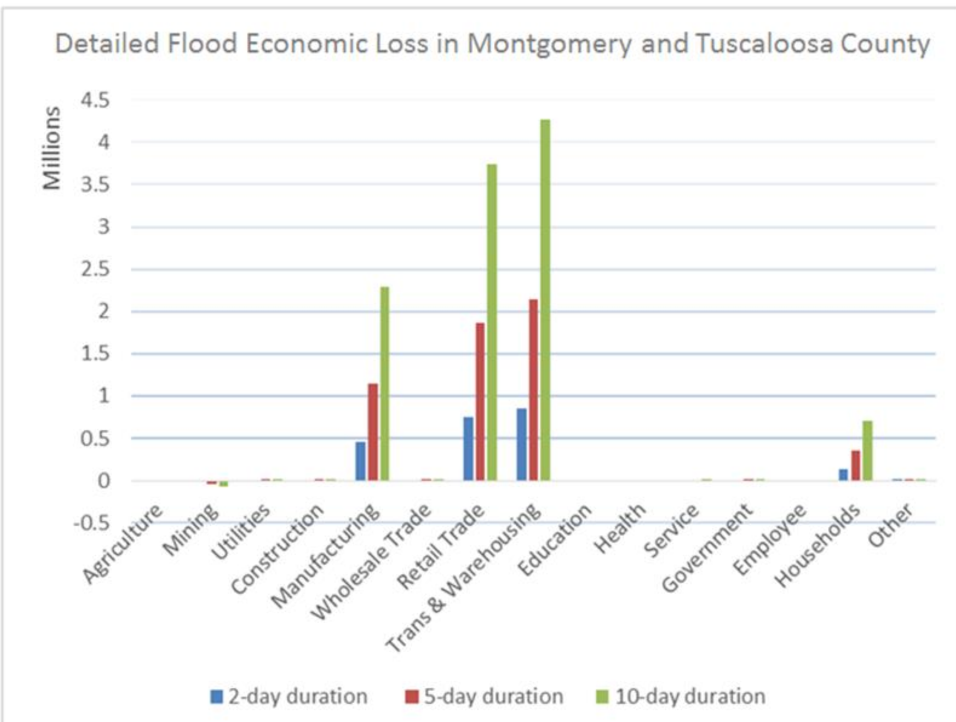

Figure 7. Detailed flood caused economic loss in 15 sector Montgomery County, and Tuscaloosa County, in dollar, 2013 value.

Flood Impacts on Retail

The impact on the retail sector is partly due to the reduction in input. Manufacturing production is the main input for retail businesses, the reduction in Manufacturing Sector output causes a shortage of inputs into the retail sector. Also, household strategies to cope with the extra expenditures on illness, care and other sectors cause a reduction in consumption of retail goods and services because of a decrease in household disposable income (Sauerborn et al., 1996; Skoufias, 2003). Business closures during flood periods also cause economic losses in the retail sector (Tierney, 1995). This result is consistent with previous research, which indicated that transportation, manufacturing and retail trade sectors have significant economic loss during water utility damage period (Chang et al., 1996; Bram, Orr, and Rappaport, 2002; Rose and Liao, 2005).

Flood Impacts on Household Expenditures

Education and Day Care services typically close during floods (McAboy et al, 2015; Otero and Key, 2015; Wilson, 2016), leading to increasing demand for babysitting. In addition, boiling water increases electric expenditures and increases travel expenditures on gasoline. During flood periods, the expenditures due to illness increase, which also contributes to the increase in household expenditure.

Sensitivity Analysis

This study investigates, using sensitivity analysis, which of the survey-based indexes have the largest effects on the total economic impact. The researchers reduced the indexes by 50% and recalculated the total economic losses. From Table 4, we conclude that, the 50% reduction in flood-caused additional household expenditures (food, overnight stay, etc.) has the most significant impact on the reduction of total economic losses. PyFECA treats additional household expenditures (food, overnight stay, etc.) as a part of economic losses due to flood. The researchers observe that the reduction of the household expenditures would reduce the modeled flood economic loss directly. During flooding events, households must spend more money on food due to the water outages disabling the homeowner's ability to cook at home. Additional costs also occur during overnight stays in temporary housing if houses are damaged by flood water or if water becomes undrinkable. The damage to the house from flood water causes households to spend more money on overnight stays in hotels or temporary housing. To cope with these extra household expenditures, households usually cut their consumption of other goods such as clothing and recreation. This reduces the demand of manufactured goods, and impacts the whole economic system. These additional costs are necessary to maintain the household's economic welfare. Thus, finding ways of reducing these unusual household expenditures would directly reduce the estimated economic losses due to flood.

Preparedness, like increasing water storage and reducing the need for emergency purchases of bottle water also has some impact on reducing the total economic impact. Increasing water storage not only reduces the need for emergency purchases of bottled water but it also reduces the cost of traveling to purchase bottle water or boiling water (if water becomes contaminated). Further, preparedness reduces the dependency placed upon other pieces of infrastructure, such as roads and electric grids, which may also incur damage during the flooding event. In PyFECA, time was a significant factor associated with economic losses. Reducing the necessary responses to flood reduces the time costs to individuals.

Reducing the illness rate and cost index by 50% would lead to 17.9% reduction in the total economic losses. Compared with the researcher's previous research on drought economic consequence analysis, flood economic loss is more sensitive to illness rate and cost than drought.

During a flood period, the illness rate and illness cost increase significantly, which leads to extra expenditures by households (Euripidou and Murray, 2004; Ahern et al., 2005; Alderman et al., 2012). Illnesses can reduce production through reduction of labor time.

In comparison to other indexes, the impact of changing the care and babysitting cost index to the total economic loss was inconsequential. This is partially due to the illness caused by flood is more common than drought. The 50% reduction in child care and babysitting would lead to only 3.6% reduction in the total flood economic loss. Compared with the previous three factors, the impact of child care and babysitting to the total economic loss was very small.

Table 4. Sensitive analysis of four indexes in PyFECA.

Index	Change in Total Economic Impact
50% reduction in water storage and bottle water consumption	-18.4%
50% reduction in illness rate and cost	-17.9%
50% reduction in child care and babysitting	-3.6%
50% reduction in additional household expenditures (food, overnight stay, etc.)	-20.4%
50% reduction in all four indexes	-58.8%

Future Research

Additional research is needed to improve the accuracy of PyFECA. As mentioned, a survey of prior business and household responses to flood induced water outages is necessary to substantiate PyFECA estimates. The interrelation between industrial sectors should also be studied. The sensitivity analysis within this research indicates that the survey should focus on illness rate and cost, water storage activities, and additional household expenditure (food, overnight stay, etc.).

The authors have developed Flood Damage Wizard, an open-source, Python based software for quickly estimating flood damage to buildings (Gutenson et al., 2017). Additional research will focus on connecting PyFECA and Flood Damage Wizard, in this way, PyFECA will be able consider hydrologic and geographic features.

Conclusions

Disaster impacts assessments are crucial for understanding disasters and effective disaster prevention. Deciding how to respond to disasters cannot be efficient without considering the disasters social and economic impacts. Social and economic disaster impacts assessments help manage the limited resources efficiently and reduce the impact of such events (Laugé, 2013).

Flooding is one of the most economically disastrous natural hazards and occur frequently throughout both the United States and the world at large. Floods occur with little or no advanced warning, and cause immense devastation to both the built environment and the economy of an impacted region.

The literature on flood damage assessment tools indicates that the Federal Emergency Management Agency United States Hazard–Multi Hazard, Hydrologic Engineering Center's Flood Damage Reduction Analysis (HEC-FDA), and Flood Impact Assessment (HEC-FIA) are the most commonly used flood impact assessment models in the United States. All of these tools focus on assessing the floods direct damage, with Hazus-MH providing the only rudimentary indirect economic impact assessment that builds upon the approach developed in the Hazus-MH Earthquake methodology (MRl & H. M. 2003). HEC-FIA 3.0 provides indirect economic impact based on labor and employment (HEC-FIA, 2015). This research studied the flood indirect economic impact of lost water service, which occurs commonly during flooding but is ignored by most of flood damage assessment tools. Different from previous research, PyFECA assesses the economic impact based on resident's behavior during flood period.

In this study, the researchers simulate two scenarios in Montgomery and Tuscaloosa County to gain insight into the socioeconomic characteristics of flood induced water outage. In addition, the socioeconomic loss of the 5-day flood induced water outage scenario in

Montgomery County was chosen to compare with the 10-year return period flood caused building damage loss. This study demonstrates that the water disruption event model (ECAT) can be combined with the direct and indirect economic losses that building damage loss has on a regional economy (PyFECA).

A sensitivity analysis of survey based customer behavior indexes was conducted to determine which of the survey-based indexes have the largest effects on the total economic impact. The sensitivity analysis of household behaviors under water restriction events indicates that socioeconomic impact of flood is most sensitive to the additional household expenditure (food, overnight stay, etc.) caused by flood induced water restrictions. In addition, increasing water storage has a significant effect on reducing the economic impact of flood. The sensitivity analysis provides guidance for future survey questions that the researchers plan to provide to businesses and households affected by flood. The sensitivity analysis also provides analytical support to policy makers and water resource managers so that they may better develop strategies for reducing economic loss before floods occur.

This study offers a method, using I-O models and social accounting matrices, to analyze water restriction events. This method can be adapted for analysis of flood impacts in other sectors, and even for buildings and infrastructures damage during earthquake, hurricanes, and tornadoes (Rose and Oladosu, 2008; Wein and Rose, 2011; Rose et al., 2011).

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CHAPTER 4 DEVELOPING AN INTERBASIN TRANSFER REGULATORY FRAMEWORK FOR ECONOMIC DEVELOPMENT: CASE STUDIES FROM IRRIGATED AGRICULTURAL PRODUCTION

Introduction

Regional water resource management is typically predicated on the allocation of water at the basin level. Interbasin transfer (IBT) projects allow dynamic reallocation of water to locations based on regional public need, availability, and economic benefit. Without appropriate regulations, interbasin transfer projects can be problematic. They can lead to drought in donor basin, unsustainable growth, social disruption, water pollution, and hydrologic characteristics changes. Appropriate regulation systems help increase the benefits and reduce the impacts of IBT projects.

This research highlights the benefits and impacts of IBTs and provides analytical support for assessing the feasibility of IBT projects in Alabama. AquaCrop, a crop water productivity model, was used to simulate agricultural production response to IBTs. In this research, eight counties in Alabama were studied: Colbert, Jackson, Lauderdale, Lawrence, Limestone, Madison, Marshall, and Morgan Counties. A total of 11 years (2000 to 2010) crop yield data for three major crops (corn, cotton, and soybean), temperature, precipitation, evapotranspiration, and soil data were collected and analyzed. In the absence of available reported data, AquaCrop was used to determine optimal irrigation methods. Crop yields under different IBT scenarios and without IBTs were simulated and compared to determine the optimal IBT plan. A series of sensitivity analyses were conducted using AquaCrop to investigate the influence of each parameter on crop yield.

The results of this research indicate that a state-level IBTs regulation in Alabama is required to improve the water management plan, protect donor basins, promote economic development and agriculture production. The focuses of future research about IBTs in Alabama are also presented in this paper.

Literature Review

Water transfer is not a new phenomenon; it is described as a man-made method of reallocating water from areas with high water availability to areas of low availability to overcome water deficits. Water transfer is a common strategy to reduce drought impact and has been used extensively to promote economic development and increase agricultural production (Kahrl, 1983; Howe and Easter, 2013; Israel and Lund, 1995; Michelsen and Robert, 1993). Water transfer can be as simple as reducing the water supply to one user to increase the supply to another or as complex as transferring water from reservoirs or river basins to others (SWRCD, 1999). The demand for IBT is two-dimensional (Noel, 1982; Gupta and Zaag, 2008), based on both time and space, as the distribution of water is uneven across both dimensions and does not always correlate with what is most economically advantageous. For instance, the state of Alabama has a great quantity of rainfall at the state scale, but the areas of greatest demand are the areas with the least supplies (Putt, 2003).

On a global scale, water transfers could divert more than a quarter of all water by the year 2025 (Gupta and Zaag, 2008; ICID, 2005; Howe and Easter, 2013). Driven by a variety of factors including promoting economic development, climate change, population growth, limited water resources, water pollution, increasing water demands, and economic and social development, water transfer is receiving increasing consideration and attention (Beattie, et al., 1971; Liu and Zheng, 2002; Savenije and Zaag, 2008; Matete and Hassan, 2005).

Complications are routine in IBT projects. IBT projects are large, costly projects which are nonreversible in short term time scales. The typical design life for an IBT project is 100 years, leading to a lack of flexibility (SWRCD, 1999; Howe and Easter, 2013). The Los Angeles Aqueduct, began in 1905, and cost $26 million (1905 value) to finish the construction (Kelly, 1913; Masters, 2012). The Colorado River Aqueduct, has an average annual throughput of 1.48 billion m3 (1,200,000 acre feet), and the construction cost more than $190 million (1931 value) (Eastman, 2011). Reports show that the South–North Water Transfer Project in China will cost more than $79 billion. The project is planned to be complete in 2050 with a throughput of 44.8 billion m3 annually (Chang, 2014; WTN 2008). Besides the construction costs, the operation costs for IBTs are also significant. The California State Water Project costs $600 million (1996 value) per year of which $192 million (32%) goes to power, and $150 million (25%) goes to labor and equipment (DWR, 2011c).

IBT projects involve and affect different interest groups, systems and communities, such as the ecological, economic, political, and hydrologic systems. IBT projects normally cause interruptions within the river systems, which leads to disruption of fish spawning and migration (WWF, 2007). Besides threatening fish, IBT projects induce deterioration of aquatic habitats and alter the composition of fauna. O'Keeffe and Moor (2006) indicated 67 percent of species have changed in Orange River and Fish River since the water transfer projects started in 1977. The Tagus-Seguta Transfer in Spain threatens native fish species, such as Chondrostoma arrigonis (IUCN Red List, 2006). Research on the Snowy River Scheme Project in Australia demonstrate that the project induces an observable reduction in fish population, change in sedimentation rates, loss of wetland habitat, and salt water intrusion in the coastal areas (WWF, 2007; Doeg et al, 1987; Davies, 1992). Research on the South-North Water Transfer Project in China indicates that the project may increase water pollution, siltation in the lower river, and harm the ecological system (Shao and Wang, 2003; Berkoff, 2003; Li et al, 2011). Researchers pointed out that the Lesotho Highlands Water Project led to the loss of agricultural and grazing lands, put women at higher risk of food insecurity, and increased communicable diseases and social disruption in Lesotho and Southern Africa (Tilt, et al., 2009; Lerer and Scudder, 1999; Braun, 2010).

Researchers evaluate IBT based on various criteria (SWRCD, 1999; Howe and Easter, 2013; Gupta and Zaag, 2007). In this paper, the researchers analyzed how IBT impacts these sectors and how these sectors impact each other by studying current IBT projects. Four large scale IBTs, California State Water Project (USA), Central Arizona Project (USA), Lesotho Highlands Water Project (South Africa), and South-North Water Transfer Project (China), are compared and discussed.

The direct and indirect benefits and costs from the IBT-based movement of water and the cost of the physical transfer system should be considered prior to IBT project implementation. As most water transfers affect agriculture, production functions based on crop values and water demands are widely used (Hartman, et al, 1970; Howe and Goemans, 2003; Booker and Young, 1994; Howe and Easter, 2013; Lund and Isreal, 1995). IBTs induce migration, reallocation of other resources and other factors incur long-term costs and benefits which are different from short-term costs and benefits, such as construction costs. This difference indicates that different functions are required to estimate each, and both sets of equations are necessary when performing a cost-benefit assessment of IBT projects. For the indirect cost and benefits, an input-output model and social accounting matrix are common in the literature (Howe and Easter, 2013; Hartman, et al, 1970; Matete and Hassan, 2005).

Problem Statement

In 2010, the total water withdrawals in Alabama were 438 m^3/s (9,998 million gallon per day (MGD)). Of the total water withdrawals, 2% of this total or 8.9 m^3/s (202 MGD) goes to irrigation. A total of 685 million m2 (169,240 acres) were irrigated. Currently, irrigation systems in Alabama are still under development (USGS, 2010). In 2012, only 457 million m^2 (113,008 acres) of irrigated cropland or 4.1% of total Alabama cropland existed. These totals in Alabama are minimal in comparison to neighboring states, such as Georgia (4.554 billion m^2 (1,125,355 acres) or 26.9% of total cropland) and Mississippi (6.685 billion m^2 (1,651,978 acres) or 32.5% of total cropland) (USDA, 2012). But the precipitations in these three states are in the same range, based on 30 years (1981 to 2010) climate data, the average annually precipitations in Alabama, Georgia and Mississippi are 134.75 cm, 126.34 cm and 137.57 cm, respectively (US Climate Data, 2017). The percentage of irrigated cropland in Alabama is much lower than the national level, which is 16.9% in 2012 based on The Food and Agriculture Organization of the United Nations (FAO) survey (FAO, 2013). Due to the uneven distribution of water resources, some parts of the state are suffering water deficits, while some parts have abundant water resources. Given these conditions, it is appropriate to discuss the potential benefits of IBT, and a state-level IBT law is suggested to regulate existing and future IBT projects.

As a result of the uneven distribution of water resources (Putt, 2003), a number of IBT projects currently exist in Alabama and have existed for many years. The specific numbers of existing IBT projects are not known since there is no state-wide definition of IBT, and there is no monitoring or reporting requirements for IBT projects (AWAWG, 2012; AWAWG, 2013;

Littlepage, 2016). In north Alabama, eight counties have enacted county-level Acts banning IBTs. There is growing interest in IBTs in Alabama for promoting both economic development and agricultural production, which requires an IBT regulatory mechanism to ensure IBT projects are reasonable and beneficial to the state (Littlepage, 2016). There are researchers and groups in Alabama highlighted the needs to regulate and permit IBTs since IBTs are fundamental to the operations of many water utilities (AWAWG, 2013). Savenije and Zaag (2008) pointed out that to achieve sustainable water resources management and improve the economic benefits, it is required to establish an appropriate and updated water policy system.

Alabama is involved in the tri-state water war with Georgia and Florida. Water transfer and over withdrawal of water leads to physical, social, and ecological issues in Apalachicola-Chattahoochee-Flint River Basin (Ruhl, 2005). Georgia takes 82% of total water withdrawals, and most of the water is from the headwaters of Apalachicola-Chattahoochee-Flint and impacts the downstream, Alabama and Florida. In order to protect the water rights of Alabama in the tri-state water war, a state level water transfer regulation is needed (Ruhl, 2005; Saunders, 2017; Ritchie, 2017; Williams, 2017; Gill, 2017).

Limited research has focused on IBTs in Alabama, which makes it difficult for the state government to regulate IBTs. The purpose of this study is to develop a preliminary framework of IBT projects to support the establishment of state-level IBT projects and improve the water resource management plan in Alabama. This study answers the question pointed out by Alabama Water Agencies Working Group (AWAWG, 2013) with regards to the future of Alabama water resource management, 'what information is required to established an IBT regulation?' Due to the lack of monitoring and reported data, assumptions and simulations are used in this research.

The main aim of this research is to identify the required information and data to regulate IBT projects, provide guides to future IBTs research in Alabama.

This research investigates the gross economic benefits or costs of IBT to the agriculture sector in northern Alabama using the AquaCrop model. Eight counties in Alabama were studied: Colbert, Jackson, Lauderdale, Lawrence, Limestone, Madison, Marshall, and Morgan counties. These eight counties are in the Tennessee River Basin, a large river basin in North Alabama that flows through seven states (USGS, 2001). This paper presents a method to study the relationship between climate, irrigation water withdrawals and crop yields. The results in this project provide analytical support, such as the factors that should be concerned, the assessment methods, and the necessity of IBT regulations, to the development of Alabama Interbasin Transfer Plan and Statewide Regulation. In future research, using reported irrigation data and detailed irrigation systems information, this method can be used to simulate the irrigation water quantity, calculate the volume of water should be transferred, and the economic benefit to agriculture from the IBTs.

Methods and Materials

Critical Dimensions of IBT Projects

Four representative IBT projects are reviewed to identify the critical dimensions of these projects and the lessons learned. The triggers of IBT projects, project scale, water distribution, cost, impact are discussed, along with the different impacts of these four projects, and guides to what should be focused on in future research of IBTs in Alabama.

California Water Transfer Project

In California, the water resource distribution is uneven; water resources are abundant in northern and eastern mountains, while the water demands are great in southern and western regions. The rapid population growth in California, especially in urban areas such as San Francisco and Los Angles, is the main trigger of water transfers (Kahrl, 1983). The California Water Transfer Project is the largest state built and operated water transfer system in the United States. It began in the 1960s, cost $5.2 billion (2001 value) for the construction (DWR, 2011a) and has an annual water yield of 3.3 billion m^3 (2.4 million acre feet). Approximately 70% of the delivered water goes to urban users, providing supplemental water to 25 million residents in California. An additional 30% irrigates 3 billion m^2 (0.75 million acres) of farmland (DWR, 2011a; DWR, 2011b; Meier, 2002). The project has a total length of 1128 kilometers (701 miles) canals and pipelines, and 34 storage facilities and 21 reservoirs (DWR, 2011a, Pi and Xiong, 2004). The annual operating cost is about $600 million (1996 value) (DWR, 2011c). In the early 1900s, when IBT projects went without appropriate regulations, the cost of IBT projects were large. During the California Water Wars of the early 20th century, Los Angeles received more than the designed water transfer yield from the Owens Valley to the east of Los Angeles. During this allocation process, plant communities have been adapted to short, regular periods of drought. Land cover, water table depth, and hydrologic characteristics changed significantly (Hollett, et al., 1991; Elmore, et al., 2003). This over allocation led the Owens Valley citizens to organize and fight against transferring water to Los Angeles in order to curtail the desertification of Owens Valley (Klein, 2006; Libecap, 2009; Kahrl, 1976).

Central Arizona Project

In Arizona, irrigation withdrawals account for more than 90% of the total water withdrawals. The Central Arizona Project (CAP) is the largest resource for renewable water supplies in Arizona. Of the total irrigation water, 40% goes to high-value intensive crops such as cotton, vegetables, and fruits. To meet the population growth and increase the agriculture economic production, the construction of the CAP began in 1973, and was completed in 1992 at a cost of $5 billion (Hanemann, 2002; Howe and Easter, 2013; CAP-AZ, 2015). CAP is a large scale water transfer project, with 541 kilometers (336 miles) of aqueducts. The project transfers approximately 1.9 billion m3 (1.5 million acre feet) of water from Colorado River to southern Arizona to provide water to more than 5 million residents in Arizona (Prietto, 2013; Zhang and Xiao, 2006; CAP-AZ, 2015). This project has reduced drought and water shortage impacts in Arizona.

Currently, CAP and the Arizona Department of Water Resources analyze the impact of CAP on water resources in the entire state of Arizona. The CAP and Arizona Department of Water Resources partnership set criteria to regulate existing and future water transfer projects within the CAP. (CAP-AZ, 2015).

Lesotho Highlands Water Project

The Lesotho Highlands Water Project is a multipurpose, bi-national water supply project which is capable of transferring 2.2 billion m^3 (1.8 million acre feet) of water per year (Mwangi, 2007). The project involves Lesotho and South Africa, and aims at satisfying the water demand in the Gauteng region and generating hydropower. This project cost more than $3.0 billion and is one of the largest water transfer and supply projects in the world (Fullalove, 1997; Haas, et al., 2010). Four rivers, the Malibamatso, Matsoku, Senqunyane and Senqu Rivers, are included in the Lesotho Highlands Water Project (Hitchcock, et al., 2006; Fullalove, 1997). The Lesotho Highlands Water Project provides income to Lesotho, but meanwhile, it leads to the loss of agricultural and grazing lands, shrinks agriculture production, and puts women at higher risk of food insecurity. The Lesotho Highland Water Project also causes social impacts, such as, increasing communicable diseases and social disruption in Lesotho, southern Africa (Tilt, et al., 2009; Lerer and Scudder, 1999; Braun, 2010).

South–North Water Transfer Project

The South–North Water Transfer Project in China, which transfers water from water-rich southern China to water-short northern China, started in 2002 after a 50-year feasibility study. (Zhang, 2009; Liu and Zheng, 2010; Yang, and Zehnder, 2005). The South-North Water Transfer Project contains three routes: East Route, Middle Route, and West Route, associated with the four largest river basins in China (Yantze River, Yellow River, Huai River, and Hai River). The South–North Water Transfer Project impacts more than ten Chinese provinces (Zhang et al., 2009; Zhang, 2009). The South-North Water Transfer Project has cost more than $79 billion to date. The project's planned completion is to occur in 2050 with a throughput of 44.8 billion m^3 per year (Chang, 2014; WTN 2008). A number of controversies surround the project; for instance, it leads to migration, increases water pollution, increases silt deposition in the lower river and causes additional ecological protection costs (Shao and Wang., 2003; Yu and Ren, 2007; Berkoff, 2003; Li et al, 2011; Xinhua, 2012; International Rivers, 2013).

Analysis of IBT Case Studies

Based on the above four IBT projects and previous research (SWRCD, 1999; Howe and Easter, 2013)the researchers conclude IBT projects are usually large scale and the construction time is on the order of decades. IBT projects are also financially expensive and the projects are irreversible in short term time frames. The distribution of IBT projects vary from area to area, population growth and overcoming uneven distribution of water resource are two main triggers. One principle component of IBT projects is an increase in the economic benefits to the area in which the IBTs are built. The impacts of IBT projects are multi-sector, including but not limited to agriculture, municipal, environment, hydrology, economic, and public health sectors.

IBT projects without appropriate regulations can be problematic. They can lead to unsustainable growth, social disruption, water pollution, and increased communicable disease. The various sectors associated with IBT and their interrelationships are presented in Figure 8. IBT impacts can be multi-sector and have interlinkages among different sector. Laws and criteria are highly needed to regulate IBT projects. Appropriate criteria help increase the benefits and reduce the impacts of IBT projects.

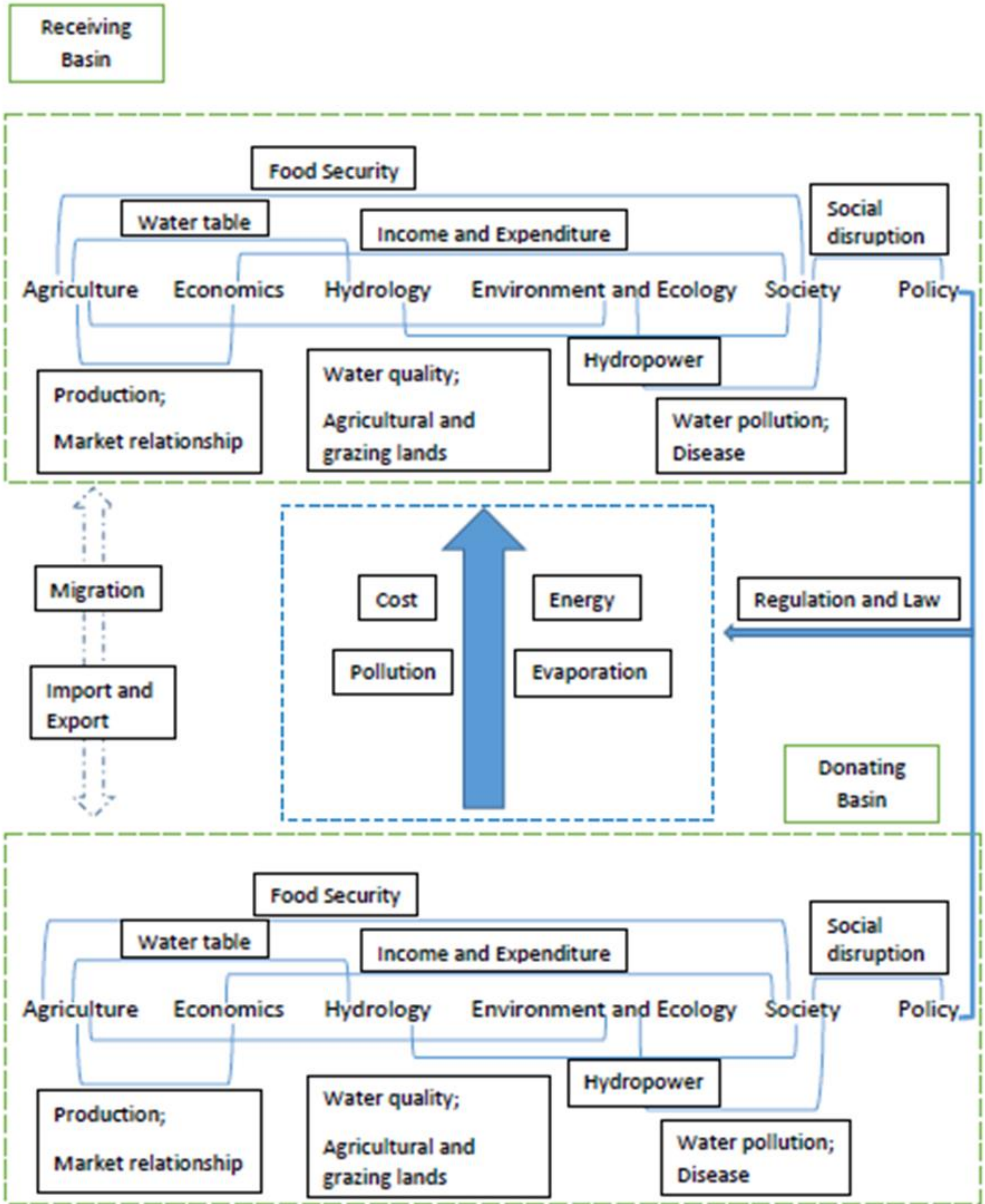

Figure 8. The sectors associated with interbasin transfer and the interrelationship between the sectors

Regulations Governing Interbasin Transfer Projects

States neighboring Alabama, such as Georgia and Tennessee, have already set regulations and laws to regulate IBT projects. In Georgia, a list of 22 criteria were developed by stakeholders and Georgia's Environmental Protection Division. Proposed IBT projects require an assessment of economic feasibility, cost effectiveness, and environmental impacts, water use, water-use efficiency, water quality, water and wastewater treatment capacity, surface water and groundwater, water conservation, authority of agencies, and return flow. The assessment of an IBT project also requires the developer to investigate the condition and impacts of the donor basin, receiving basin and both basins as a system (GWC, 2010).

In Tennessee, proposed IBTs undergo an application process. According to Tennessee Interbasin Transfer Permit Requirements (TNDEC, 2016), in order to get the permit a developer must provide the transfer yield, withdrawal, return, and transfer points, and return flow. Additional assessment of a proposed IBT project includes the peak capacity of facilities, engineering and economic justification, capacity of the transfer program and receiving basin, hydraulic and environmental impacts, and the feasibility of the project. The IBT assessment must provide the initial data and transfer time period and the water conservation programs in the IBT project.

The Nevada Interbasin Transfers Law considers the justness of an IBT project. The law requires the developer to assess the current water-use efficiency, environmental impacts, and long-term impacts concerning future growth and development in both donor and receiving basins. The Nevada Interbasin Transfers Law suggests that before a developer considers an IBT project, they should first consider increase water-use efficiency (NVDWR, 2013).

The Alabama Water Resources Act does not include water transfer. A state-level IBT Law can help Alabama regulate existing and future IBT project. With appropriate assessment and regulation, IBT project can be beneficial to the state.

Studies and detailed analyses are needed to create state-level IBT Project Laws and Regulations. Currently, in Alabama, there is a lack of IBT monitoring or regulation. The neighbor states, Tennessee, Georgia, North Carolina, and South Carolina, have already developed IBT regulatory mechanisms (GWC, 2010; TNDEC, 2016; AWAWG, 2012; AWAWG, 2013).

Based on four case studies, current IBT regulations in United States, and the simulation of irrigation in Alabama, we can conclude, in order to develop a state-level IBT regulatory mechanism, the following factors should be processed and considered:

1. The current water sources and water-use efficiency in the receiving basin;
2. Current and future water demand with a concern for developing and population growth in both donor and receiving basin;
3. The impact of an IBT project on the environment and ecology, hydrology, agriculture, economics in both the donor and receiving basin;
4. The purpose of IBT projects and the water consumption of the transferred water;
5. The cost-benefit of the IBT project; consider the agriculture sector as an example. As it is shown in this research, crops have different sensitivities to water, and high-value intensive crops such as cotton and other vegetables can bring more economic benefits with the same amount of water;
6. The capacity of the water and wastewater treatment facilities in the receiving basin;

7. Return flows to the hydrologic system and the impact of groundwater; and
8. Climate during the transferring period, climate extremes, such as drought and flood period.

Developing a IBT Decision Support

Study Area

This research investigated the gross economic benefits or costs of IBT to the agriculture sector in northern Alabama using the AquaCrop Dynamic Model. The study area in this project covers Lauderdale, Colbert, Limestone, Lawrence, Madison, Morgan, Marshall, and Jackson County. These eight counties are all in the Tennessee River Basin, which is a large river basin in North Alabama and flows through seven states (USGS, 2001). A USGS Survey shows that in 2005 and 2010, the total water withdrawals in the study area are 52% and 55% of the total water withdrawals in the whole state, respectively. The open water resources and croplands in the study area are shown in Figure 9. From the graph we can conclude, croplands are a main land cover in the study area. Additionally, in 2006, these eight counties enacted several IBT acts to ban IBT projects in the eight counties. By simulating several irrigation scenarios within the confines of the IBT acts, this research studies and discusses the relationship between the water yield of IBT projects and the agriculture production.

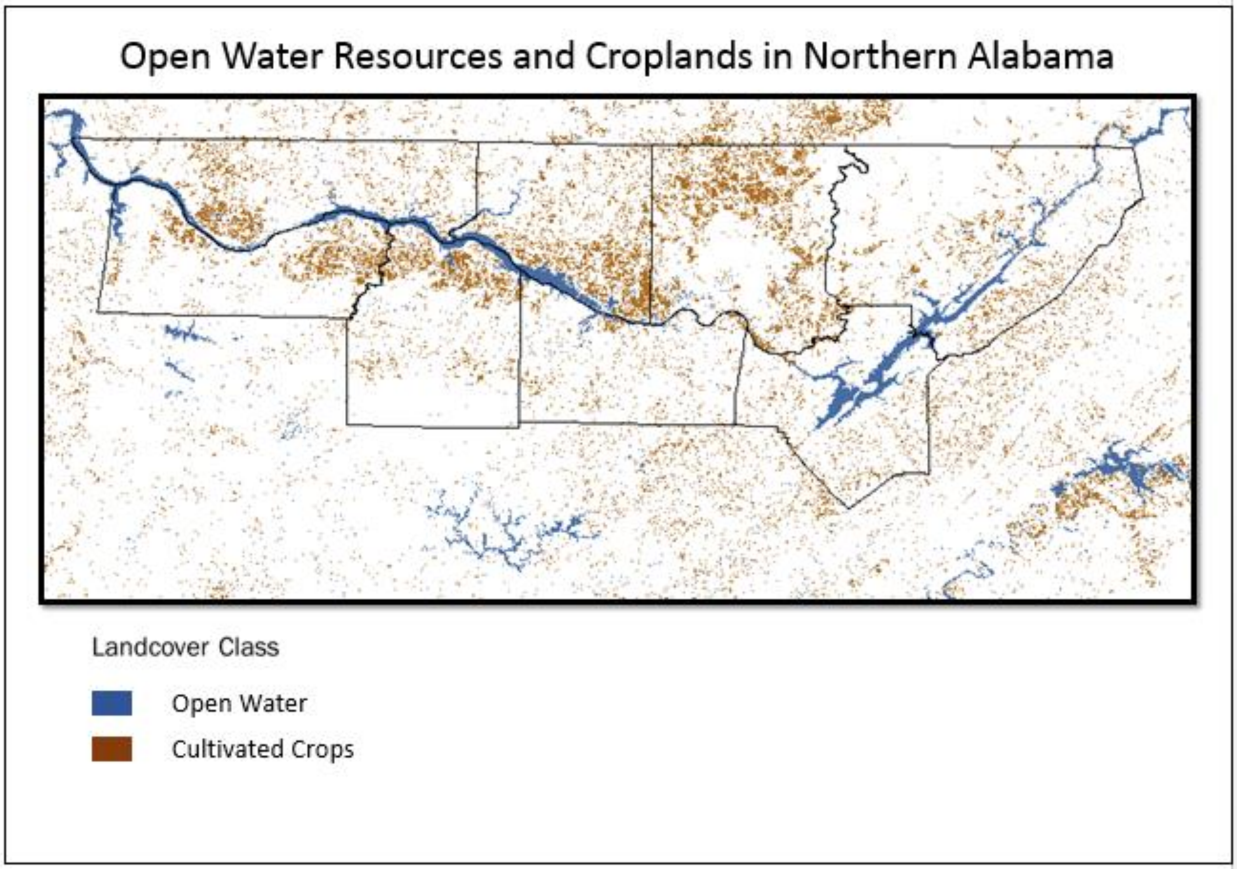

Figure 9. Landcover in Northern Alabama, 2001 Source: Homer, C. C. Huang, L. Yang, B. Wylie and M. Coan. 2004. Development of a 2001 National Landcover Database for the United States. Photogrammetric Engineering and Remote Sensing, Vol. 70, No. 7, July 2004, pp. 829-840.

Crops Studied

This research studies corn, cotton, and soybean yields. These three crops are the main crops in the study area. In 2010, the cotton production in the study area accounted for 28.2% of the total cotton production in the state; the corn production accounted for 54.62% of the total corn production in the state, and the soybean production accounted for 55.07% of the total soybean production in the state (USDA, NASS, 2011). Cotton is one of the most water-intensive crops. Seventy-three percent of global cotton is planted on irrigated land, and it takes more than 20,000 liters of water to produce 1 kg of cotton (WWF, 1999; FAO, 2012). FAO uses the yield response factor (K_y) to address the essence of the complex linkages between crop yield and water use by a crop. The larger the K_y is, the more sensitive the crop response to water deficit will be. According the FAO irrigation and drainage paper, the K_y of corn is 1.25, K_y of cotton is 0.85, and K_y of soybean is 0.85.

Data

A total of 11 years (2000 to 2010) of crop yield data for the studied crops (corn, cotton, and soybean), temperature, precipitation, evapotranspiration, and soil data were analyzed. Monthly average county-level minimum temperature, maximum temperature, precipitation, evapotranspiration data are collected from the National Oceanic and Atmospheric Administration (NOAA) (2016). The evapotranspiration data used in this research was collected from Rain Master Control System (2016), which considers a 30-year period of historical data from nationally recognized weather stations and observation systems and generated monthly average data. The default atmospheric CO_2 concentration, 359.41 ppm, was used in this simulation. For each crop, the researchers considered climate condition during the growing season. The crop yield data was collected from USDA-NASS (AgroClimate, 2016).

Modeling Methods

AquaCrop, a dynamic crop simulation model, was used to simulate the relation between crop yields and irrigation water withdrawals. The AquaCrop model is used to explore management options to improve irrigation water use efficiency, and reduce food insecurity. It also has been commonly used as a part of decision support systems by farmers, policy makers, and organizations to optimize use of the available resources, crop land and water (Steduto, et al., 2009; Araya, et al., 2010; García-Vil and Fereres, 2009). In AquaCrop, precipitation, evapotranspiration, temperature, CO_2 concentration, crop type, irrigation, field management, soil profile, and groundwater are considered. In this research, in the absence of available reported data, default CO_2 concentration, field management plans, and soil profiles were used (Steduto, et al., 2009; Raes, et al., 2009).

The AquaCrop software simulates the irrigation water withdrawals (irrigation net application). The researchers made iterative changes to net irrigation application until the reported crop yield matches the estimated crop yield in AquaCrop. Based upon the Normal Crop Progress (USDA, 2011), the AquaCrop model developed by the researchers assumes that farmers in the study area plant corn on April 1st, and harvest on August 10th The researchers also assume that farmers plant cotton on April 15th, and harvest on October 5th. Further, the AquaCrop model assumes that farms plant soybean on June 1st, and harvest on October 8th. This study investigates, using sensitivity analysis, which of the studied crops are sensitive to irrigation water withdrawals. The researchers increased the irrigation water withdrawals to increase the yields by 20%.

Results and Discussion

Modeling Results

The AquaCrop Dynamic Model simulates net irrigation application requirement, which defined as the net amount of water that must be applied by irrigation to supplement stored soil water and precipitation and supply the water required for the full yield of an irrigated crop (Döll, Siebert, 2002). The results are shown in Table 5, Table 6 and Table 7. Based on the 11 years of data and simulation results from AquaCrop, the water needed to achieve the yield of 1 ton/ha is 45 millimeter (mm) for corn, 150 mm for cotton, and 157 mm for soybean, among which 30 mm for corn, 31 mm for cotton and 106 mm for soybean comes from irrigation.

Table 5. Corn yield, irrigation net application and climate data from 2000 to 2010.

Year	Corn Yield (ton/ha)	Irrigation Net Application (mm)	Precipitation (mm)	Highest Temperature (℃)	Lowest Temperature (℃)
2000	5.5	185	103	28.7	16.3
2001	8.1	67	140	27.9	16.2
2002	6.5	198	101	28.4	16.6
2003	8.6	80	147	27.2	16.2
2004	8.4	183	116	27.6	16.3
2005	8.2	239	108	27.6	15.6
2006	4.8	243	82	29.6	16.6
2007	5.3	276	80	28.8	15.5
2008	7.1	360	97	28.2	15.6
2009	7.5	199	134	27.4	15.8
2010	7.8	306	88	29.9	17.3

Table 6. Cotton yield, irrigation net application and climate data from 2000 to 2010.

Year	Cotton Yield (ton/ha)	Irrigation Net Application (mm)	Precipitation (mm)	Highest Temperature (℃)	Lowest Temperature (℃)
2000	0.7	0	79	29.9	17.3
2001	0.9	38	140	28.2	16.8
2002	0.7	0	116	29.4	17.8
2003	1.0	52	137	28.2	16.9
2004	0.9	31	118	28.2	17.0
2005	0.9	37	98	29.1	16.9
2006	0.8	0	82	30.0	17.1
2007	0.8	0	71	30.5	17.1
2008	0.9	55	90	29.0	16.6
2009	0.9	21	135	28.0	17.1
2010	1.0	67	81	30.9	18.1

Table 7. Soybean yield, irrigation net application and climate data from 2000 to 2010.

Year	Soybean Yield (ton/ha)	Irrigation Net Application (mm)	Precipitation (mm)	Highest Temperature (℃)	Lowest Temperature (℃)
2000	1.1	94	70	31.2	18.3
2001	2.3	223	138	28.8	17.8
2002	1.6	171	109	30.6	19.5
2003	2.3	289	107	29.2	17.7
2004	2.3	218	129	28.8	17.9
2005	2.1	215	105	30.4	18.8
2006	1.3	133	74	31.0	18.1
2007	1.3	101	77	31.8	18.8
2008	2.3	270	79	30.3	17.9
2009	2.7	294	116	29.1	18.2
2010	1.8	225	73	32.1	19.2

Sensitivity Analysis

The sensitivity analysis results are shown in Table 8 and Figure 10. The results indicate that in order to achieve a 20% increase in yields, a 49%, 38%, and 75% increase in irrigation water withdrawals are needed for corn, cotton, and soybean, respectively. Based on Figure 3, precipitation affects the percentage of irrigation water needed for a 20% increase in corn yield. The relationship between precipitation and the percentage of irrigation water needed for a 20% increase in cotton and soybean is negligible. This difference is because the K_y for corn is 1.25, while K_y for cotton and soybean is 0.85 (FAO, 2012), which indicates corn is more sensitive to water.

The sources of irrigation water in 2005 and 2010 were compared in order to investigate the change of an irrigation water source over the past 5 years. It is shown in Figure 11, 13 and 13, the percentage of groundwater irrigation water withdrawal in total irrigation was increased from 29% (2005) to 48% (2010). In 2005, only 1 county, Lauderdale County, among the 8

Table 8. Percentage of irrigation water withdrawals need to achieve a 20% increase in yields for corn, cotton and soybean, from 2000 to 2010.

Year	Corn	Cotton	Soybean
2000	12%	-	49%
2001	106%	87%	35%
2002	34%	-	20%
2003	163%	56%	28%
2004	66%	84%	32%
2005	49%	78%	30%
2006	24%	-	59%
2007	10%	-	58%
2008	22%	49%	28%
2009	26%	105%	49%
2010	27%	75%	26%
Average	49%	75%	38%

counties in this study consumed more groundwater for irrigation than surface water. In 2010, 4 counties in the study area consumed more groundwater for irrigation than surface water. Marshall County, which didn't use any groundwater for irrigation in 2005, used 45% groundwater in 2010. Previous research (Howell, 2003) on irrigation costs shows that the cost of irrigation with on-farm surface water is 0 to 37 dollar/ha (0 to 15 dollar/acre), while the cost of irrigation with groundwater is 17 to 170 dollar/ha (7 to 69 dollar/acre). The increase of groundwater percentage in irrigation water withdrawals indicates the reduction of available surface water, as costs for using groundwater are typically greater. This switch from surface water to groundwater for irrigation suggests that there may be a need for IBT projects. Based upon cost comparison, the agriculturalists in the study area seem to be moving to more inefficient uses of water.

Figure 10. Irrigation water needed to achieve 120% of the original production, and precipitation from 2000 to 2010.

Figure 11. Source of irrigation withdrawals in study area, 2005 and 2010. Data source, USGS 2005, USGS 2010.

Figure 12. County-level water source of irrigation withdrawals, 2005. Data source, USGS, 2005.

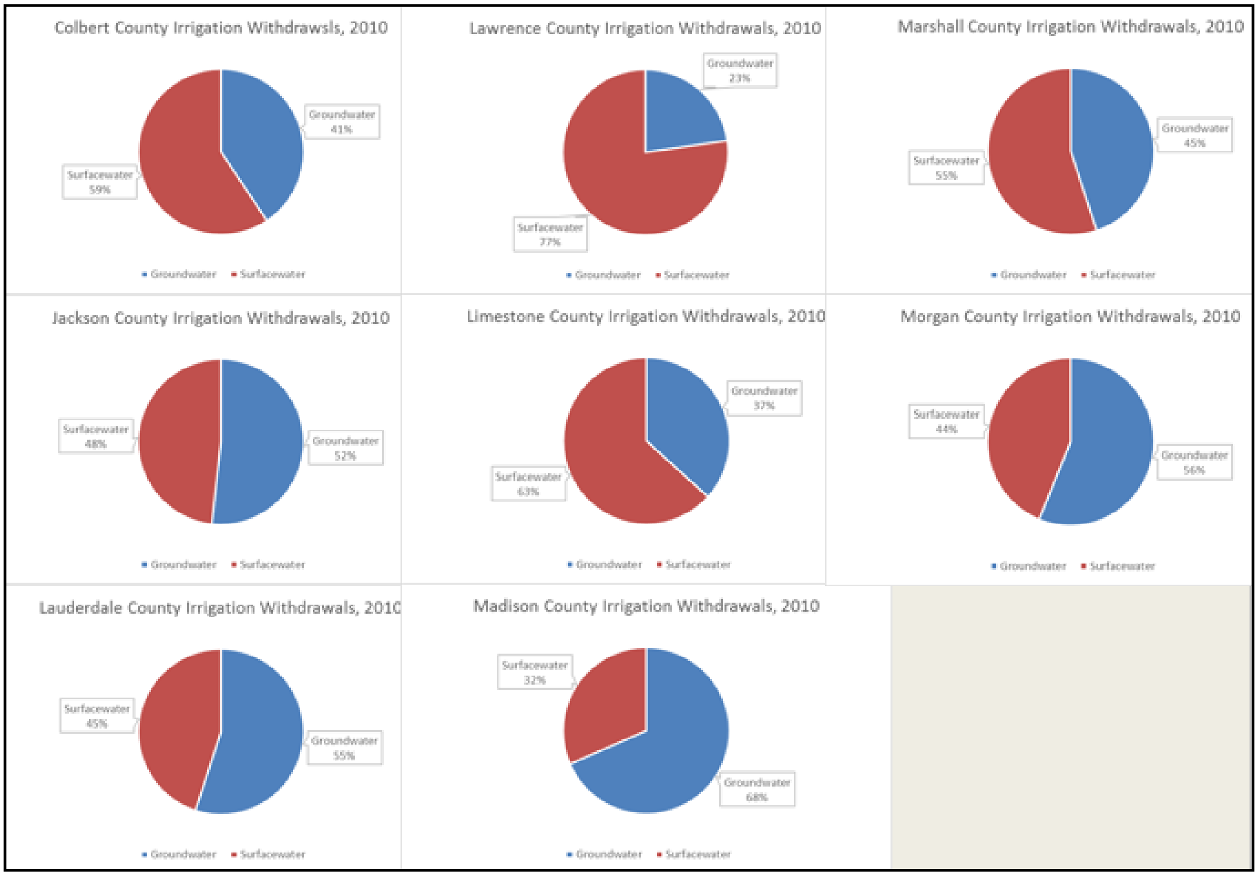

Figure 13. County-level water source of irrigation withdrawals, 2010. Data source, USGS, 2010.

Irrigation Efficiency

The irrigation systems in Alabama lack development. The percentage of irrigated cropland in Alabama is 4.1%, much lower than the national average irrigated land percentage, 16.9% (USGS, 2010; FAO, 2012). It is clear that irrigation can increase agricultural production, but whether it has net economic benefits, should be simulated with consideration of climate and other factors.

Research shows surface irrigation, sprinkler irrigation, and drip irrigation are three commonly used irrigation methods. The drip irrigation efficiency can be as high as 95%, the highest among the three methods. The efficiency range of surface irrigation, sprinkler irrigation, and drip irrigation is 55% - 87%, 70% - 90%, and 74% - 95%, respectively (FAO, 2012; Hoffman, et al., 1990; Howell, 2003). Improvements in the irrigation system can increase irrigation efficiency and save irrigation water. Additionally, minimizing leakage in the irrigation system helps to increase irrigation efficiency (Zakai and Shfaram, 1987; Giustolisi, et al., 2008)

Conclusions

IBT projects are usually large-scale, costly, and unchangeable over a short period of time. The projects associate with and can affect different interest groups, systems and communities, such as ecology system, economics, policy, and hydrology. IBT projects without appreciate regulations cause drought in donor basin, hydrologic characteristics changes, unsustainable growth, water pollution, and alternative of land cover. Based on the case studies in this research, we can conclude that:

1) regulations and laws are needed to legalize IBT projects;

2) regulations and laws should be set before IBT projects;

3) in Alabama, a state level IBT management is required to improve the water resources management plan; and

4) studies, monitoring and data collections are needed before regulate IBTs in Alabama.

In this research, researchers studied the relation among agricultural production, irrigation and climate, discussed the data should be collected when assess the cost-benefit of IBT projects. Additionally, the method of using AquaCrop to simulate irrigation water withdrawals was presented. With AquaCrop, farmers and policy makers can improve irrigation water use efficiency and optimize the available resources, crop land and water.

This study investigated the irrigation systems in northern Alabama based on data from 8 counties: Colbert, Jackson, Lauderdale, Lawrence, Limestone, Madison, Marshall, and Morgan Counties. And found out, the irrigation system in Alabama is lack of development and monitoring. The increase of using groundwater for irrigation, which costs more than using surface water for irrigation, suggests that there may be a water deficit in the study area. There is a desire to improve the irrigation systems and increase the agriculture production. In this case, IBT projects may help the study area overcome the uneven distribution of surface water resources, reduce the water deficits, support irrigation, and move to more efficient uses of water. IBT projects can bring benefit to agriculture on the premise that the transferred water is accessible to farmers. Climate, water transfer yields, and the time when water is transferred affect IBT projects' benefits to agriculture.

Through studying three main crops, corn, cotton and soybean in the study area, we conclude that under the modeled condition, the water needed to get the same yield is varied from crops; soybeans have the highest water demand among the three studied crops, 157 mm for the yield of 1 ton/ha. The irrigation water withdrawals are associated with the climate. They are mainly affected by the precipitation during the growing season. The results of sensitivity analysis indicate that crop type and climate affect the among of irrigation water need to achieve a 20% increase in yields. Among these three crops, corn and cotton are more sensitive to water than soybeans. The above outcomes indicate that when assessing benefits of IBT projects in agriculture sector, water transfer yield, climate, and crop type should be considered. The crop types and climate changed yearly, these outcomes also support the annual application of IBT permit.

Due to lack of available reported data, the default value of soil type, CO_2 concentration, and field management methods is used in this research. This may cause uncertainty in the simulated irrigation application net results. In order to get more accurate results, the specific local data should be used. This research highlight, in order to better understand and regulate IBT projects in Alabama, monitoring of existing water system and IBT projects is needed. Currently, no reported irrigation data is available in Alabama, to assess the IBT projects for irrigation, more researches should be done focus on the irrigation system in Alabama.

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CHAPTER 5 CONCLUSIONS

Overall Conclusions

This dissertation discusses the methods to develop efficient economic impact models which can take into consideration sector vulnerability and resiliency strategies in response to extreme climate events, and to provide analytical supports to decision makers in devising response strategies and developing water resources management plans. In this dissertation, through studying the economic consequences of drought induced water restriction, the economic consequences of flood impacts in public water supply systems, and the cost-benefit of IBT projects, we demonstrate impacts of water resources are multi-sector (Loucks, 2000; Van der Zaag, 2005). We conclude water outage impact assessments and the water benefit assessments are crucial for effective disaster prevention, managing the limited water resources efficiently and developing sustainable water resources management (Laugé, 2013).

This research demonstrates that the water disruption event model in our previous work can be transformed into extreme event economic analysis tools. Two extreme climate events assessment models, PyWREM and PyFECA, are developed and tested in counties in Alabama. PyWREM and PyFECA evaluate the regional economic impact of water restrictions resulting from extended drought conditions, and water contamination and outage resulting from flood conditions, respectively. These two models consider customers' behavior under extreme climate event induced water disruption and the inter-industry relationships between each industry sector. PyWREM and PyFECA offer an insight into the extreme climate event impact in 13 industrial sectors, and find out manufacturing sector, households sector, and transportation and warehousing sectors are vulnerable sectors to both drought and flood induced water disruption event, while retail trade sector is only vulnerable to flood induced water disruptions. The results in this dissertation highlight extreme climate event causes considerable impacts in public water supply system, for instance, the economic impact of flood induced water service closure are about 10% of the build damage economic loss during flood period.

This research points out the methods of using IO models and social accounting matrices to analyze water restriction events can be adapted for analysis of extreme climate event impacts in other sectors, and even for buildings and infrastructures damage during floods, earthquake, hurricanes, and tornadoes (Wein and Rose, 2011; Rose, et al., 2011; Rose and Oladosu, 2008).

This research indicates IBT projects can help the study area overcome the uneven distribution of surface water resources, reduce extreme climate impacts and water deficits, support irrigation, and move to more efficient uses of water. IBT projects are usually large-scale, costly, and unchangeable over a short period of time. The projects associate with and can affect different interest groups, systems and communities, such as ecology system, economics, policy, and hydrology. A state-level IBT regulation is highly recommended to help reduce the impact of IBT projects and increase the benefit of IBT projects.

Through studying three main crops, corn, cotton and soybean in the study area, we conclude that under the modeled condition, the water needed to get the same yield is varied from crops. Among these three crops, corn and cotton are more sensitive to water than soybeans. Climate during the growing season, mainly the precipitation, impacts the irrigation water withdrawals. Above outcomes indicate that when assessing IBT projects, benefits and impacts in agriculture sector, climate, and crop type should be considered. The crop types and climate changed yearly, these outcomes also support the annual application of IBT permit.

The three topics addressed in this dissertation, by analyzing the economic impact of losing water service and the economic benefits of IBT projects, provide analytical support to decision makers in managing limited water resources. The results also provide analytical support to policy makers and water resource managers so that they may better develop strategies for reducing economic loss before drought and floods occur, and increasing the economic value of water in IBT projects.

Additional Research

The evaluation of economic value of water, though difficult and complicated, can facilitate reallocation of water supplies to meet growing demands, offer analytical support to overcome water supply problems (Faux & Perry, 1999; Gibbons, 2013; Steinnes, 1992; Young, & Loomis, 2014). Ward (2002) and Young (2014) suggested information on economic value of water enables decision makers to make informed choices on water development, conservation, allocation, and use when growing demands for all uses are made in the face of increased scarcity. Further research can focus on widening the application of the methods and improving the accuracy of the models.

Widen Application

Firstly, the economic assessment methods used in this research, coupled with additional surveys, can be applied to other extreme climate events, such as earthquake and tsunami, and updated to assess the economic consequence during reconstruction period. Secondly, water is a public good such as fisheries habitat, water quality and recreational use (Young, & Loomis, 2014). The evaluation of the economic value of water should not be limited to agriculture, industry, and household sectors, but consider the value to ecosystems and recreation (De Groot, et al., 2002; Loomis, et al., 2000). Thirdly, the application of this dissertation work to integrated water management and sustainable water resources management can be a topic of further research (Biswas, 2004; Bouwer, 2000).

Improved Accuracy

The two extreme climate event economic consequence assessment models, PyWREM and PyFECA, are developed on the water disruption event model, ECAT. The survey data within ECAT is based on water disruptions. Surveys of business and household responses to drought induced water restriction and flood induced water outage are necessary to refine PyWREM and PyFECA estimates, and to improve the accuracy of PyWREM and PyFECA. The sensitivity analysis within this research indicates that the survey should focus on household expenditure, water storage activities, and child care usage. In addition, interindustry linkages during flood period and reconstruction period should be investigated. To achieve a comprehensive drought and flood socioeconomic impact model, additional research should investigate the impacts of drought and flood on other non-agriculture sectors, such as tourism and recreation, and plant nurseries. The reliability and vulnerability of water supply system during extreme climate events is another topic of further research. Better understanding and increased resiliency of the operation of water supply systems during extreme climate events will help reduce negative impacts (Chou & Wu, 2010; Hashimoto, et al., 1982; Jinno, 1995; Shih& ReVelle, 1994).

Due to the lack of available reported data, only default values of soil type, CO_2 concentration, and field management methods is used in this research. This reduces the precision of the simulated irrigation application net results. In order to get more reliable results, specific local data should be used. Currently, no reported irrigation data is available in Alabama, the monitoring of irrigated agricultural production helps to assess the benefit of IBT projects for agricultural production. This research within this dissertation using the agriculture sector as an example to discuss the possible benefits from IBT projects and the factors should be considered when assessing the feasibility of an IBT project. In order to establish an IBT regulatory mechanism in Alabama, future research should investigate the IBT impact in other industrial sectors.

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APPENDIX

NAICS

The North American Industry Classification System (NAICS) is the standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy.

Python

Python is a widely used high-level programming language for general-purpose programming. An interpreted language, Python has a design philosophy which emphasizes code readability (notably using whitespace indentation to delimit code blocks rather than curly braces or keywords), and a syntax which allows programmers to express concepts in fewer lines of code than possible in languages such as C++ or Java. The language provides constructs intended to enable writing clear programs on both a small and large scale.