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Value Focused Inland Waterway Infrastructure Investment Decisions

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Value Focused Inland Waterway Infrastructure Investment Decisions

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By

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Abstract

Maritime transportation functions as the backbone of world trade. The U.S. inland waterway transportation system is comprised of 12,000 miles of navigable waterways that connect and move freight between the global supply chain and thirty eight States. When investing in inland waterway infrastructure, we should aim to maximize all benefits associated with the investment including flood protection, water supply, hydropower generation, recreation, and environmental impact benefits. We formulate an initial qualitative value model for the inland waterway infrastructure investment decision based on a value-focused thinking approach which allows us to holistically evaluate project investment alternatives. Given limited resources, a portfolio optimization model is formulated to maximize the total value associated with the project investments while considering budget and minimally acceptable benefit constraints. To demonstrate application of our developed approach, we present a case study based on the McClellan Kerr Arkansas River Navigation System.

Acknowledgments

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Lastly, I would like to thank my advisor Dr. Heather Nachtmann for her support and help during the past 20 months. I also would like to express my gratitude to her and to Dr. Ed Pohl and Dr. Greg Parnell for serving on my Thesis Committee and supporting me in this research.

Dedication

I would like to dedicate this thesis to my family who have always motivated me and believed in me. Lalla Nezha Abouelfaraj, Abdellah, Mohamed, and Salma Boudhoum, thank you for being the awesome family that you are. I would also like to dedicate this to every faculty member at the University of Arkansas who helped shape my academic career.

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1. Introduction

1.1 Maritime Transportation

Maritime transportation functions as the backbone of world trade. Approximately 80% of world trade by volume and approximately 70% by value are transported by sea (United States Conference on Trade and Development (UNCTAD), 2014). Seaborne trade reached a total volume of 9.6 billion tons in 2013 accounting for a total of 500 billion ton-miles (UNCTAD, 2014). Economically developed countries' imports accounted for 38% of total imports transported by water, in comparison with 60% for developing countries and 2% for emerging economies. Developing countries accounted for the majority of exports using water transportation with 61% of total volume, and developed countries accounted for 33% (UNCTAD, 2014).

In 2011, a total of 1.34 billion tons of waterborne freight valued at $1.73 trillion was imported to and exported from the United States (U.S.) (Chambers, 2012). Maritime transportation contributed more than $36 billion to the U.S. economy in 2010 and directly and indirectly supported thirteen million jobs. In 2011, the maritime transportation system accounted for 95% of the U.S. foreign trade by volume (Chambers, 2012). Maritime transportation accounted for 53% and 38% of U.S. import and export values as shown in Figure 1 (Chambers, 2012).

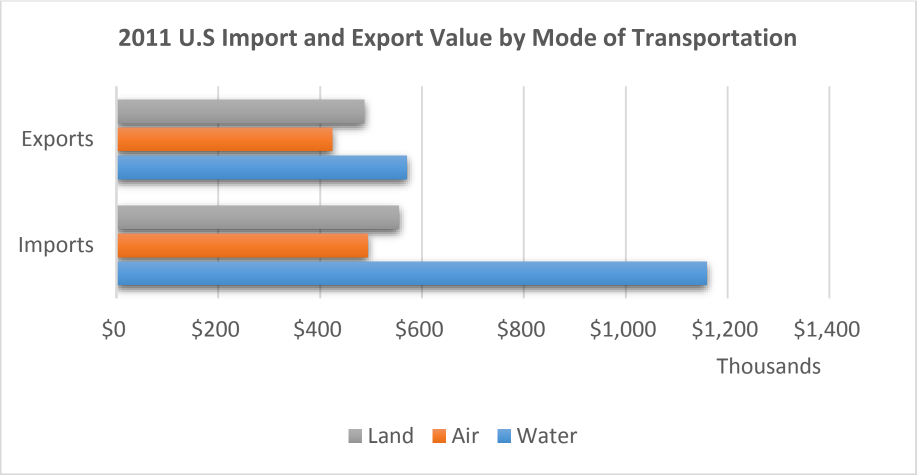

Figure 1: U.S import and export value by mode (Chambers, 2012)

The inland waterway system (IWS) of the U.S. is comprised of 25,000 miles of navigable rivers and canals. Twelve thousand miles of navigable waterways are used for navigation purposes, facilitated by approximately 200 lock chambers (Texas Transportation Institute (TTI), 2014). The inland waterway system connects and moves freight to and from thirty eight states. Each year, approximately 624 million tons of cargo is carried throughout the inland waterways, which constitutes 14% of all intercity freight. Figure 2 represents the scale of intercity freight based on mode of transportation in 2010. Use of these navigation channels helped to avoid 58 million truck trips which would have double the number of trucks on the road (TTI, 2014). In 2010, the cargo transported on the U.S. IWS had a value of $70 billion. In 2010, the economic output of the total U.S. maritime industry is estimated to be over $100 billion. In 2010, the U.S maritime industry supported 500,000 jobs and provided more than 33,000 jobs aboard its vessels and barges alone (American Waterways Operators, 2013).

Figure 2: Freight flows by highway, railroad, and waterway (U.S. Department of Transportation, 2013)

The IWS is commonly used to transport coal, petroleum and petroleum products, crude materials, food and farm products, and chemicals (World Wide Inland Navigation Network, nd.). Figure 3 represents a breakdown of the freight transported by the U.S. IWS.

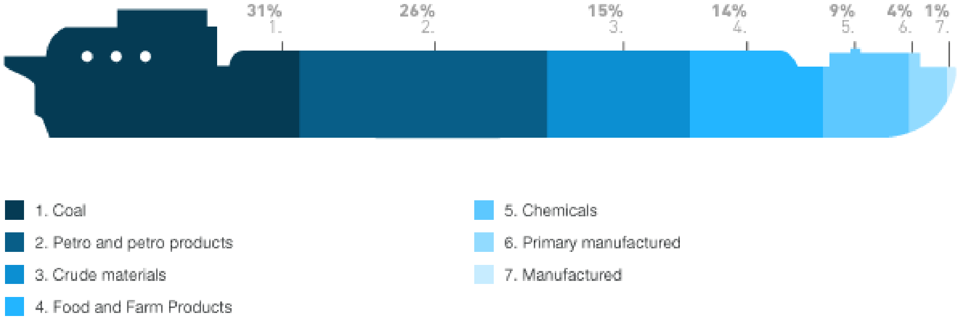

Figure 3: Breakdown of freight transported in inland waterways in 2010 (World Wide Inland Navigation Network, n.d.)

Along with providing a low cost, reliable, and environmental friendly mode of transportation, inland waterways provide other ancillary benefits including flood protection, water supply, hydropower generation, recreation, and environmental benefits. A wide range of consumers benefit from the pools of water created to facilitate navigation (U.S. Government Accountability Office, 2011).

Flood protection is considered a key benefit of the inland waterways. Dams and reservoirs are used to regulate the rivers' levels and flooding downstream by holding the excess of water temporarily and releasing it later. The U.S. Army Corps of Engineers (USACE) estimated the damages avoided by their flood risk management program in 2010 to be approximately $23 billion (USACE, 2013-1).

The inland waterways are an important supplier of water used for commercial and industrial uses, irrigation, and drinking water. A reliable and effective water supply is necessary for a functioning economy. The USACE sustains many water supply projects across the United States. In 2010, 135 out of the 380 reservoir projects overseen by the USACE included a water supply function. The water storage space is estimated to be 9.67 million acre-feet which has a potential yield of up to 6,385 million gallons a day (USACE, 2013-1).

Hydropower is considered the largest source of renewable energy in the U.S., supplying approximately 52% of the total renewable energy and 6% of the electricity to the nation. As of 2010, 257 billion kilowatt-hours were produced by hydroelectric sources (U.S. Energy Information Administration, 2011). Figure 4 is a map of the geographical distribution of the hydropower plants across the United States (USACE, 2013-2). The USACE is considered the largest operator of hydroelectric plants with a total production of 68 billion kilowatt-hours per year, which is enough energy to serve approximately 10 million households. One key benefit of hydropower generation is its low cost. Hydroelectric plants do not require fuel to produce electricity, which decreases their operating costs. Hydropower keeps electricity costs low, which has a positive influence on the economy. Hydropower plants are able to convert 90% of the energy in falling water into electric power, which is far more efficient than the other power generation alternatives which lose more than half of their energy content as shown in Figure 5. In addition to being low cost and efficient, hydropower is considered an environmental friendly, reliable, and flexible source of energy (USACE, 2013-2)

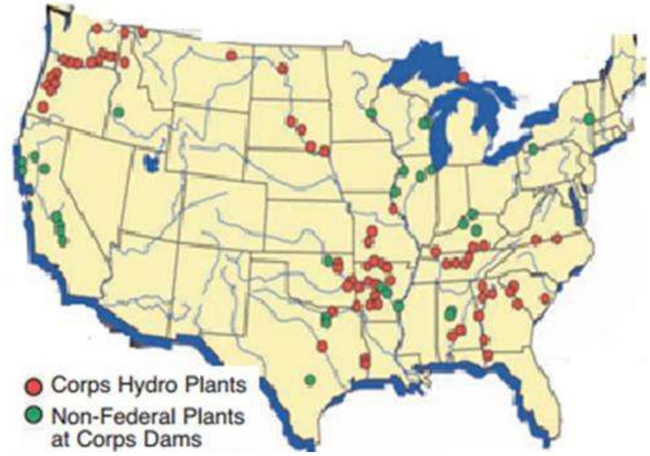

Figure 4: U.S. hydroelectric plants (USACE, 2013-2)

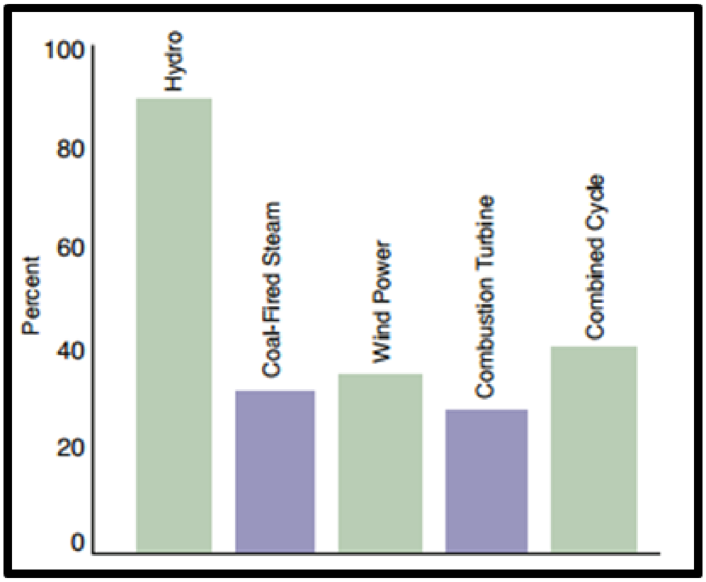

Figure 5: Efficiency of power generating alternatives (USACE, 2013-2)

The inland waterways provide many recreational opportunities including fishing, boating, and hiking. The USACE is considered the largest federal provider of outdoor recreation. USACE projects attract approximately 370 million visits with approximately 10% of the U.S. population visiting a USACE project at least once a year. These recreational projects generate $18 billion annually and sustain approximately 350,000 jobs. The USACE aims to provide “quality outdoor public recreation experiences to serve the needs of present and future generations and contribute to the quality of American life, while managing and conserving natural resources consistent with ecosystem management principles.” (USACE, 2010).

Waterway transportation is considered the cheapest mode of transportation. It leads to a total annual savings of $7 billion in the transportation costs nationwide. It costs 0.72 cents per ton mile for a barge in comparison with 26.62 cents for a large semi-truck (Guler et al., 2012). As seen in Figure 6, water transportation is considered a fuel efficient mode of transportation as one gallon of fuel can move a ton of freight 576 miles by barge in comparison with 155 miles by truck (TTI, 2012). Figure 7 shows that one barge can carry the equivalent of 58 large semi-trucks, and a one 15 barge tow can carry as much as 870 large semi-trucks, which helps relieve road congestion (Iowa Department of Transportation, 2008). Traffic on the inland waterways is equivalent to 58 million truck trip per year (Oklahoma Department of Transportation, 2014).

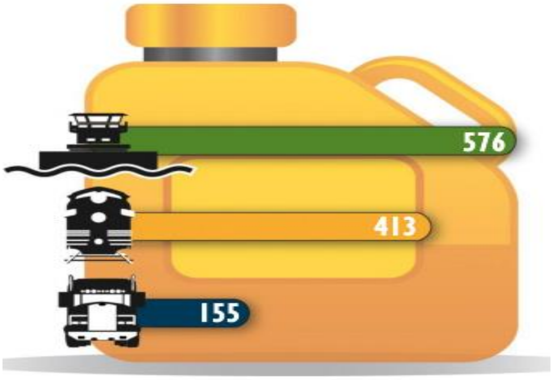

Figure 6: Fuel-efficiency of different modes of transportation (TTI, 2012)

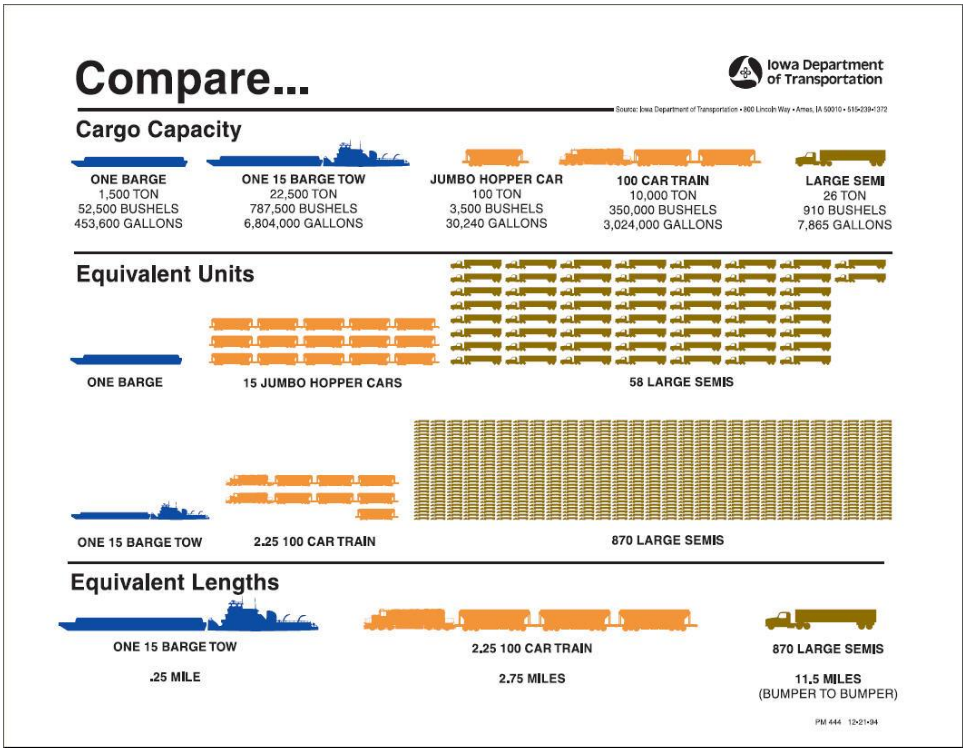

Figure 7: Comparison of cargo capacity (Iowa Department of Transportation, 2008)

If the IWS is maintained, we will continue to keep waterborne commerce moving, preserve recreational benefit, provide a clean, efficient, and low cost energy source, provide water supply for personal, industrial, and irrigation uses, and preserve the assets from flooding damages. Without the IWS, our roads would be more congested, the cost of energy would likely increase, and many jobs will be lost.

1.2 Value Focused Thinking

In this section, we will begin with an overview of the value focused thinking (VFT) methodology (Keeney, 1992) in general, and then summarize the characteristics of research efforts that have employed the technique. Generally, decisions are made based on the alternatives available for consideration. This approach, generally referred to as alternative-focused thinking (AFT), will solve the problem, but “a price is paid later when the consequences accrue” (Keeney, 1992). When using AFT, you first come up with the available alternatives and then choose the best option; while the VFT approach consists of determining your goal first and then determining how best to achieve it (Keeney, 1992). Value focused thinking consists of three major ideas: “start with values, use values to generate better alternatives, and use values to evaluate these alternatives” (Parnell, 2007). Keeney (1992) identified nine benefits of the VFT method as shown in Figure 8.

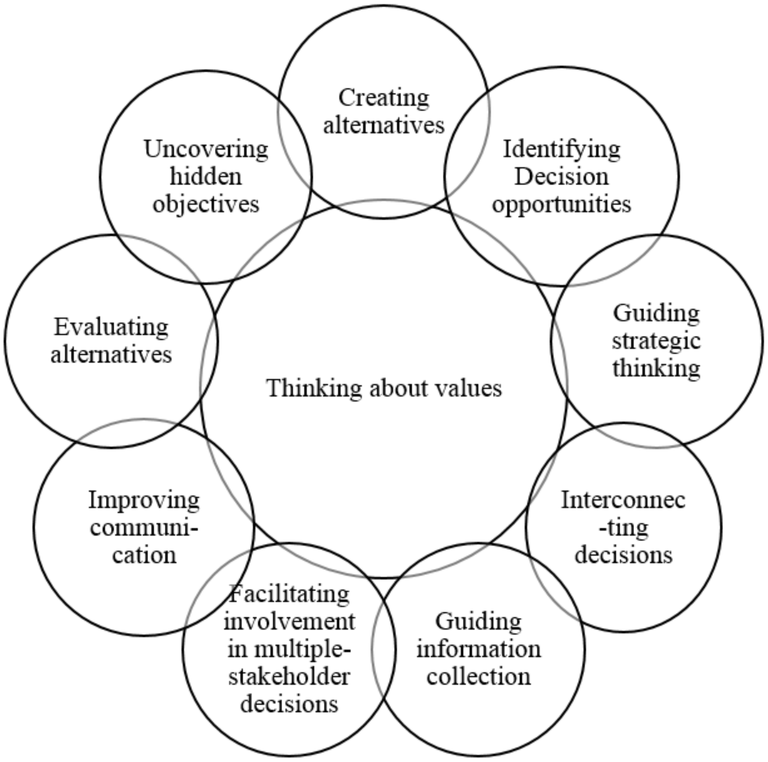

Figure 8: VFT benefits (Keeney, 1992)

Recently, Parnell et al. (2013) published a VFT literature survey paper. According to Parnell et al. (2013), eighty-nine VFT articles have been published in twenty-nine different journals. The majority of articles (58/89) were application articles where VFT was used in a diverse set of problem domains with defense being the largest domain. Figure 9 constitutes a breakdown of the application domains of articles employing the VFT methodology (Parnell et al., 2013).

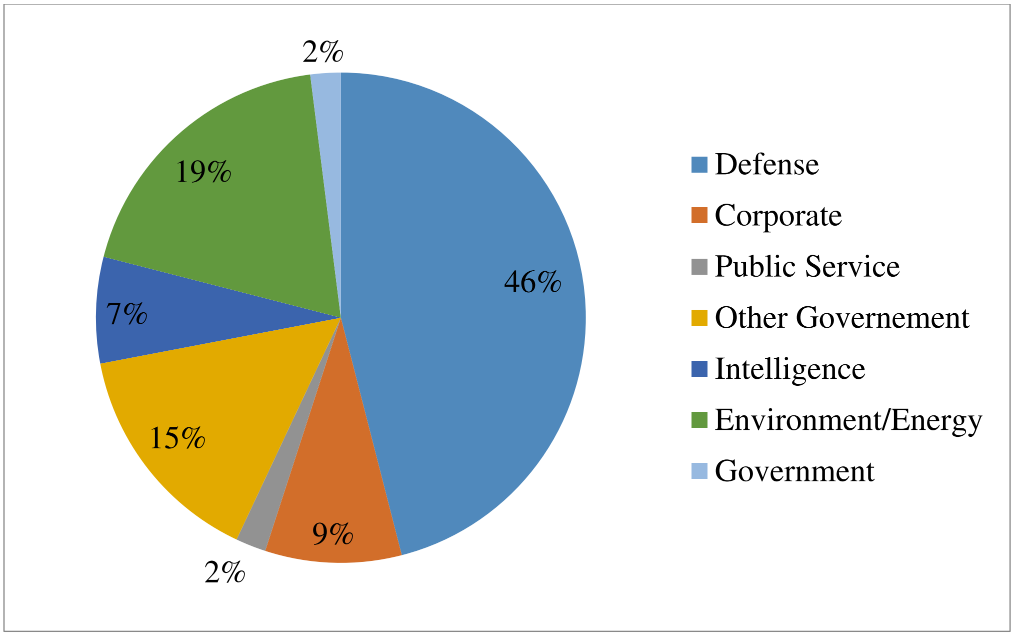

Figure 9: VFT literature application domains (Parnell et al., 2013)

Kirkwood (1997) defines the five desirable properties of value hierarchies as complete, non-redundant, decomposable, operable, and few in number. Figure 10 is a breakdown of the number of values measured in the application studies surveyed by Parnell et al. (2013). The range of value measures used in these articles ranged from two to 256 with an average of thirty and a median of seventeen. Eleven articles did not describe the number of value measures used.

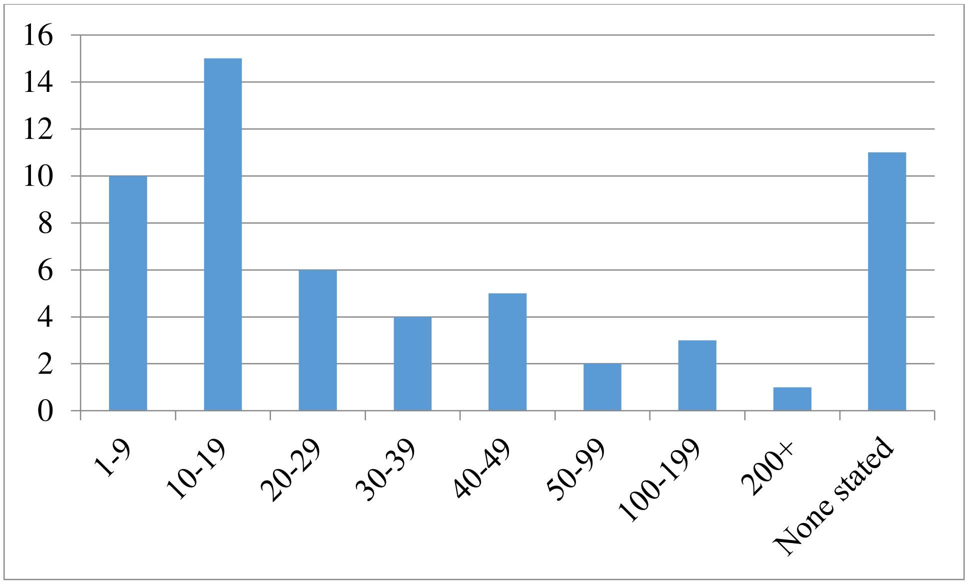

Figure 10: Number of value measures surveyed in VFT literature (Parnell et al., 2013)

Parnell et al. (2013) determined that resources were not considered in 46% of the application articles surveyed, while 23% considered resources as part of their value hierarchy and 31% considered resources separately from the value hierarchy. Figure 11 represents a breakdown of how resources were considered in the value models found in the literature (Parnell et al., 2013).

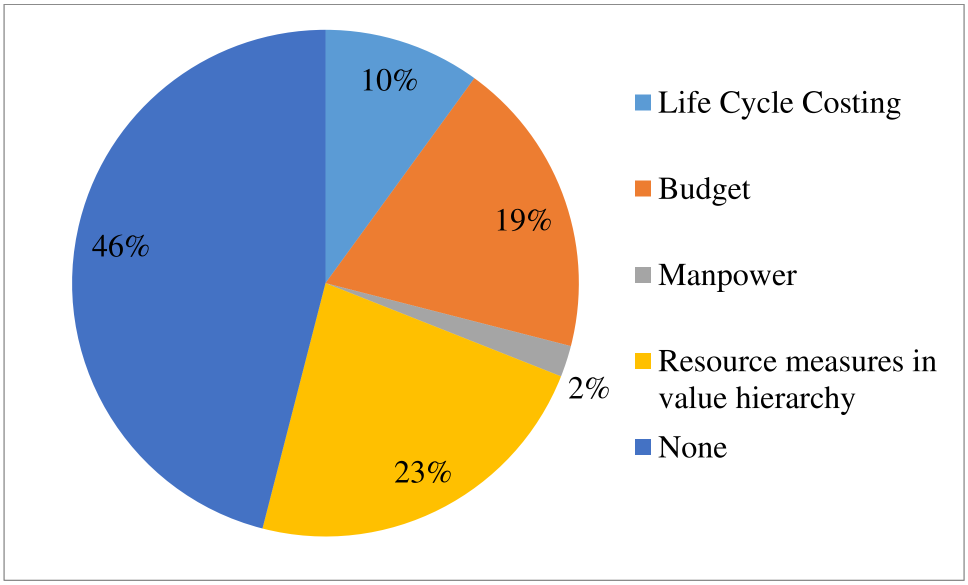

Figure 11: Use of resources in VFT literature (Parnell et al., 2013)

We examined the VFT literature specifically related to the transportation, logistics, and supply chain (TLSC) area. Tong et al. (2013) published a survey paper of VFT literature within the application domain of TLSC. According to Tong et al. (2013), the VFT methodology is not widely implemented in the TLSC area. Tong et al. (2013) identified and reviewed seven studies that implemented VFT in the TLSC area. Table 1 is directly retrieved from Tong et al. (2013) and represents a matrix that summarizes seven studies that use the VFT philosophy in projects that touches the TLSC area.

Table 1: Tong et al. (2013) literature assessment matrix

	Neiger, Rotaru & Churilov, 2009	Olson & Wu, 2010	Jordan, 2012	Nachtmann & Pohl, 2013	Axtell, 2011	Katzer, 2002	Winthrop, 1999
Publication	Journal	Book Chapter	Dissertation	Journal	Thesis	Thesis	Thesis
Authors	Australia	U.S.	U.S.	U.S.	U.S.	U.S.	U.S.
Year of publication	2009	2010	2012	2012	2011	2002	1999
Type of study	Theory	Theory/ Case study	Theory/ Case study	Theory/ Case study	Theory/ Case study	Theory/ Case study	Theory/ Case study
Problem domain	Supply chain	Supply chain	Supply chain	Transportation	Transportation	Transportation	Transportation
Clients	Corporate leaders	Corporate leaders	Corporate leaders	Government policy makers	Military leaders	Military leaders	Military leaders
Alternatives by VFT	N/A	Previously known	Previously known	Previously known	Previously known	Previously known	Previously known
Value/Utility model	N/A	Value model	Value model	Value model	Value model	Value model	Value model
Number of measures	N/A	12 (Case study)	8 (Case study)	8 (Model)	29 (Model)	10 (Model)	31 (Model)

1.3 Research Motivation

A preliminary report states that “a wide range of consumers benefit from the pools of water created and operated to facilitate commercial navigation and other uses, but commercial navigation itself appears to be a relatively small beneficiary of this system” (U.S. Government Accountability Office, 2011). Water navigation is an important factor in determining the value of the IWS; however, a failure of the inland waterways will impact more people than anticipated when the transportation system was originally conceived. Nachtmann (2007) argues that the value of inland waterways should be evaluated based on additional factors such as flood protection, water supply, recreation and tourism, and hydropower generation. Sudar (2005) argues that while economic measures are important, nontraditional benefits should be taken into consideration when evaluating the performance of an inland waterway and when making investment decisions to improve the system. While some tangible benefits are easily associated with economic value, other more intangible benefits are not.

In general, when making an investment, we should aim for the ‘biggest bang for the buck.’ However, due to the fact that IWS investment benefits are not limited to its transportation impacts but should also consider other social and environmental benefits, it is difficult to quantify the total value of these investment decisions. Quantifying the total value of the investment will depend on what the decision maker values. While an environmentalist may place more value on environmental benefits, an economist will likely care more about the economic value of the investment. One of the challenges associated with this method is how to measure non-traditional benefits (Walker, 2007). The challenge is how to quantify the value of an inland waterway investment alternative while considering relevant ancillary benefits.

1.4 Research Objective

When investing in inland waterway infrastructure, we should aim to maximize all benefits associated with the investment. The ancillary benefits along with the transportation benefits associated with the IWS are the focus of our IWS infrastructure investment decision. We formulate an initial qualitative value model for the inland waterway infrastructure investment decision utilizing the initial stage in the VFT philosophy (Keeney, 1992). This value model contains the values that the decision maker cares about when investing in inland waterway infrastructure. Creating a value hierarchy for the IWS infrastructure investment decision allows us to holistically evaluate investment alternatives while considering transportation and ancillary benefits. Given the fact that decision makers have limited resources to invest in inland waterway infrastructure, a portfolio optimization model (Salo et al., 2011) is formulated to maximize the overall value associated with inland waterway infrastructure investments while taking in consideration the budgetary constraints and the minimum desirable value measures outcome constraints.

2. Methodology

The methodology used this research is summarized in Table 2, which outlines the tasks that were completed in order to achieve our research objective.

Table 2: Proposed methodology

Task	Description
1. Literature Review	1a. Review relevant literature on Value Focused Thinking 1b. Review literature related to IWS values and benefits
2. Model Development	2a. Develop the qualitative value model for the IWS infrastructure investment decision 2b. Develop portfolio optimization model to maximize the value of IWS infrastructure investment decisions
3. Data Collection	3a. Collect model data relevant to the McClellan-Kerr Arkansas River system (MKARNS)
4. Case Study Analysis	4a. Conduct MKARNS case study analysis

2.1 Literature Review

Our VFT literature review is primarily based on two recent survey papers, Parnell et al. (2013) and Tong et al. (2013) (Section 1.2) . We also reviewed the literature related to the ancillary benefits of inland waterways (Section 2.2- step 2 and 3).

2.2 Model Development

Subtask 2a of Model Development Task 2 is to develop the qualitative value model for the IWS infrastructure investment decision. In order to develop the qualitative value model, we followed the first four modeling steps defined by Parnell (2007) as shown in Figure 12.

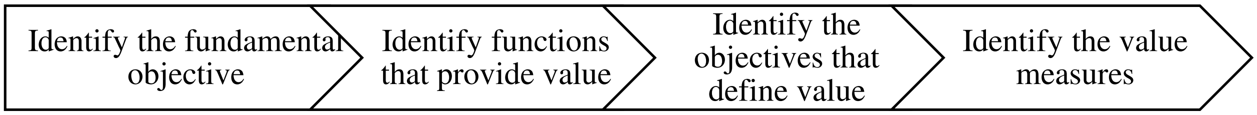

Figure 12: Steps to develop value hierarchy (Parnell, 2007)

Step 1: Identify Fundamental Objective

Identifying the reason why a decision must be made was the first step in developing our qualitative VFT model. As stated in Section 1.4, when making an investment decision related to IWS infrastructure, one should aim to maximize all benefits associated with the investment by accounting not only for economic value but also for other ancillary benefits.

Steps 2 and 3: Identify Functions and Objectives

Parnell (2007) states that we can identify the functions that provide value from gold standard sources (existing documents) or develop them using functional analysis. In order to determine the functions, a diagram (see Figure 14) was developed to identify the functions and objectives that provide value. While brainstorming and organizing our gold standard data, a certain amount of redundancy was generated, but Keeney (1992) states that it is easier to recognize redundant values if they are explicitly listed than identify the missing ones.

Jacobs Engineering U.K. (2011) provides a comprehensive list of inland waterways benefits using an ecosystem approach. He classified the benefits from inland waterways into three main categories as shown in Table 3.

Table 3: Benefits of inland waterways (Jacobs Engineering U.K., 2011)

Provisioning	**Regulating**	**Cultural Services**
• Creation of business opportunities • Property premium • Renewable energy • Transport • Provision of water • Volunteering	• Carbon savings • Flood protection • Water regulation • Water quality	• Recreation • Community benefits • Visual amenity • Non-use values

A study of the inland waterways in England (Town and Country Planning Association, 2009) views inland waterways as a form of multi-functional green infrastructure. Interventions and investments made into IWS infrastructure can create many benefits as summarized in Figure 13.

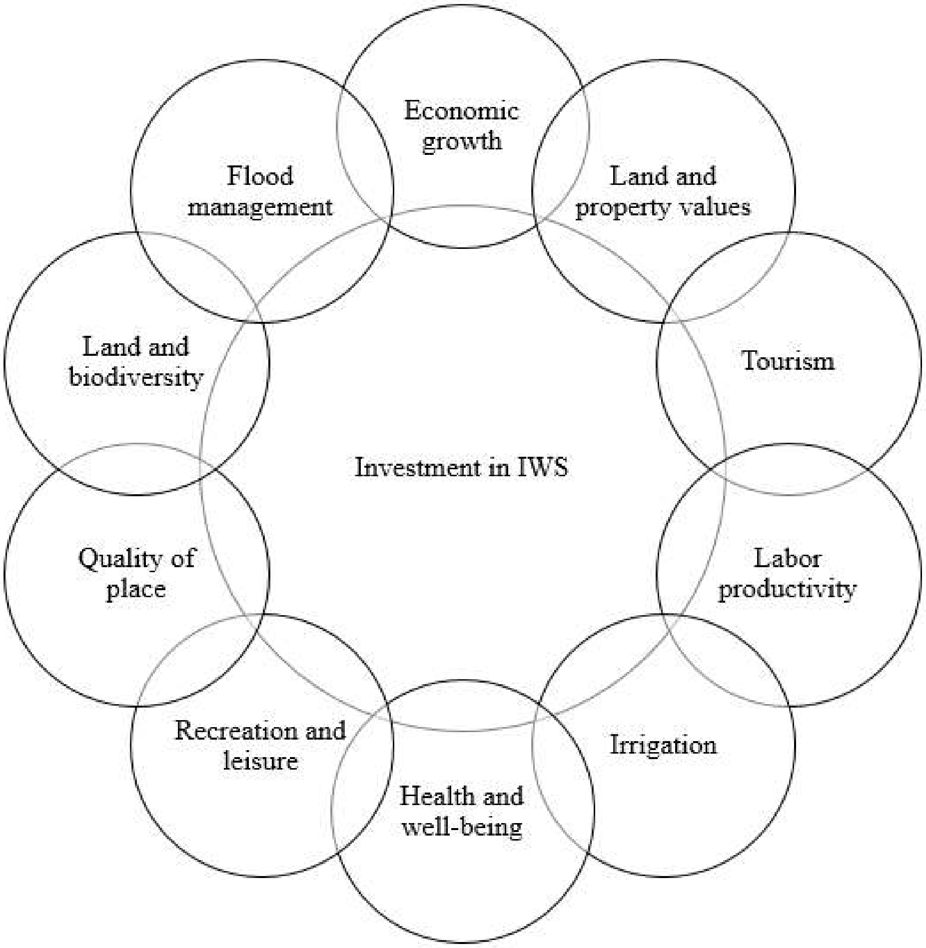

Figure 13: Benefits of inland waterways. (Town and Country Planning Association, 2009)

In her study of the Ouachita River, Nachtmann (2007) stated that this inland waterway contributes to the region through recreational benefits, water supply, electrical generation, and environmental effects. Bray et al. (2011) presents a set of benefits that can help stakeholders make comparisons of the many categories of inland waterways beneficiaries. They defined a set of benefits that can be organized into ten groups: navigation, recreation, flood protection, hydropower generation, irrigation, water supply, sewage assimilation (savings in treatment costs due to the higher pool levels required for navigation), property values, congestion reduction, and environmental impacts.

An affinity diagram can be an effective tool to derive the functions, objectives, and supporting objectives of the IWS infrastructure investment decision. This diagram will enable us to effectively derive mutually exclusive objectives and supportive objectives. Figure 14 represents the summary developed in order to summarize the main functions and objectives for our decision problem.

Maintain the environment	Provisioning	Provide cultural services
• Flood protection • Fish and wild life	• Transport • Water supply • Renewable energy	• Recreation

Figure 14: Objectives of the IWS infrastructure investment decision

Once we finalized our VFT hierarchy, we combined our VFT model with portfolio optimization in order to maximize the Benefit associated with our investment decisions related to IWS infrastructure.

Step 4: Identify the Value Measures

Value measures are used as metrics to evaluate the degree of attainment of a given value (Kirkwood, 1997). Kirkwood (1997) identified value measures as being two dimensional. The first dimension deals with the alignment of the measure with the objective as direct or proxy. A direct scale directly measures “the degree of attainment of an objective,” while proxy measures are used to reflect “the degree of attainment of its associated objective but does not directly measure the value” (Kirkwood, 1997). For example, Miles per Gallon could be a direct measure of automobile fuel efficiency; while it would be a proxy measure of the time that it takes to empty a full tank of fuel. The second dimension deals with the type of measure. Measures can be either natural or constructed. Many measures have natural scale, such as dollars for measuring cost, but others do not have natural scale such as customer satisfaction. Table 4 represents the preferences of Parnell (2007) for the types of measures.

Table 4: Types of measures preference Parnell (2007)

Type	Direct Alignment	Proxy Alignment
Natural	1	3
Constructed	2	4

In Table 5, we describe the value measure used for all the objectives and the type of measure used.

Table 5: Value measures used

Objective	Value Measures	Type
Flood protection	Storage Capacity (acre-ft)	Direct alignment- Natural
Environmental Impact (Fish and Wildlife)	Number of Endangered and threatened species to be affected	Direct alignment- Constructed
Transportation	Tons transported	Direct alignment- Natural
Water supply	Yield in million gallons per day(mgd)	Direct alignment- Natural
Energy Production	Kilowatt-hours generated	Direct alignment- Natural
Recreation	Number of visitors	Proxy alignment- Natural

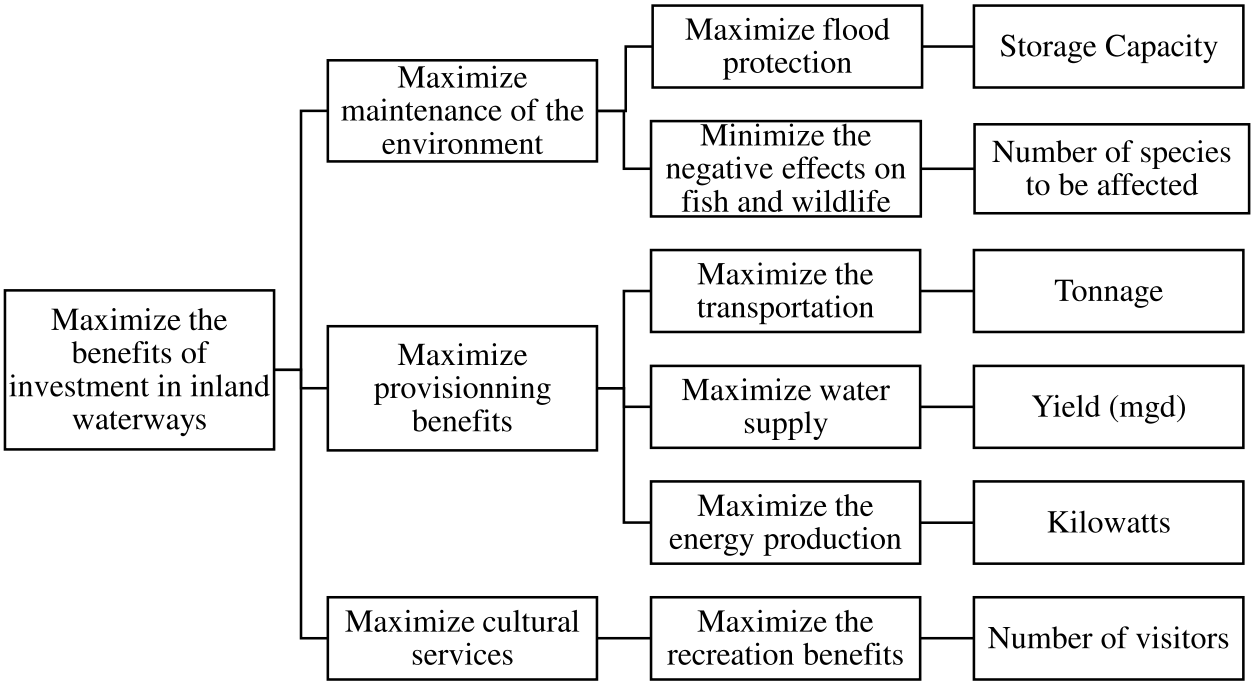

Figure 15: Basic value hierarchy

We believe that IWS stakeholders may place different levels of importance (weight) on each of the objectives. We identified six primary IWS stakeholders:

- Environmental agencies
- Cargo shippers/ cargo carriers
- Port authorities/ terminal owners
- Department of parks and tourism
- Utility companies
- Local communities.

To allow for multiple stakeholder viewpoints, we developed our value hierarchy to account for multiple stakeholder values. Figure 16 represents the value hierarchy used in our VFT modeling.

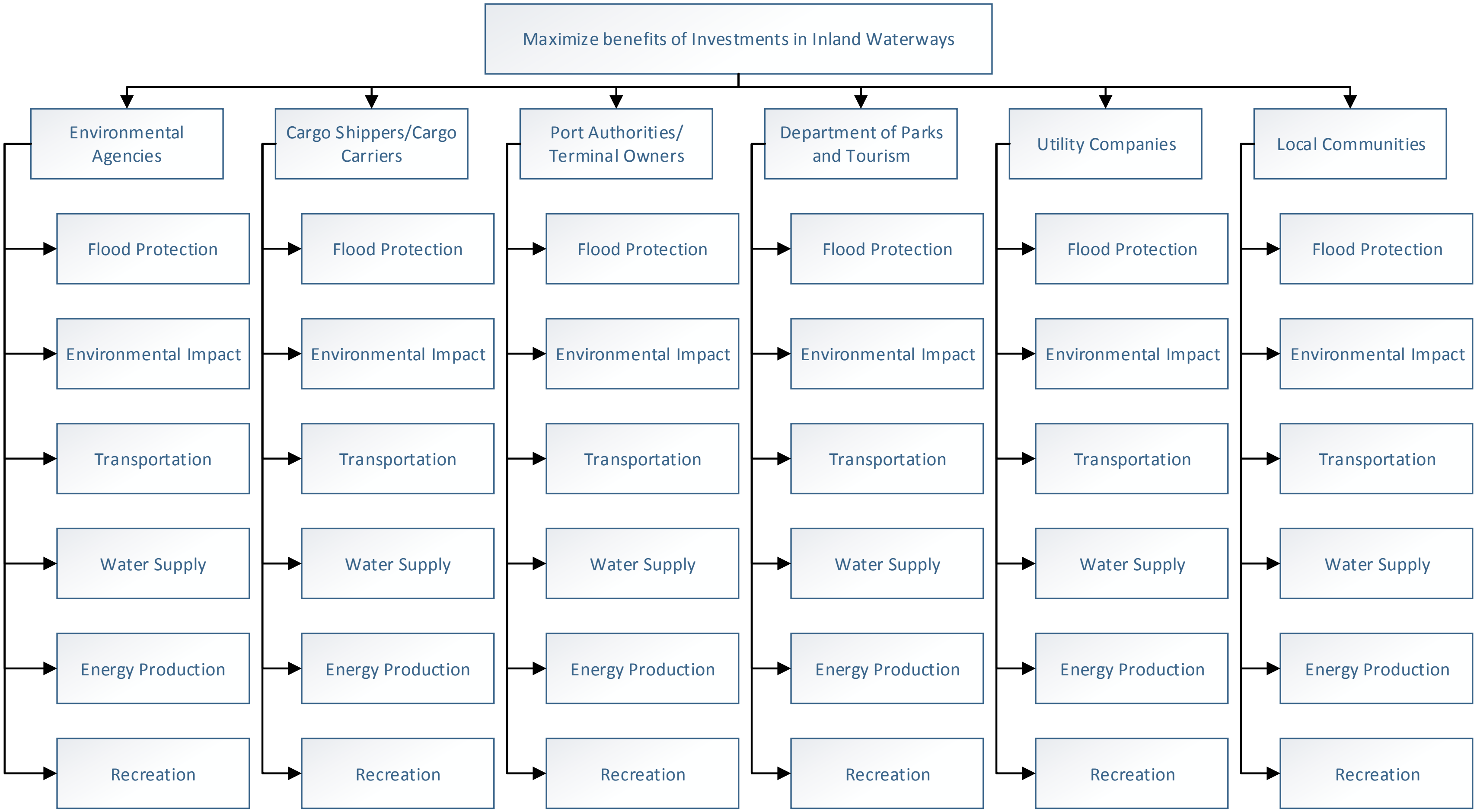

Figure 16: Value hierarchy including stakeholders

3. Case Study Development

The McClellan-Kerr Arkansas Navigation System (MKARNS) is a 445 mile navigation system originating from the Tulsa Port of Catoosa. The MKARNS flows in the southeast direction from Oklahoma through Arkansas to the Mississippi River. Approximately 308 miles of the MKARNS is located in Arkansas, while 137 miles are situated in Oklahoma (King, 2012). In 2011, the total tonnage throughout the entire MKARNS was approximately 10.6 million tons with a value of $3.1 billion (Oklahoma Department of Transportation, 2014). Approximately 105,808 railcars or 423,230 semi-trucks would be needed to transport an equivalent tonnage (Oklahoma Department of Transportation, 2014). There is a 420 foot drop in elevation from the Port of Catoosa to the Mississippi River. A series of eighteen locks and dams (L/Ds) was established to facilitate cargo transportation (King, 2012). In addition to economic freight transportation benefits, the system of L/Ds provides numerous ancillary benefits. Figure 17 represents the locks and dams in the MKARNS:

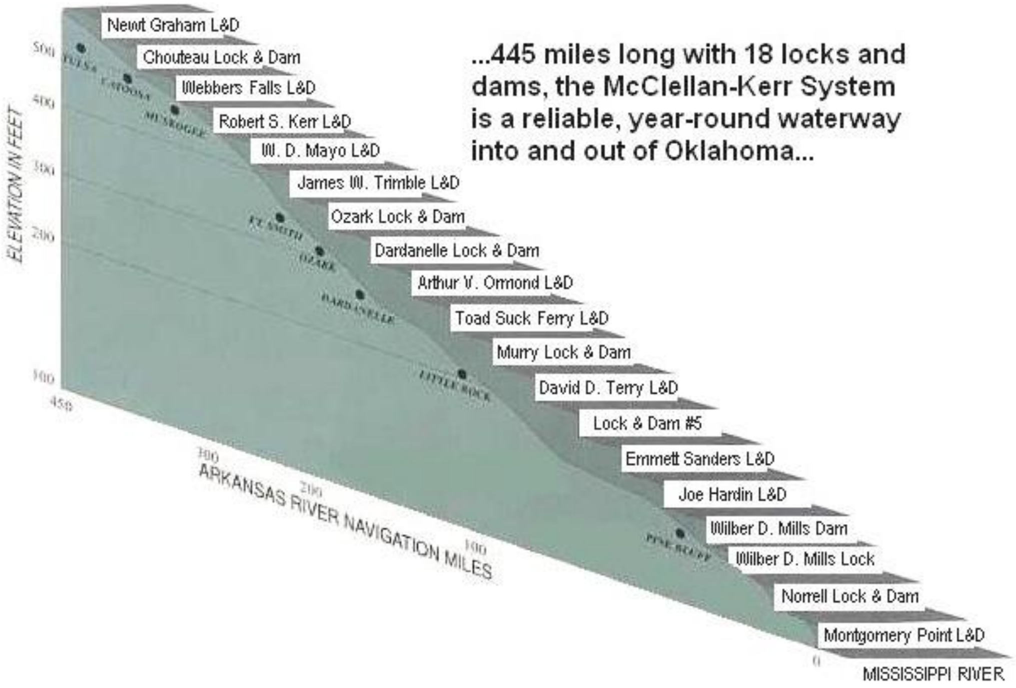

Figure 17: MKARNS lock lift (King, 2012)

The MKARNS is also composed of reservoirs that have the capacity to control flows on the MKARNS and contribute to the multipurpose activities of the system (USACE, 2005). A report from the USACE identifies eleven reservoirs in the Oklahoma section of the MKARNS and two in Arkansas (USACE, 2005). These reservoirs provide flood protection, water supply, power generation, and recreation benefits. (USACE, 2005). Figure 18 represents a map of the MKARNS L/D and the reservoirs projects under study in this case study. Table 6 represents a list of the projects under consideration in the case study.

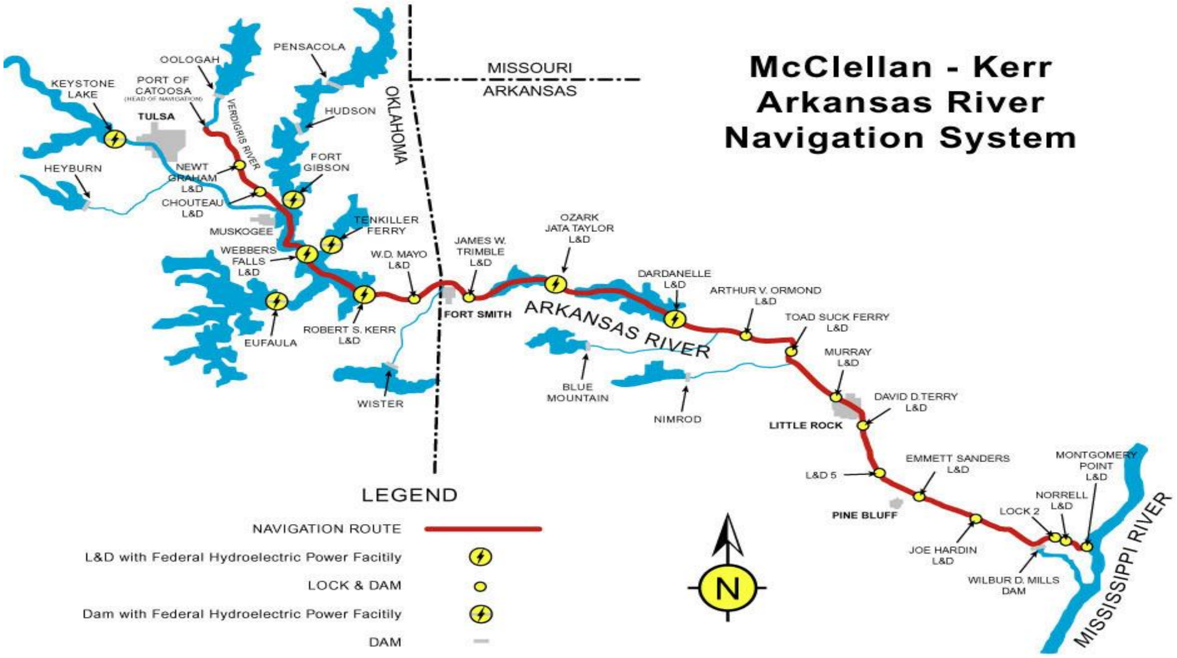

Figure 18: Map of MKARNS project locations (USACE, 2005

Table 6: List of case study projects, type, and state location

State	MKARNS Project	Type of Project
Arkansas	Norrell L&D	L/D
	Arkansas L&D 2	L/D
	Emmett Sanders L&D	L/D
	Joe Hardin L&D	L/D
	Arkansas L&D 5	L/D
	David D Terry L&D	L/D
	Toad Suck Ferry L&D	L/D
	Murray L&D	L/D
	Dardanelle L&D	L/D
	Arthur V Ormond L&D	L/D
	Ozark-JetaTaylor L&D	L/D
	James W Trimble L&D	L/D
	Blue Mountain	Reservoir
	Nimrod	Reservoir
Oklahoma	Robert S Kerr L&D	L/D
	W D Mayo L&D	L/D
	Webbers Falls L&D	L/D
	Newt Graham L&D	L/D
	Chouteau L&D	L/D
	Keystone	Reservoir
	Oologah	Reservoir
	Pensacola Dam	Reservoir
	Markham Ferry Dam	Reservoir
	Fort Gibson	Reservoir
	Tenkiller Ferry	Reservoir
	Eufaula	Reservoir
	Kaw	Reservoir
	Hulah	Reservoir
	Copan	Reservoir
	Wister	Reservoir

3.1 Flood Protection

The Oklahoma upstream reservoirs and the two Arkansas reservoirs provide flood protection and water supply benefits. The pools of the MKARNS L/D projects are used to keep the water levels in the river deep enough for the navigation and are not used for any type of flood protection (USACE, n.d.). Table 7 provides the flood control pool storage capacities in acre-feet for each MKARNS project with a flood protection benefit.

Table 7: MKARNS Project flood control pool storage capacity in acre-ft (USACE, 2005) (USACE, n.d.)

MKARNS Project	Type of Project	Flood Control Pool Storage Capacity (acre-ft)
Keystone	Reservoir	1,167,232
Oologah	Reservoir	1,007,060
Pensacola Dam	Reservoir	525,000
Markham Ferry Dam	Reservoir	244,210
Fort Gibson	Reservoir	919,200
Tenkiller Ferry	Reservoir	576,700
Eufaula	Reservoir	1,511,000
Kaw	Reservoir	919,400
Hulah	Reservoir	257,932
Copan	Reservoir	184,318
Wister	Reservoir	366,056
Blue Mountain	Reservoir	257,900
Nimrod	Reservoir	307,000

3.2 Environmental Impact

In order to account for the environmental impact of the IWS, we used the threatened and endangered species living in the area as our value measure. A report by the USACE identifies the "threatened" and "endangered" species living in the MKARNS region (USACE, 2005). The list of endangered and threatened species is given at the county level, so we matched the L/D projects to the counties they are located in to identify the number of species living in the project area. Endangered species refers to the species facing extinction; while threatened species are species that are likely to become endangered. Table 8 represents the number of endangered and threatened species located at each MKARNS project.

Table 8: Number of endangered and threatened species for each MKARNS project (USACE, 2005)

MKARNS Project	Type of Project	# of Endangered Species	# of Threatened Species
NorrellL&D	L/D	1	1
Arkansas L&D 2	L/D	1	1
Emmett Sanders L&D	L/D	1	1
Joe Hardin L&D	L/D	1	1
Arkansas L&D 5	L/D	1	1
David D Terry L&D	L/D	2	0
Toad Suck Ferry L&D	L/D	1	0
Murray L&D	L/D	2	0
Dardanelle L&D	L/D	2	0
Arthur V Ormond L&D	L/D	2	0
Ozark-JetaTaylor L&D	L/D	2	1
James W Trimble L&D	L/D	2	1
Blue Mountain	Reservoir	2	2
Nimrod	Reservoir	4	0
Robert S Kerr L&D	L/D	2	2
W D Mayo L&D	L/D	3	2
Webbers Falls L&D	L/D	2	2
Newt Graham L&D	L/D	3	2
Chouteau L&D	L/D	3	2
Keystone	Reservoir	1	2
Oologah	Reservoir	3	2
Pensacola Dam	Reservoir	0	3
Markham Ferry Dam	Reservoir	0	3
Fort Gibson	Reservoir	3	2
Tenkiller Ferry	Reservoir	4	2
Eufaula	Reservoir	1	2
Kaw	Reservoir	1	1
Hulah	Reservoir	2	2
Copan	Reservoir	1	2
Wister	Reservoir	3	2

3.3 Transportation

The MKARNS L/Ds are approximately 110 feet wide and 600 feet long. Five L/Ds (L/D 12 and 13 in Arkansas and L/Ds 14, 17, and 18 in Oklahoma) were classified as low use based on 2010 data (USACE, 2013-3). The Montgomery Point L/D is not used frequently as it is submerged during high water conditions and is only used when the Mississippi River elevation is low

(USACE, 2005). Freight traffic through the MKARNS varies from L/D to L/D as shown in Figure 19, which represents the upbound and downbound tonnages (in thousand tons) for each of the eighteen MKARNS L/Ds (Waterways Council, 2013).

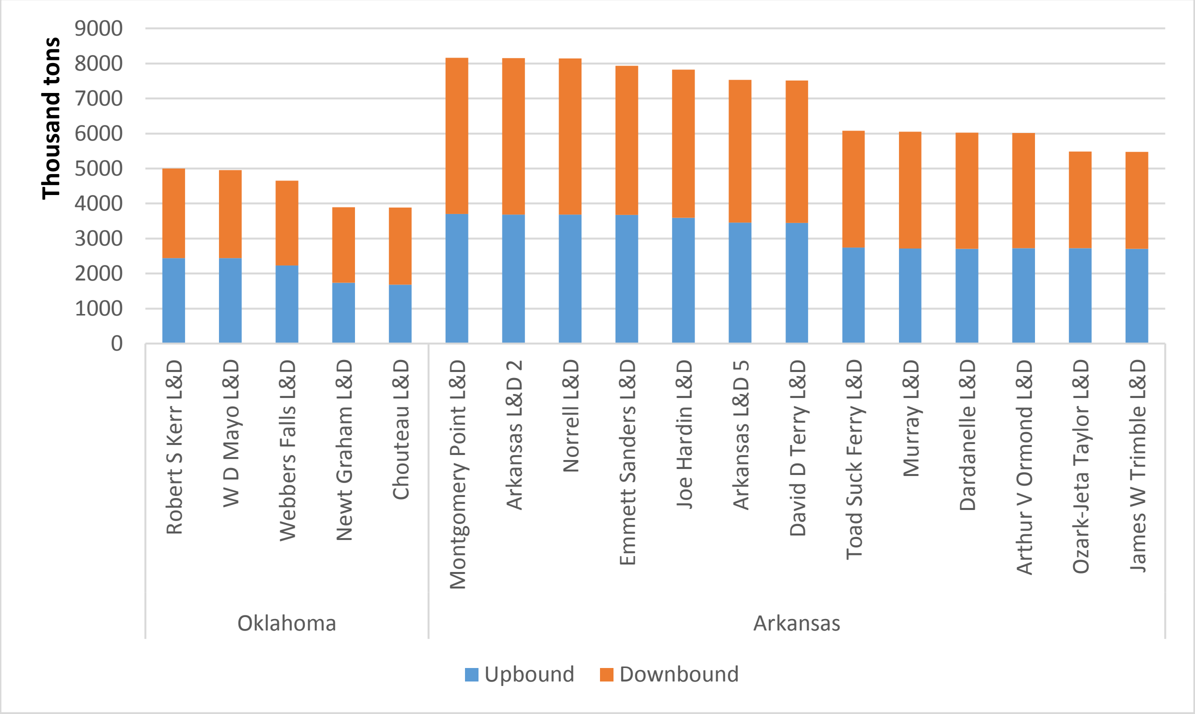

Figure 19: 2011 tonnages (in thousand tons) through each MKARNS L/D

3.4 Water Supply

In order to determine the MKARNS projects that provide water supply benefit, we used the USACE website. Many USACE projects play an important role in fulfilling and sustaining water supply needs. Table 9 represents the MKARNS projects that have a water supply purpose and their associated yield in millions gallons per day:

Table 9: Water supply MKARNS projects with yield in millions gallons per day (USACE, 2013 - 4)

MKARNS Project	Type of Project	Total Project Yield (mgd)
Keystone	Reservoir	14.5
Oologah	Reservoir	136.6
Tenkiller Ferry	Reservoir	26.8
Eufaula	Reservoir	53.5
Kaw	Reservoir	167.1
Hulah	Reservoir	12.4
Copan	Reservoir	2
Wister	Reservoir	19.5
Blue Mountain	Reservoir	2
Nimrod	L/D	0.3
Dardanelle L&D	L/D	1100

3.5 Energy Production

Along the MKARNS, there are eight hydropower plants, six located in Arkansas and two located in Oklahoma. An additional six hydropower plants are installed in the reservoirs associated with the MKARNS. In the Arkansas portion of the MKARNS, the USACE originally constructed two hydroelectric facilities as part of the MKARNS. These hydroelectric plants are the Ozark-Jetta Taylor powerhouse and the Dardanelle. Due to increasing energy costs, four additional hydroelectric facilities were constructed at existing locks and dams on the MKARNS post-initial construction. Three of the new facilities were sponsored by the Arkansas Electric Cooperative Corporation (Ellis, Whillock, and Dam 2); while the Murray facility was developed by the city of North Little Rock. In the Oklahoma portion of the MKARNS, two hydropower plants were installed in Robert S. Kerr and Webber Falls reservoirs, which are operated by the USACE (Reynolds, 2013). Four of the plants located in MKARNS reservoirs are also operated by the USACE (Keystone, Fort Gibson, Tenkiller Ferry, and Eufala). The Kaw hydroelectric plant is run by Oklahoma Municipal Power Authority, and the Pensacola Dam is operated by the Grand

River Dam Authority. Table 10 represents the installed capacity (in Kilowatts (KWs)) of each MKARNS project with hydropower capability.

Table 10: MKARNS Projects with hydropower installed capacity in Kilowatts (USACE, 2005)

MKARNS Project	Type of Project	Installed Hydropower Capacity (KWs)
Arkansas L&D 2	L/D	108,000
Murray L&D	L/D	39,000
Dardanelle L&D	L/D	148,000
Arthur V Ormond L&D	L/D	32,400
Ozark-Jeta Taylor L&D	L/D	100,000
James W Trimble L&D	L/D	32,400
Robert S Kerr L&D	L/D	110,000
Webbers Falls L&D	L/D	60,000
Keystone	Reservoir	70,000
Pensacola Dam	Reservoir	96,000
Fort Gibson	Reservoir	45,000
Tenkiller Ferry	Reservoir	39,100
Eufaula	Reservoir	90,000
Kaw	Reservoir	25,600

3.6 Recreation

The MKARNS created important lakes that are considered recreational havens for outdoor recreation users. Lakes and parks play an important role in the tourism-based economy in Arkansas. According to USACE (2012-1), the Little Rock Corps of Engineers district is ranked in the top five Corps districts based on recreational project visitation. In 2011, 3,547 recreational vessels locked through the thirteen locks on the Arkansas portion of the MKARNS; while 1,134 recreational vessels locked through the Oklahoma locks (King, 2012). Table 11 provides the USACE estimates of the number of visits to the L/D recreation spots alongside the MKARNS and the reservoirs associated with the MKARNS.

Table 11: MKARNS projects with number of recreational visitors (USACE, 2012-2)

MKARNS Project	Type of project	# of Recreational Visitors
Norrell L&D	L/D	23,702
Arkansas L&D 2	L/D	142,694
Emmett Sanders L&D	L/D	256,564
Joe Hardin L&D	L/D	38,506
Arkansas L&D 5	L/D	163,320
David D Terry L&D	L/D	1,256,852
Toad Suck Ferry L&D	L/D	146,983
Murray L&D	L/D	461,504
Dardanelle L&D	L/D	1,304,569
Arthur V Ormond L&D	L/D	74,187
Ozark-JetaTaylor L&D	L/D	519,159
James W Trimble L&D	L/D	473,808
Blue Mountain	Reservoir	405,025
Nimrod	Reservoir	226,048
Robert S Kerr L&D	L/D	271,719
W D Mayo L&D	L/D	48,921
Webbers Falls L&D	L/D	663,913
Newt Graham L&D	L/D	123,019
Chouteau L&D	L/D	95,036
Keystone	Reservoir	1,062,635
Oologah	Reservoir	894,978
Pensacola Dam	Reservoir	167,467
Markham Ferry Dam	Reservoir	167,467
Fort Gibson	Reservoir	1,677,535
Tenkiller Ferry	Reservoir	2,583,915
Eufaula	Reservoir	2,466,286
Kaw	Reservoir	155,102
Hulah	Reservoir	59,350
Copan	Reservoir	52,311
Wister	Reservoir	205,815

4. Model Development

4.1 Development of the Value Functions

The value functions measure the returns to scale of the value measures. According to Parnell (2007), the value functions can take on four shapes: linear, convex, concave, and S-curve. In our study, we assume that each increment of the measure is equally valuable for flood protection, transportation, water supply, energy production, and recreation. Therefore, we represent their value function as linear in shape. Figures 20 to 24 represent the value function of each value measure associated with our objective.

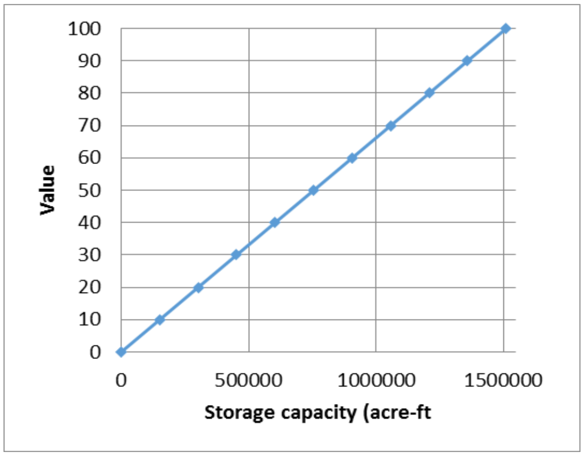

Figure 20: Flood protection value function

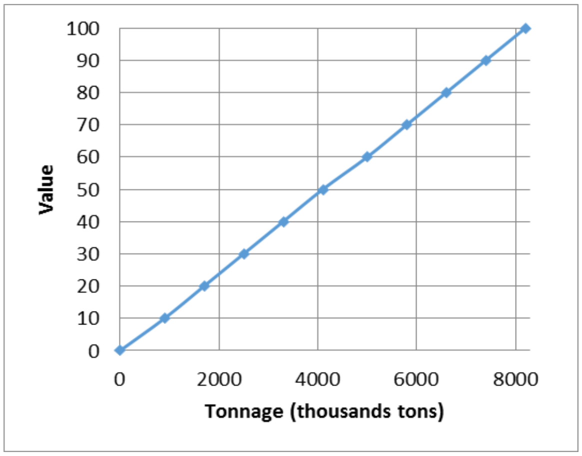

Figure 21 :Transportation value function

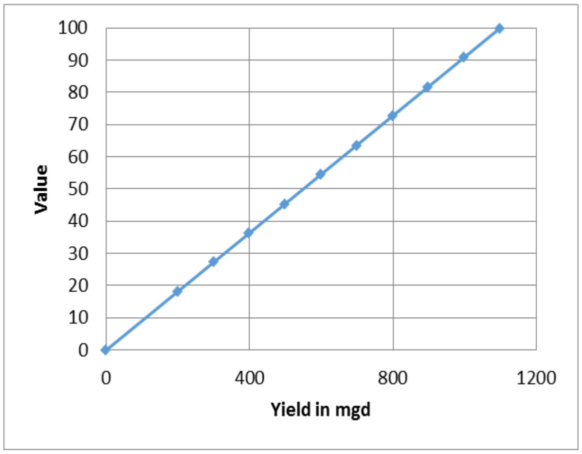

Figure 22: Water supply Value Function

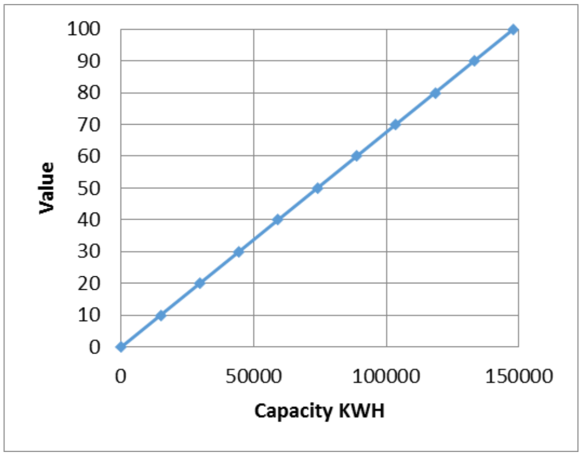

Figure 23: Energy production value function

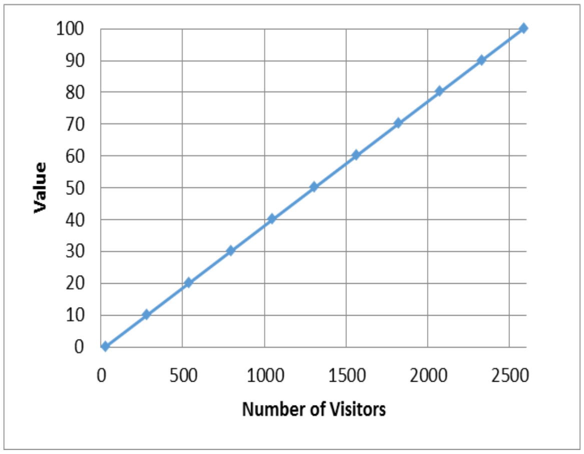

Figure 24: Recreation value function

Given a lack of directly representative data, we construct a value function for the environmental impact value measure based on the number of endangered and threatened species. We establish a constructed scale ranging from 1 to 5 as shown in Table 12.

Table 12: Evaluation measure for environmental impact

Score	Description
5	No endangered species and less than two threatened species
4	No endangered species and more than two threatened species
3	Less than two endangered species and less than two threatened species
2	Less than two endangered species and more than two threatened species
1	More than two endangered species and more than two threatened species

4.2 Additive Model

In order to evaluate the total value (Benefit) of the MKARNS projects, we apply an additive model which is widely used. We weight each value measure in the value hierarchy based on its importance and variance. We sent an explanatory document to representatives from the six stakeholder groups and then conducted phone interviews to assess their weights. We used the swing weighting method to determine the weights of each objective (Kirkwood, 1997). For each stakeholder, the weights are normalized to sum to 1(equation 2). Let α_j be represents the importance of each of the stakeholder weight, w_{ji} the weight for objective *i* for stakeholder *j,* and $\upsilon(x_i)$ is the single dimensional value function that converts the evaluation measure to a common value scale (Parnell, 2005) represented by Figures 20 to 24. The value function $\upsilon(\alpha_j, x_i)$ allows us to score the alternatives and is defined by Equation (1).

$$\mathrm{V}(\alpha\mathrm{j}, x\mathrm{i}) = \sum_j \sum_i \alpha_j \, \mathrm{w}_{ji} \, \upsilon(x_i) \qquad (1)$$

Such as

$$\sum_i w_{ji} = 1 \quad \forall j \in stakeholders \qquad (2)$$

$$\sum_j \alpha_j = 1 \qquad (3)$$

In order to obtain the weights for each stakeholder group, we attempted to conduct phone interviews with at least one representative of each group. Each stakeholder was asked to provide an assessment f_{ij} of the importance of each objective *i* between 0 and 10, while taking in consideration the ranges attainable on each objective (Kirkwood, 1997). After the assessments f_{ij} were collected or assumed for all objectives *i* for each stakeholder *j*, the weights were normalized so that their sum is equal to 1 for each stakeholder *j*, by using Equation (4):

$$w_{ji} = \frac{f_{ij}}{\sum_i f_{ij}} \quad \forall j \in stakeholder \qquad (4)$$

Tables 13 to 18 represent the assessments f_{ij} and their associated weights w_{ij} for each stakeholder *j*. As date of submission, we have received weights from two stakeholder groups, department of parks and tourism and port authorities/ terminal owners. At this time, we have assumed weights for the other four stakeholder groups and are continuing to contact these stakeholders. We plan to rerun the analysis once additional expert assessments are received.

Table 13: Values assessments and weights for environmental agencies

Values	Assessment f_{ij}	Weight w_{ij}
Flood protection	8	21.05%
Environmental impact	10	26.32%
Transportation	3	7.89%
Water supply	7	18.42%
Energy production	5	13.16%
Recreation	5	13.16%

Table 14: Values assessments and weights for cargo shippers/cargo carriers

Values	Assessment f_{ij}	Weight w_{ij}
Flood protection	9	26.47%
Environmental impact	3	8.82%
Transportation	10	29.41%
Water supply	5	14.71%
Energy production	6	17.65%
Recreation	1	2.94%

Table 15: Values assessments and weights for local communities

Values	Assessment f_{ij}	Weight w_{ij}
Flood protection	10	22.22%
Environmental impact	5	11.11%
Transportation	5	11.11%
Water supply	8	17.78%
Energy production	7	15.56%
Recreation	10	22.22%

Table 16: Values assessments and weights for port authorities/ terminal owners

Values	Assessment f_{ij}	Weight w_{ij}
Flood protection	7	18.92%
Environmental impact	5	13.51%
Transportation	4	10.81%
Water supply	10	27.03%
Energy production	10	27.03%
Recreation	1	2.70%

Table 17: Values assessments and weights for department of parks and tourism

Values	Assessment f_{ij}	Weight w_{ij}
Flood protection	9	21.43%
Environmental impact	7	16.67%
Transportation	7	16.67%
Water supply	6	14.29%
Energy production	3	7.14%
Recreation	10	23.81%

Table 18: Values assessment and weights for utility companies

Values	Assessment f_{ij}	Weight w_{ij}
Flood protection	7	18.92%
Environmental impact	5	13.51%
Transportation	4	10.81%
Water supply	10	27.03%
Energy production	10	27.03%
Recreation	1	2.70%

4.3 Alternative Scoring

We examined two different scenarios of weighting the importance of our stakeholder's input. First we assume that all stakeholders are equally important (Section 4.3.1), and second we define stakeholder importance based on expert opinion (Section 4.3.2).

4.3.1 Equal Stakeholders' Importance

Here we assume all the stakeholders are equally important, thus we assigned a weight α_j to each of the six stakeholders equal to $\frac{1}{number\ of\ stakeholders}$ (one sixth in our case). When all the stakeholders are treated equally, flood protection seems to be the most important criterion. Flood protection has the highest average assessment with an average assessment of 8.83, followed by an assessment of 6.5 for transportation, 6.3 for water supply, 5.83 for environmental impact, 5.6

for energy production, and lastly 5.5 for recreation. Table 19 shows the average calculated assessment for each of the six values.

Table 19: Stakeholders assessments for values and average assessment for each value

Stakeholders	**Flood Protection**	**Environ-mental Impact**	**Transpo-rtation**	**Water Supply**	**Energy Produc-tion**	**Recreation**
Environmental agencies	8	10	3	7	5	5
Cargo shippers/ cargo carriers	9	3	10	5	6	1
Local communities	10	5	5	8	7	10
Port authorities/ terminal owners	7	5	4	10	10	1
Department of parks and tourism	9	7	7	6	3	10
Utility companies	7	5	4	10	10	1
Average assessment	8.83	5.83	6.5	6.33	5.67	5.5

Assuming equal weight for the importance of each stakeholder, the MKARNS project alternatives were scored and ranked using the additive model in Equation 1. These results are presented in Table 20.

Table 20: Results of MKARNS project VFT analysis under equal stakeholder importance

Rank	MKARNS Project	Type of Project	Benefit
1	Dardanelle L&D	Lock And Dam	57.8
2	Eufaula	Upstream Reservoir	52.7
3	Keystone	Upstream Reservoir	37.8
4	Arkansas L&D 2	Lock And Dam	36.0
5	Robert S Kerr L&D	Lock And Dam	30.1
6	Fort Gibson	Upstream Reservoir	29.7
7	David D Terry L&D	Lock And Dam	29.7
8	Tenkiller Ferry	Upstream Reservoir	28.9
9	(Pensacola Dam)	Upstream Reservoir	28.2
10	Webbers Falls L&D	Lock And Dam	26.5
11	Murray L&D	Lock And Dam	26.2
12	Kaw	Upstream Reservoir	26.0
13	Emmett Sanders L&D	Lock And Dam	25.3
14	NorrellL&D	Upstream Reservoir	24.5
15	James W Trimble L&D	Lock And Dam	24.4
16	Arkansas L&D 5	Lock And Dam	23.9
17	Joe Hardin L&D	Lock And Dam	23.9
18	Oologah	Upstream Reservoir	23.5
19	Arthur V Ormond L&D	Lock And Dam	23.4
20	Ozark-JetaTaylor L&D	Lock And Dam	21.4
21	Toad Suck Ferry L&D	Lock And Dam	20.7
22	(Markham Ferry Dam)	Upstream Reservoir	16.8
23	Blue Mountain	Upstream Reservoir	13.3
24	W D Mayo L&D	Lock And Dam	12.9
25	Hulah	Upstream Reservoir	11.6
26	Newt Graham L&D	Lock And Dam	11.2
27	Chouteau L&D	Lock And Dam	11.0
28	Copan	Upstream Reservoir	10.3
29	Wister	Upstream Reservoir	9.1
30	Nimrod	Upstream Reservoir	8.2

Figure 25 contains a graphical representation of the Benefits components of the thirty MKARNS project alternatives. Each color shown in the key represents a value (for example, flood control) for a group of the stakeholders. The length of the colored segment on the bar indicates the Benefits portion contributed by each value for each stakeholder. For example, department of parks and tourism flood protection represents the portion of the Benefit contributed by the flood protection value evaluated by the department of parks and tourism, and it can be calculated using the following formula: $\alpha_{dpt} \times w_{dpt,fp} \times \upsilon(x_{fp})$.

The Dardanelle L/D ranks highest in terms of Benefit. Although the Dardanelle L/D does not provide flood protection, this project alternative is highly valued on recreation, energy production, and water supply. The Dardanelle L/D ranks highest in energy production and water supply, and fifth in recreation. The two types of project alternatives (reservoir and L/D) may not contribute to all ancillary benefits. The reservoir project alternatives do not contribute to transportation, and most of the L/D project alternatives do not contribute to water supply or flood protection. Thus, the ranking of projects shows an alternation between the two types, L/Ds and reservoirs. For example Arkansas L&D 2 is ranked third based on the Benefit, followed by Keystone (reservoir), followed by two L/Ds projects, and then three reservoir projects and so on. The project alternative rankings in this section depend on the assumption that all the stakeholders are treated equally. The need for a sensitivity analysis is needed in order to determine how the ranking of project alternatives fluctuate based on the weights placed on the importance of each stakeholder's input. The results of this sensitivity analysis are reported in Section 4.4.

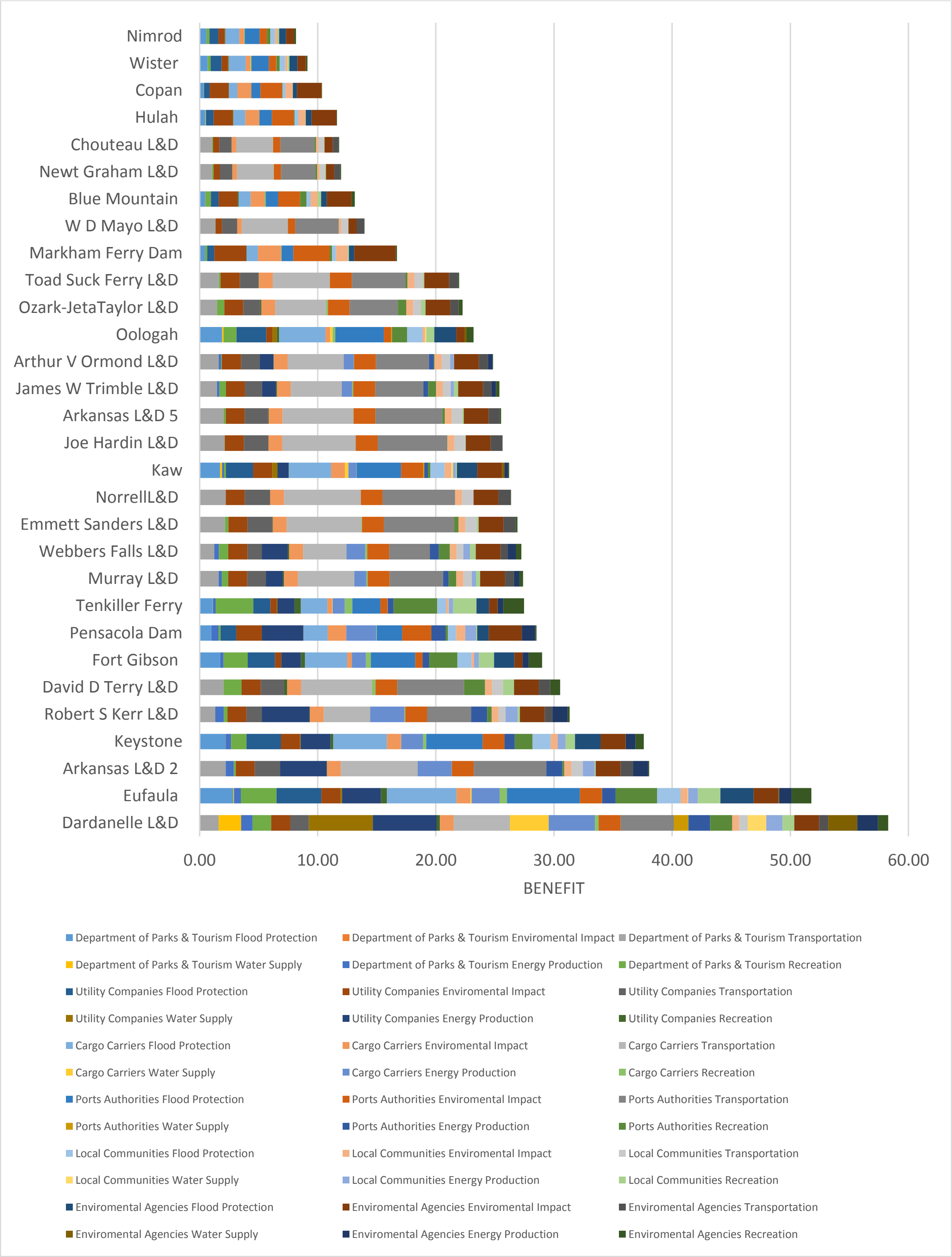

Figure 25: Breakdown of Benefits of the projects

4.3.2 Expert Stakeholders Importance

To study the case where stakeholder input is not equally weighted, we contacted the executive director of the Arkansas Waterways Commission (AWC) and obtained his expert opinion regarding the importance of each stakeholder on this decision. He provided an assessment between 0 and 10 on the importance of each stakeholder. His assessments were normalized to sum to 1.

$$a_j = \frac{f_j}{\sum_j f_j} \qquad (5)$$

Table 21 provides the resulting weights of stakeholder importance based on expert opinion.

Table 21: Expert assessments and normalized weights for stakeholder importance

Stakeholder	**Importance Assessment**	**Normalized Weight**
Environmental agencies	6	0.13
Cargo shippers/ cargo carriers	10	0.22
Port authorities/ terminal owners	10	0.22
Department of parks and tourism	6	0.13
Utility companies	9	0.20
Local communities	4	0.09

Examination of Tables 22 and Table 20 shows that there are not large differences between the final Benefits for the equal stakeholder project alternative results and the expert stakeholder project alternative results. The overall change in Benefits varied on average less than four percent. More project alternative Benefits increase under expert stakeholder importance (21 out of 30). In addition, we observe that all L/D project alternative Benefits increase under expert stakeholder importance. The reservoir project alternative Benefits show a slight decrease in most instances (9 out of 12). The project alternative rankings did not show significant variation. The five projects with the highest Benefits are the same when using both equal and expert stakeholder weights. However, Arkansas L/D 2 ranks third and Keystone ranks fourth under expert stakeholder weight; while Keystone ranks third and Arkansas L/D 2 ranks fourth under equal stakeholder weight. Out of the thirty projects, only three projects change in their ranking by two positions when using expert stakeholder weights. Ten projects did not show any change in their ranking position; while seventeen project rankings varied by one position under each of the two scenarios. In summary, changing from equal to expert weighting of stakeholder importance did not produce important changes in the rankings or Benefits of the project alternatives. Figure 26 provides a comparison between the total project alternative Benefits under expert and equal stakeholder importance.

Table 22: Results of MKARNS project VFT analysis under expert stakeholder importance

Rank	MKARNS Project	Type of Project	Benefit
1	Dardanelle L&D	Lock And Dam	58.30
2	Eufaula	Upstream Reservoir	51.79
3	Arkansas L&D 2	Lock And Dam	38.06
4	Keystone	Upstream Reservoir	37.61
5	Robert S Kerr L&D	Lock And Dam	31.33
6	David D Terry L&D	Lock And Dam	30.52
7	Fort Gibson	Upstream Reservoir	29.00
8	Pensacola Dam	Upstream Reservoir	28.52
9	Tenkiller Ferry	Upstream Reservoir	27.46
10	Murray L&D	Lock And Dam	27.38
11	Webbers Falls L&D	Lock And Dam	27.23
12	Emmett Sanders L&D	Lock And Dam	26.92
13	NorrellL&D	Upstream Reservoir	26.35
14	Kaw	Upstream Reservoir	26.21
15	Joe Hardin L&D	Lock And Dam	25.64
16	Arkansas L&D 5	Lock And Dam	25.52
17	James W Trimble L&D	Lock And Dam	25.39
18	Arthur V Ormond L&D	Lock And Dam	24.84
19	Oologah	Upstream Reservoir	23.20
20	Ozark-JetaTaylor L&D	Lock And Dam	22.27
21	Toad Suck Ferry L&D	Lock And Dam	21.98
22	Markham Ferry Dam	Upstream Reservoir	16.70
23	W D Mayo L&D	Lock And Dam	13.95
24	Blue Mountain	Upstream Reservoir	13.13
25	Newt Graham L&D	Lock And Dam	11.97
26	Chouteau L&D	Lock And Dam	11.82
27	Hulah	Upstream Reservoir	11.62
28	Copan	Upstream Reservoir	10.36
29	Wister	Upstream Reservoir	9.13
30	Nimrod	Upstream Reservoir	8.15

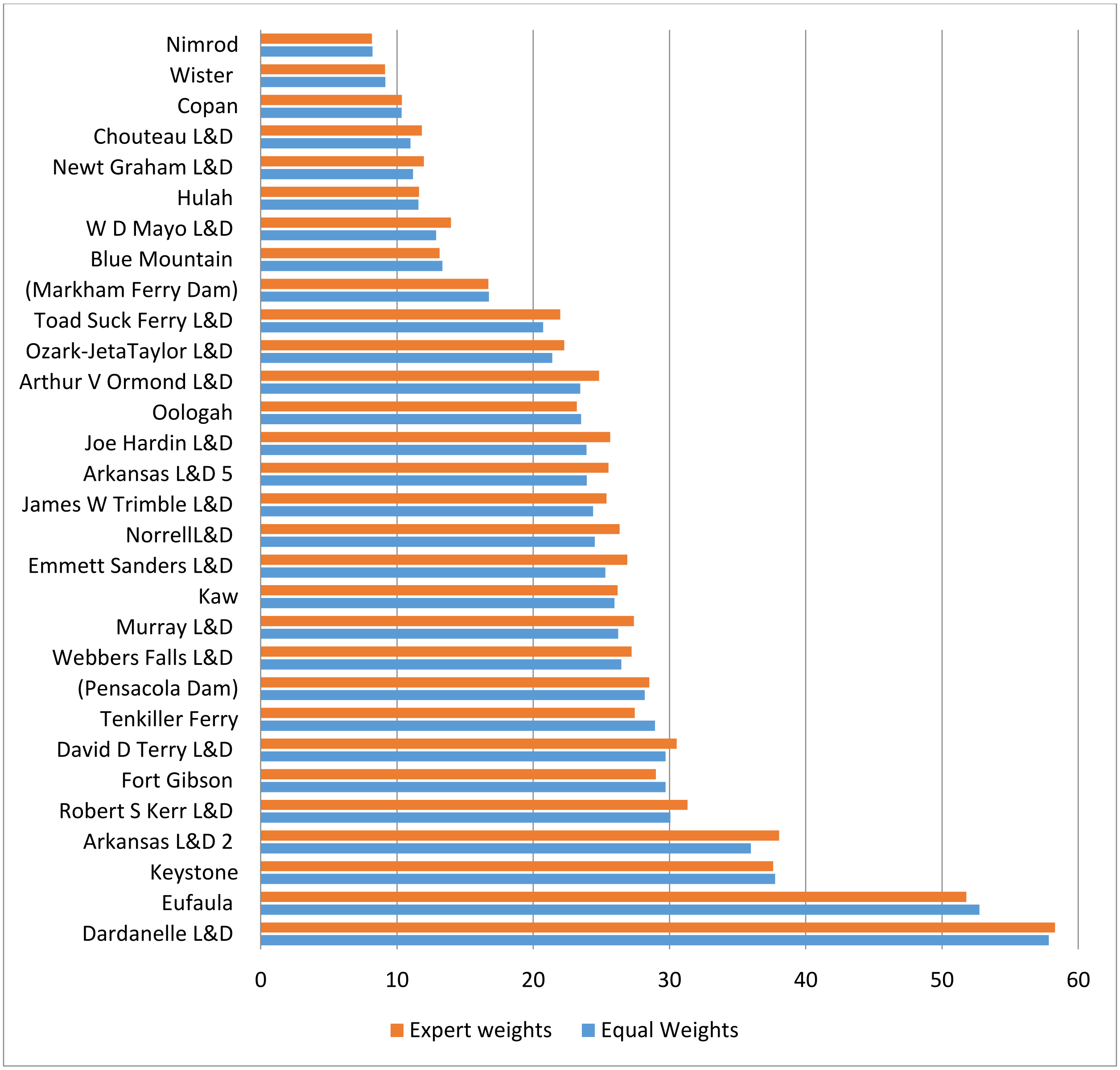

Figure 26: Comparison of total project alternative Benefits using expert and equal stakeholder importance

4.4 Sensitivity Analysis

To study the effect stakeholder importance has on the total Benefits and overall rankings of the project alternatives, we conduct a one-way sensitivity analysis on the stakeholder importance assessments. We used the expert stakeholder importance weights as our baseline weights.

4.4.1 Environmental Agencies

We vary the environmental agencies importance assessment from 1 to 10. As the importance of environmental agencies increases, the Benefits of the reservoir project alternatives increase, while eleven out of eighteen L/D project alternative Benefits decrease. There was an average change on the Benefits of 4.3% when increasing the environmental agencies assessment from 1 to 10. The Markham Ferry project alternative exhibited the greatest increase in Benefit (+19%) but this did not increase its overall ranking (22th of 30). The Kaw project alternative shows an increase in its overall ranking from sixteenth to twelfth. Figure 27 shows how Benefits change for each of the project alternatives based on the change in importance of environmental agencies. Here we see that the change in the weights of environmental agencies importance does not have a large influence on the Benefits of the project alternatives.

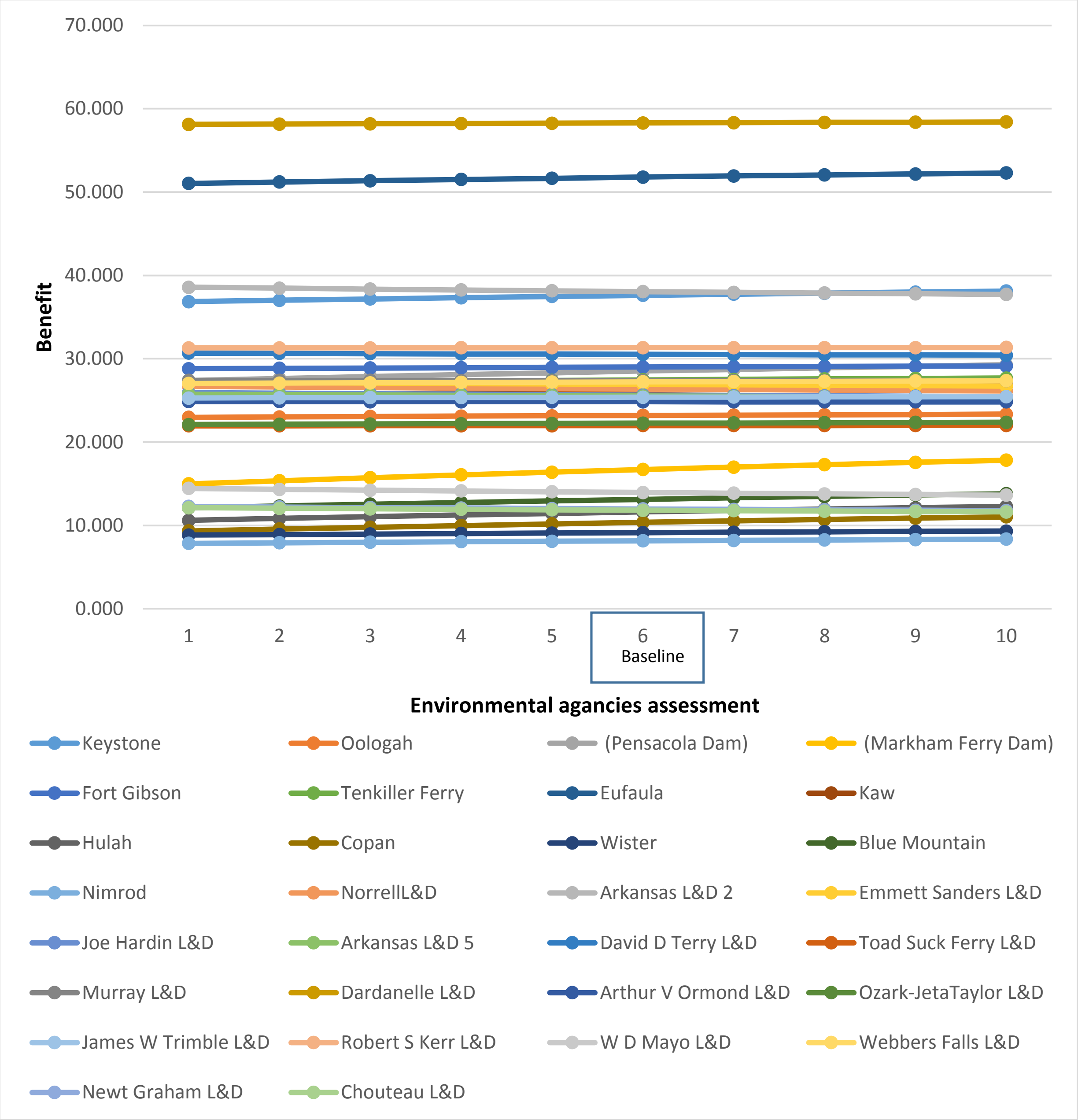

Figure 27: One way sensitivity analysis of environmental agencies importance

4.4.2 Cargo Shippers /Cargo Carriers

We repeat our one-way sensitivity analysis varying cargo shippers/ cargo carriers' importance between 1 and 10 and kept all the other stakeholders constant. Varying cargo shippers/ cargo carriers importance shows some interesting results. Increasing their importance increases the Benefits associated with the L/D project alternatives on average by 6% and decreases the

Benefits of the reservoir project alternatives by an average of 3%. Figure 28 shows how the Benefits vary when altering cargo shippers/cargo carriers' importance.

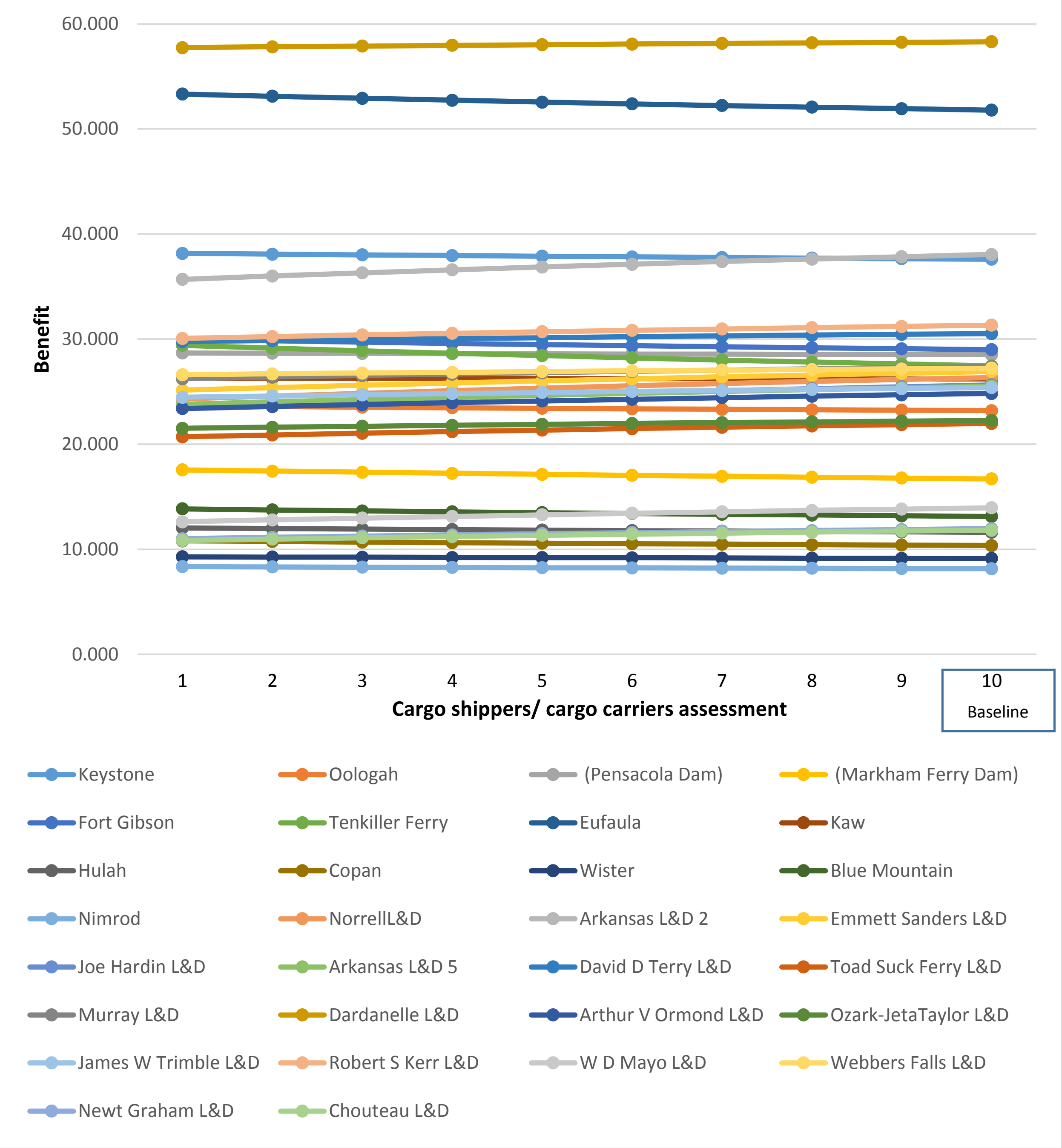

Figure 28: One way sensitivity analysis of cargo shippers/ cargo carriers' importance

4.4.3 Port Authorities/ Terminal Owners

We varied the port authorities/terminal owners’ importance assessment between 1 and 10 and kept all the other stakeholders constant in order to understand the effect this will have on the overall scoring and ranking of project alternatives. When port authorities/terminal owners’ importance is increased, only two project alternatives show a decrease in their Benefits. On average, an overall increase of 4% is observed in the reservoir project alternatives Benefits, and an overall increase of 8% on L/D project alternative scoring. There is not a substantial change in the project alternative rankings. Fourteen of the thirty project alternatives did not change their rankings; while the other project alternative rankings varied by one or two positions. Figure 29 shows how the different project alternative Benefits are affected by varying the port authorities/terminal owners’ importance.

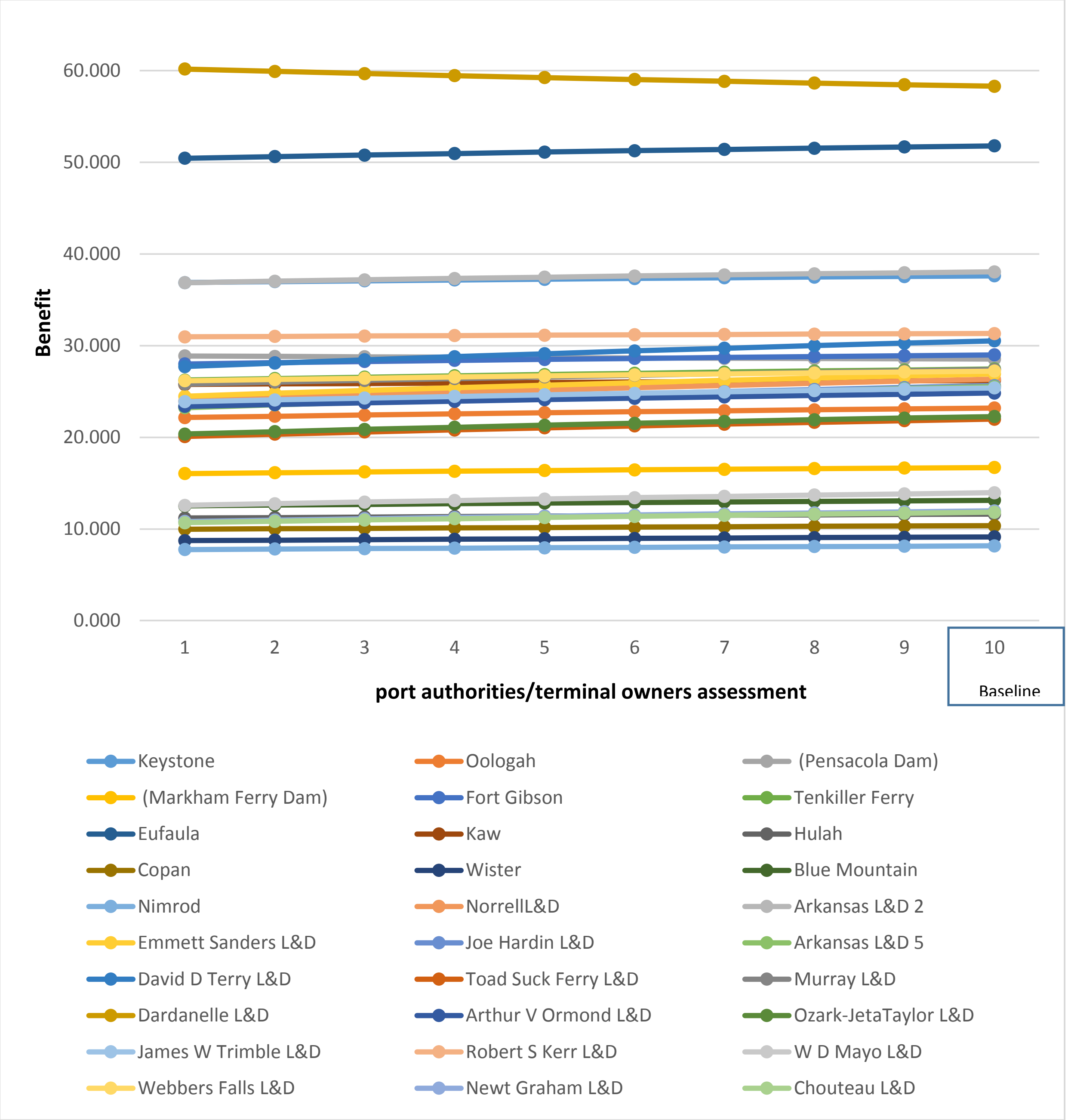

Figure 29: One way sensitivity analysis of ports authorities/terminal owners' importance

4.4.4 Department of Parks and Tourism

We vary the department of parks and tourism importance assessment between 1 and 10 in our next one-way sensitivity analysis. Increasing the importance of department of parks and tourism decreases the Benefits of the L/D project alternatives by 7% on average. The Benefits of nine of the twelve reservoir projects decrease as the department of parks and tourism importance increases. An average 7% decrease was noted in the Benefits of the reservoir project alternatives. Two of these, Copan and Markham Ferry, however show an increase in their Benefits of nearly 14%. The Tenkiller Ferry project alternative ranking increased by eight positions. Thirteen project alternatives did not experience any change in their rankings; while remaining seventeen project alternative rankings varied by two or less positions. Figure 32 shows the variation in project alternative Benefits when department of parks and tourism importance is increased.

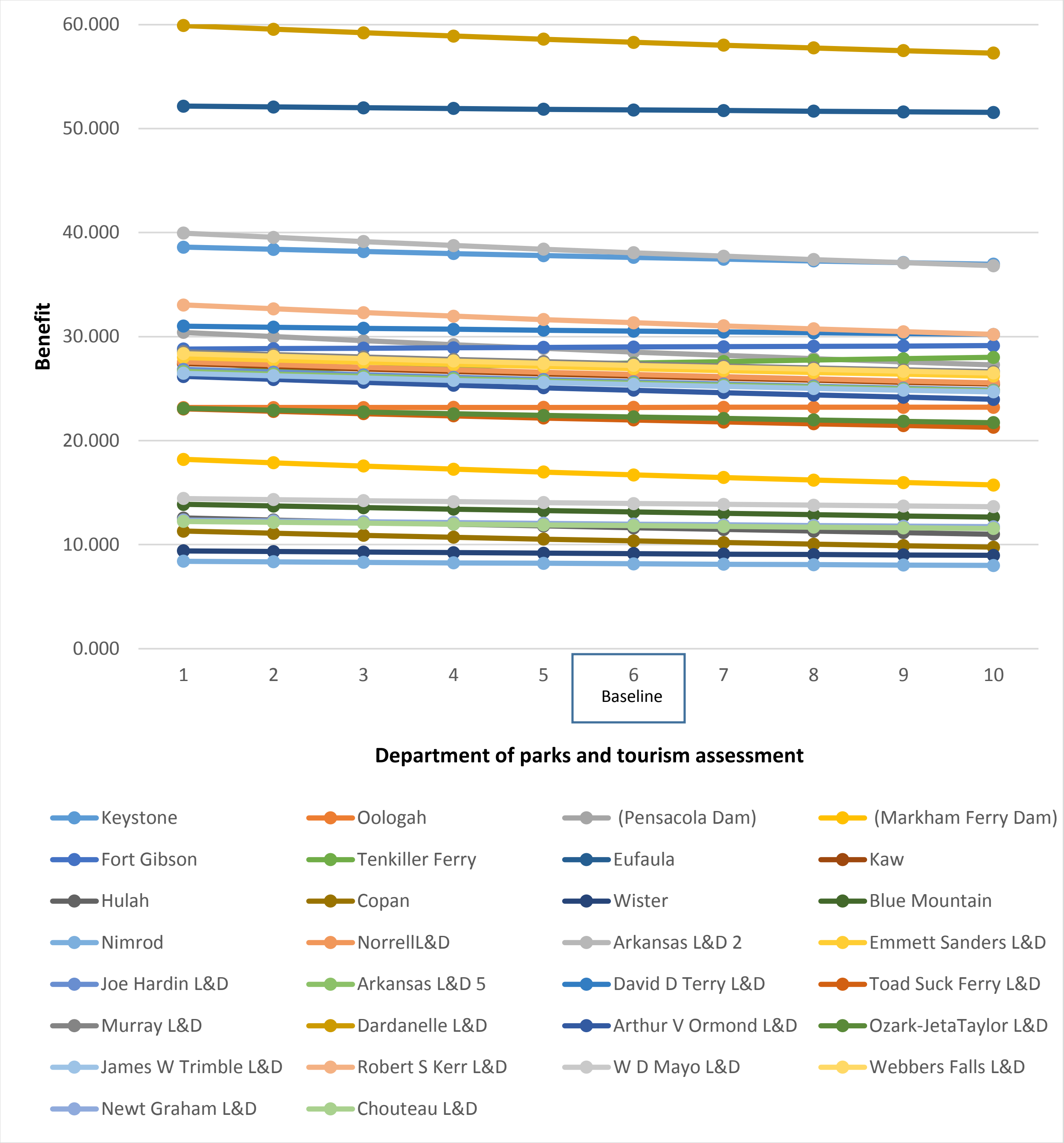

Figure 30: One way sensitivity analysis of department of parks and tourism' importance

4.4.5 Utility Companies

Our one-way sensitivity analysis is repeated while varying utility companies' importance assessment between 1 and 10 and keeping all other stakeholder assessments constant. When utility companies' importance is increased, fifteen of the eighteen L/D project alternative

Benefits decrease (6% on average. Eight out of the twelve reservoir project alternatives exhibit a decrease in Benefit with an average decrease of 3%. Two reservoir project alternatives show a large advancement in their ranking as Fort Gibson advances seven positions and Kaw advances four positions. Nineteen projects did not experience any change in their ranking; while nine projects ranking varied by three or less positions. Figure 31 shows how the project alternative Benefits change when utility companies' importance is varied.

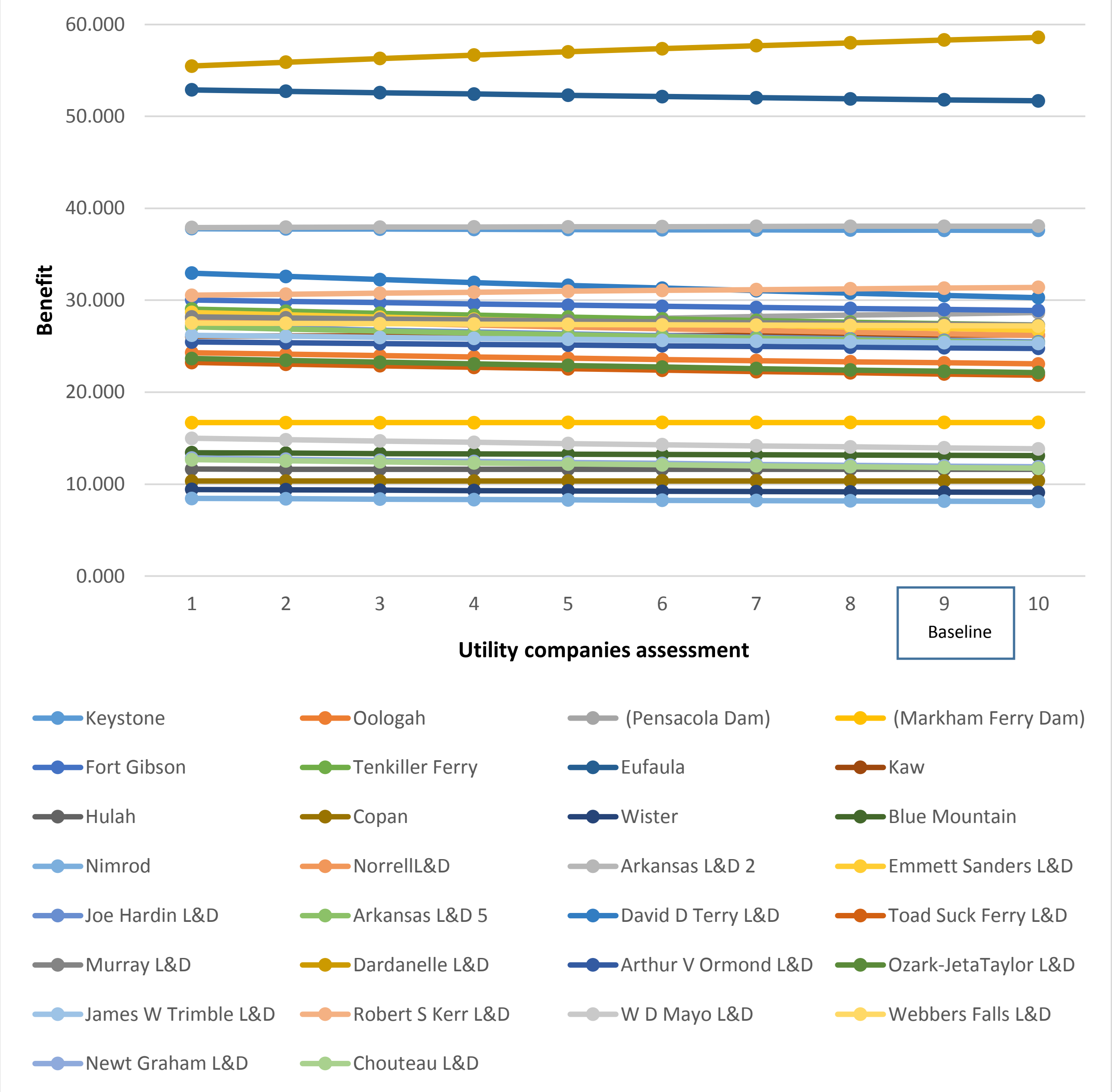

Figure 31: One way sensitivity analysis of utility companies' importance

4.4.6 Local Communities

We repeat our one-way sensitivity analysis by varying the local communities' importance assessment between 1 and 10 and keeping all the other stakeholders' importance assessments constant in order to understand the effects this will have on the scoring and ranking of project alternatives. When increasing the local communities' importance, all L/D project alternative Benefits decrease except for the Dardanelle L/D. On average, the L/D project alternative Benefits decrease by 4%. When local communities' importance is increased, five out of twelve reservoir project alternative Benefits decreased. The Tenkiller Ferry project alternative exhibits the largest increase in Benefit (+7%) which causes it to move up five positions in the overall rankings. All the other project rankings either remained constant or vary no more than two positions. Figure 30 shows the impact on overall project alternative Benefits when the local communities' importance is varied.

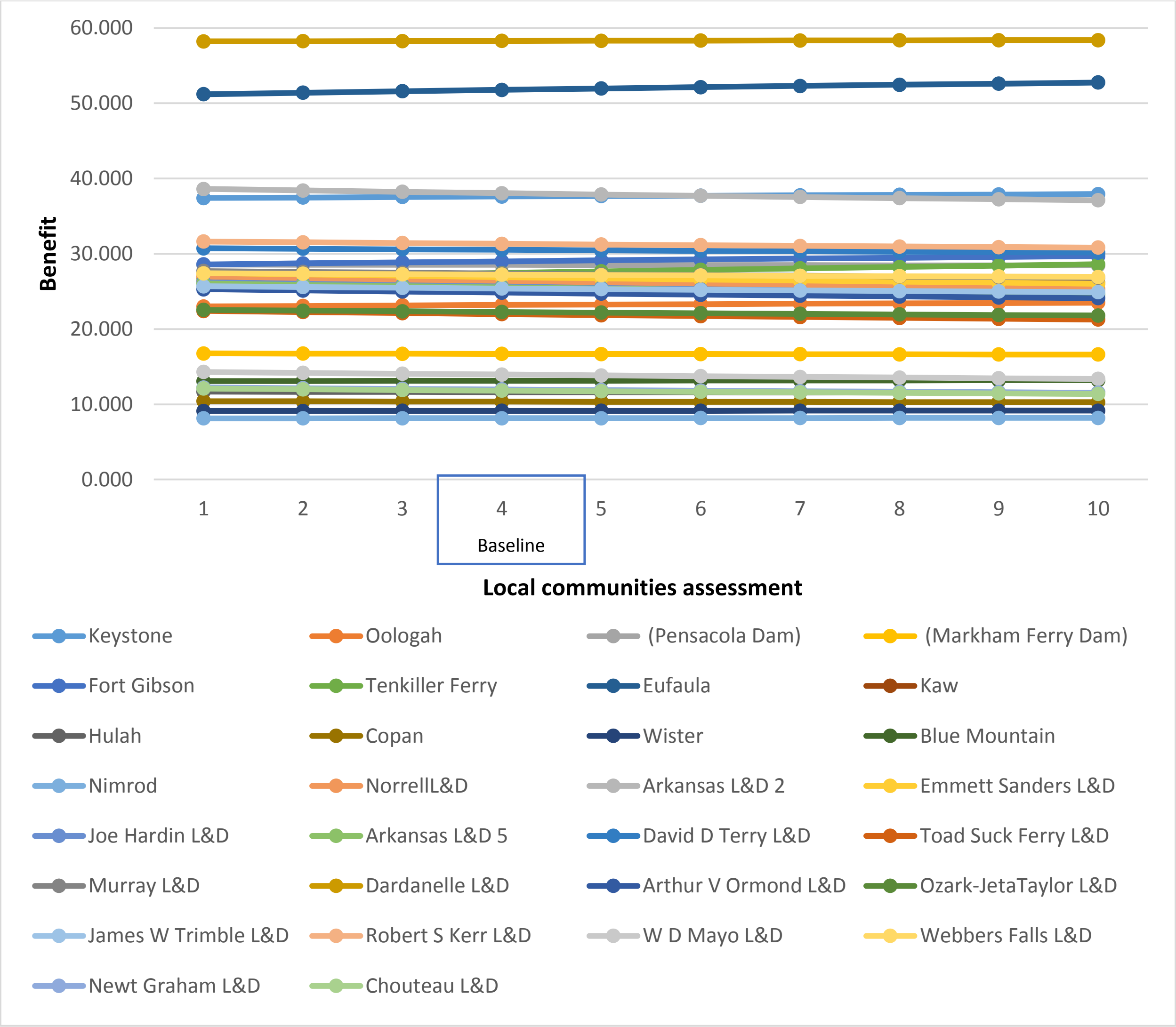

Figure 32: One way sensitivity analysis of local communities' importance

4.5 Portfolio Optimization

In general, multiple projects decision analysis is different and more complicated in comparison with single choice decision analysis. The complexity of the decision results from the potential interactions between projects. Morton et al. (2013) identified three types of interactions:

- Resource interactions: savings or extra costs are incurred when doing two projects simultaneously

- Technical interactions: One project depend on another project or projects are mutually exclusive
- Benefit interactions: Benefits of doing two projects together is different than the sum of benefits if done individually.

When considering the final allocation of projects, it is important to make sure that the benefits of multiple projects are balanced and we avoid choosing projects that have the same benefits. Balance constraints is a common method to balance the project portfolio. This method allows achievement of a minimum desirable outcome for a particular criterion.

In our inland waterways infrastructure investment model (IWII), we assume that there are no interactions of any type between our project alternatives. We include balance constraints to attain a minimum desirable outcome for five of the six values. The objective function of the model is to maximize the total benefit of a portfolio of IWS infrastructure investment projects. The IWII model is a binary integer programming model that is formulated as follows:

Sets:

P	Set of projects *p*
I	Set of evaluation measures and single dimensional value functions *i*
J	Set of stakeholders *j*

Parameters:

x_{ip}	Evaluation measure score of project *p* for value measure *i*
$V_i(x_{ip})$:	Single dimensional value of value measure *i* score of project *p*
w_{ij}	Weight of the i^{th} single dimensional value for stakeholder *j*
α_j	Weight of stakeholder *j*
B	Budget available
L_i	Minimum acceptable evaluation score for value measure *i*

C_p Cost of project p

Decision Variable

$$y_p : \begin{cases} 1 & \mathit{if\ project\ is\ in\ the\ portfolio} \\ 0 & \mathit{Otw} \end{cases}$$

Objective function

Maximize

$$\sum_{p} \sum_{j} \sum_{i} \alpha_j \boldsymbol{w_{ij} V_i (x_{ip}) y_p} \qquad \mathbf{(6)}$$

Constraints

$$\sum_{p} \boldsymbol{C_p y_p \leq B} \qquad \mathbf{(7)}$$

$$\sum_{p} \boldsymbol{x_{ip} y_p \geq L_i} \ \forall \boldsymbol{i} \in I \qquad (8)$$

$$\boldsymbol{y_p} \in \{0,1\} \qquad (9)$$

The objective function represented by Equation (6) aims to maximize the Benefits associated with the projects that we decide to include in the IWS investment portfolio. Constraint (7) ensures that we do not exceed the budget available to invest in the IWS infrastructure projects. Constraint (8) ensures that we attain a minimum desirable evaluation score for flood protection, transportation, water supply, energy production, and recreation. Constraint (9) ensures that we can only invest in a whole project, and not a portion of a project.

In our case study, we utilized the American Recovery and Reinvestment Act (ARRA) of 2009 (USACE, 2009) in order to estimate the costs to modernize and maintain the projects. The ARRA is composed of projects that are intended to modernize infrastructure, including inland waterways. The costs of modernizing some of the projects under consideration were stated separately in the Act. The total cost of modernizing the Arkansas and Oklahoma portions of the MKARNS was provided. We divided the total cost by the number of L/D projects in the Arkansas and Oklahoma portion and added it to the projects' specific costs in order to obtain the total cost for each project. The Markham Ferry reservoir cost was not given in the Act, so we used the average cost of modernizing the other reservoirs. Table 23 represents the cost associated with modernizing each of the projects.

Table 23: Project modernization and maintenance costs

Project	Cost ($ thousands)
Keystone	2,252.0
Oologah	3,042.0
Pensacola Dam	678.5
Markham Ferry Dam	2,260.3
Fort Gibson	19,194.0
Tenkiller Ferry	3,971.0
Eufaula	7,140.0
Kaw	2,253.0
Hulah	659.0
Copan	606.0
Wister	1,719.0
Blue Mountain	282.0
Nimrod	1,987.0
NorrellL&D	3,153.8
Arkansas L&D 2	3,153.8
Emmett Sanders L&D	3,153.8
Joe Hardin L&D	3,153.8
Arkansas L&D 5	3,153.8
David D Terry L&D	9,653.8
Toad Suck Ferry L&D	10,853.8
Murray L&D	10,053.8
Dardanelle L&D	4,853.8
Arthur V Ormond L&D	3,153.8
Ozark-JetaTaylor L&D	6,878.8
James W Trimble L&D	3,153.8
Robert S Kerr L&D	5,557.4
W D Mayo L&D	2,381.4
Webbers Falls L&D	8,007.0
Newt Graham L&D	2,381.4
Chouteau L&D	3,181.4

Figure 33 represents the Benefits of MKARNS project alternatives plotted against their associated costs. The projects circled in red represent project alternatives that dominate other project alternatives and lie on the efficient frontier as they provide a larger overall Benefit at a lower cost than other alternatives.

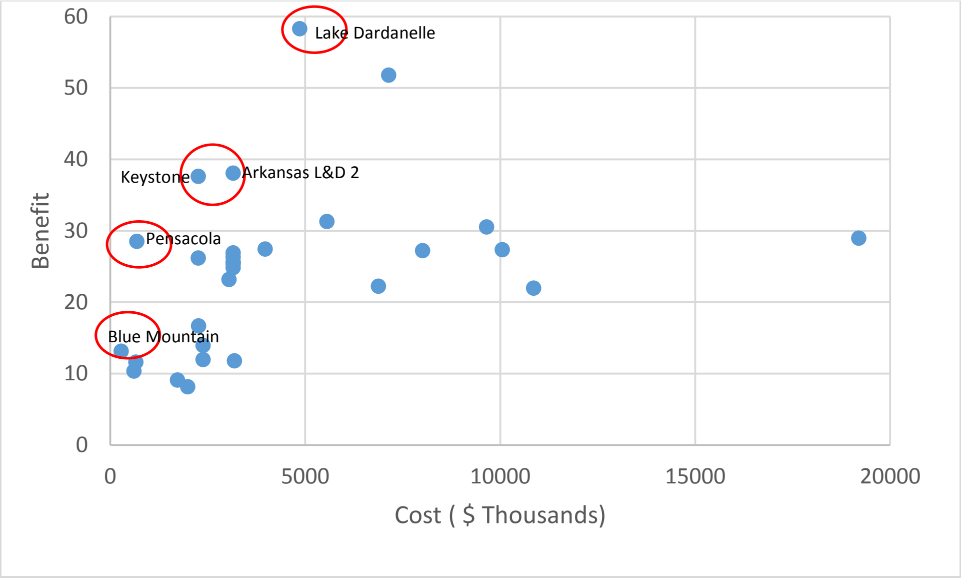

Figure 33: Project efficient frontier (Cost vs Benefit)

4.5.1 Balance Constraint

In order to test our IWII model, we run a scenario with an assumed budget equal to half of the cumulative total cost to complete all project alternatives ($65.96 millions) and set balance constraints equal 70% of the maximum total possible recreation, water supply, transportation, energy production, and flood protection benefits while maximizing the total Benefit of the MKARNS project alternative portfolio. Table 24 represents the constraints and outputs of our IWII model. The maximum possible output column represents the value measures and Benefit attainable if all the projects are included in the portfolio. The minimum acceptable balance constraints column represents the constraints associated with each of the six value measures, while the optimization output column represent the value measures and Benefits resulting from investing in the projects included in the optimal portfolio.

Table 24: Portfolio Optimization objective function, constraints, and results

	Maximum Possible Output	**Minimum Acceptable Balance Constraint score**		**Optimization Output**	
Benefit	742	-	-	558	75%
Flood protection (acre-ft)	8,243,008	5,770,106	70%	6,406,542	78%
Transportation (Tonnage)	104,608	73,226	70%	75,357	72%
Water supply (mgd)	1,535	1,074	70%	1,515	99%
Energy production (Kilowatts)	895,500	626,850	70%	751,500	84%
Recreation (# of visitors)	16,188,390	11,331,873	70%	11,333,352	70%

The optimal project portfolio consumes $65.81 million of the available $65.96 million budget. Overall, we invest in twenty-one MKARNS projects out of the thirty possible projects. Interestingly, the total cost of the nine projects that the optional solution does not include the optional portfolio is equal to the total cost of the selected twenty-one projects. Even though the David D Terry and Fort Gibson projects are highly ranked as sixth and seventh, they are not selected as part of the optimal portfolio because their cost to benefit ratio is very large. Table 25 presents the detailed results of the optimal MKARNS project portfolio.

Table 25: Optimal MKARNS project portfolio summary

Project	Benefit	Ranking	Cost ($thousands)	Cost/Benefit
Dardanelle L&D	58.30	1	4853.85	83.26
Eufaula	51.79	2	7140.00	137.85
Arkansas L&D 2	38.06	3	3153.85	82.87
Keystone	37.61	4	2252.00	59.88
Robert S Kerr L&D	31.33	5	5557.40	177.39
Pensacola Dam	28.52	8	678.50	23.79
Tenkiller Ferry	27.46	9	3971.00	144.62
Emmett Sanders L&D	26.92	12	3153.85	117.18
NorrellL&D	26.35	13	3153.85	119.70
Kaw	26.21	14	2253.00	85.98
Joe Hardin L&D	25.64	15	3153.85	122.99
Arkansas L&D 5	25.52	16	3153.85	123.57
James W Trimble L&D	25.39	17	3153.85	124.23
Arthur V Ormond L&D	24.84	18	3153.85	126.98
Oologah	23.20	19	3042.00	131.14
Ozark-JetaTaylor L&D	22.27	20	6878.85	308.90
Blue Mountain	13.13	24	282.00	21.48
Newt Graham L&D	11.97	25	2381.40	198.93
Chouteau L&D	11.82	26	3181.40	269.16
Hulah	11.62	27	659.00	56.72
Copan	10.36	28	606.00	58.50
Total	**558.29**		**65813.31**	

4.5.2 Unconstrained problem

We also run the optimization model with no balance constraints in order to understand how the balance constraints affect the output results. The Benefit of the portfolio showed an increase of 3% as the portfolio Benefit increased from 558 to 576. Table 26 represents a comparison of the outputs of running the IWII model with no constraints and with a minimum acceptable score of 70% for flood protection, transportation, water supply, energy production, and recreation.

Table 26: Comparison of portfolio optimization outputs (no constraints vs. minimum acceptable score of 70%

	Maximum Possible Output	**Optimization Output(No Balance Constraint)**		**Optimizatio Output (70 % Balance Constraint)**	
Benefit	742	576	78%	558	75%
Flood protection (acre-ft)	8,243,008	7,016,808	85%	6,406,542	78%
Transportation (Tonnage)	104,608	74,830	72%	75,357	72%
Water supply (mgd)	1,535	1,534	100%	1,515	99%
Energy production (Kilowatts)	895,500	751,500	84%	751,500	84%
Recreation (# of visitors)	16,188,390	11,236,396	69%	11,333,352	70%

The optimal project portfolio consumes $65.29 million of the available $65.96 million budget. Figure 34 is a graphical representation of the difference between the outputs of the two cases. When running the model with no constraints, we can see an increase in flood protection and water supply total scores, while there was a small decrease in transportation and recreation total scores (less than 1%). This can be explained by the fact that flood protection has the highest weight and projects that have flood protection have water supply benefit.

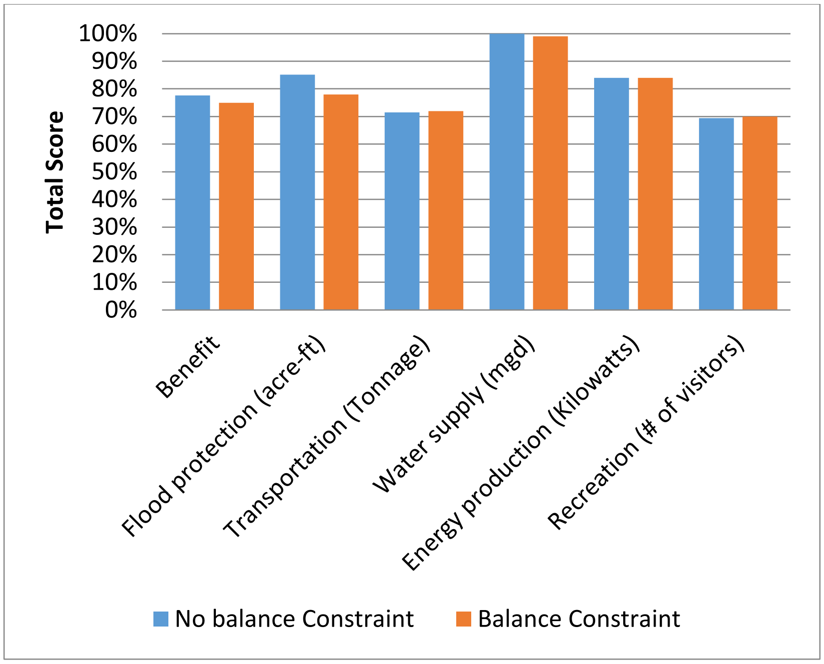

Figure 34: Comparison of portfolio optimization outputs (no constraints vs. minimum acceptable score of 70%

Table 27 represents the projects included in the portfolio. Overall, we invest in twenty-three MKARNS projects out of thirty possible projects. The projects with the lowest cost to Benefit ratio are included in the portfolio.

Table 27: Optimal MKARNS project portfolio summary

Project	Value	Cost ($thousands)	Cost/Value	Ranking Cost/Benefit
Blue Mountain	13.13	282.00	21.48	1
Pensacola Dam	28.52	678.50	23.79	2
Hulah	11.62	659.00	56.72	3
Copan	10.36	606.00	58.50	4
Keystone	37.61	2252.00	59.88	5
Arkansas L&D 2	38.06	3153.85	82.87	6
Dardanelle L&D	58.30	4853.85	83.26	7
Kaw	26.20	2253.00	85.98	8
Emmett Sanders L&D	26.91	3153.85	117.18	9
NorrellL&D	26.35	3153.85	119.70	10
Joe Hardin L&D	25.64	3153.85	122.99	11
Arkansas L&D 5	25.52	3153.85	123.57	12
James W Trimble L&D	25.39	3153.85	124.23	13
Arthur V Ormond L&D	24.84	3153.85	126.98	14
Oologah	23.20	3042.00	131.14	15
Markham Ferry Dam	16.70	2260.25	135.32	16
Eufaula	51.79	7140.00	137.85	17
Tenkiller Ferry	27.46	3971.00	144.62	18
W D Mayo L&D	13.95	2381.40	170.68	19
Robert S Kerr L&D	31.33	5557.40	177.39	20
Wister	9.13	1719.00	188.26	21
Newt Graham L&D	11.97	2381.40	198.93	22
Chouteau L&D	11.82	3181.40	269.16	24
Total	**575.8**	**65295.15**		

5. Conclusion and Future Work

In this paper, we formulate an initial qualitative value model for the inland waterway infrastructure investment decision utilizing the initial stage in the VFT philosophy and develop IWII optimization model to maximize the overall Benefit associated with inland waterway infrastructure investments. Instead of limiting our IWS infrastructure project investment decision to its transportation benefit, we took into consideration other ancillary benefits including recreation, water supply, energy production, impact on fish and wildlife, and flood protection. From the literature search, we found that there is no prior published research that incorporates these multiple IWS ancillary benefits into a single decision model to evaluate IWS infrastructure investments. This paper proposes a new methodology to evaluate the Benefit of IWS infrastructure using a VFT philosophy and multiple objective decision optimization.

In this research effort, we attempt to capture the stakeholder opinion on how they value each of the six ancillary benefits that were assessed. One challenge in conducting this research was accurately capturing the expert opinion of these values. The importance of ancillary benefits differs among IWS stakeholders. One common assessment among all IWS stakeholders is highly valuing flood protection. Another challenge was the assessment of the level of importance placed on each stakeholder. First, we examined the case when all the stakeholders were considered equally important in the decision, and then we examined a second scenario where expert opinion of stakeholder importance was applied. These two assumptions did not show important differences in the final MKARNS project alternative scoring or rankings, which led us conduct a set of one-way sensitivity analyses to understand the effects of stakeholders' importance on the Benefits and ranking of the project alternatives. As a whole, the one-way sensitivity analysis shows that the stakeholder importance does not have a significant effect on the scoring or ranking results. Once the MKARNS project alternatives were evaluated using our VFT approach, a binary integer programming portfolio optimization model was employed to maximize the total Benefit of the portfolio while taking in consideration budget and balance constraints.

There are multiple opportunities to further develop the model present in this paper. The first potential area for future work is to further examine if linear functions represent the true shape of the value functions: linear, convex, concave or an S-curve for all the value measures. Another area of potential model improvement is to consider the interactions between the different projects. The current IWII model assumes that there are no resources, technical, or benefits interactions between the project alternatives. It is anticipated that difficulties will arise in located the historical data necessary to make these improvement but further expert input could potentially enhance the model's representation of the IWS.

To conclude, the developed value-focused, multi objective portfolio optimization model is a useful approach in selecting a portfolio of IWS project investments. This methodology allows us to maximize the total Benefit associated with the project investments while taking in consideration the necessary budgetary constraints and minimally acceptable IWS benefit evaluation scores constraints. The developed model allows us to identify a combination of projects that maximize the total system benefits instead of considering each project individually.

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Appendix A

Appendix A contains the single dimensional values associated with the projects evaluation measure scores

Table 28: Projects single dimensional value for flood protection

Project	**Evaluation Measure Score (Acre-ft)**	**Value (0-100)**
Keystone	1,167,232	77.2
Oologah	1,007,060	66.6
Pensacola Dam	525,000	34.7
Markham Ferry Dam	244,210	16.2
Fort Gibson	919,200	60.8
Tenkiller Ferry	576,700	38.2
Eufaula	1,511,000	100.0
Kaw	919,400	60.8
Hulah	257,932	17.1
Copan	184,318	12.2
Wister	366,056	24.2
Blue Mountain	257,900	17.1
Nimrod	307,000	20.3
NorrellL&D	0	0.0
Arkansas L&D 2	0	0.0
Emmett Sanders L&D	0	0.0
Joe Hardin L&D	0	0.0
Arkansas L&D 5	0	0.0
David D Terry L&D	0	0.0
Toad Suck Ferry L&D	0	0.0
Murray L&D	0	0.0
Dardanelle L&D	0	0.0
Arthur V Ormond L&D	0	0.0
Ozark-JetaTaylor L&D	0	0.0
James W Trimble L&D	0	0.0
Robert S Kerr L&D	0	0.0
W D Mayo L&D	0	0.0
Webbers Falls L&D	0	0.0
Newt Graham L&D	0	0.0
Chouteau L&D	0	0.0

Table 29: Projects single dimensional value for environmental impact

Project	**Evaluation Measure Score**		**Value (0-5)**
	Threatened	**Endangered**	
Keystone	2	1	3
Oologah	2	3	1
(Pensacola Dam)	3	0	4
(Markham Ferry Dam)	2	0	5
Fort Gibson	2	3	1
Tenkiller Ferry	2	4	1
Eufaula	2	1	3
Kaw	1	1	3
Hulah	2	2	3
Copan	2	1	3
Wister	2	3	1
Blue Mountain	2	2	3
Nimrod	0	4	1
NorrellL&D	1	1	3
Arkansas L&D 2	1	1	3
Emmett Sanders L&D	1	1	3
Joe Hardin L&D	1	1	3
Arkansas L&D 5	1	1	3
David D Terry L&D	0	2	3
Toad Suck Ferry L&D	0	1	3
Murray L&D	0	2	3
Dardanelle L&D	0	2	3
Arthur V Ormond L&D	0	2	3
Ozark-JetaTaylor L&D	1	2	3
James W Trimble L&D	1	2	3
Robert S Kerr L&D	2	2	3
W D Mayo L&D	2	3	1
Webbers Falls L&D	2	2	3
Newt Graham L&D	2	3	1
Chouteau L&D	2	3	1

Table 30: Projects single dimensional value for transportation

Project	**Evaluation Measure Score (thousands of tons)**	**Value (0-100)**
Keystone	0	0.00
Oologah	0	0.00
Pensacola Dam	0	0.00
Markham Ferry Dam	0	0.00
Fort Gibson	0	0.00
Tenkiller Ferry	0	0.00
Eufaula	0	0.00
Kaw	0	0.00
Hulah	0	0.00
Copan	0	0.00
Wister	0	0.00
Blue Mountain	0	0.00
Nimrod	0	0.00
NorrellL&D	8,144.6	99.31
Arkansas L&D 2	8,151.9	99.40
Emmett Sanders L&D	7,932.5	96.66
Joe Hardin L&D	7,821	95.26
Arkansas L&D 5	7,529.9	91.62
David D Terry L&D	7,513.7	91.42
Toad Suck Ferry L&D	6,080.1	73.50
Murray L&D	6,050	73.13
Dardanelle L&D	6,023.8	72.80
Arthur V Ormond L&D	6,017.6	72.72
Ozark-JetaTaylor L&D	5,483.8	66.05
James W Trimble L&D	5,477.8	65.97
Robert S Kerr L&D	5,004.2	60.05
W D Mayo L&D	4,956.1	59.51
Webbers Falls L&D	4,651.1	56.12
Newt Graham L&D	3,889.8	47.37
Chouteau L&D	3,880.4	47.26

Table 31: Projects single dimensional value for water supply

Project	Evaluation Measure Score (mgd)	Value (0-100)
Keystone	14.5	0.73
Oologah	137	6.83
Pensacola Dam	0	0.00
Markham Ferry Dam	0	0.00
Fort Gibson	0	0.00
Tenkiller Ferry	27	1.34
Eufaula	54	2.68
Kaw	167	8.36
Hulah	12	0.62
Copan	2	0.10
Wister	20	0.98
Blue Mountain	2	0.10
Nimrod	0.3	0.02
NorrellL&D	0	0.00
Arkansas L&D 2	0	0.00
Emmett Sanders L&D	0	0.00
Joe Hardin L&D	0	0.00
Arkansas L&D 5	0	0.00
David D Terry L&D	0	0.00
Toad Suck Ferry L&D	0	0.00
Murray L&D	0	0.00
Dardanelle L&D	1,100	100.00
Arthur V Ormond L&D	0	0.00
Ozark-JetaTaylor L&D	0	0.00
James W Trimble L&D	0	0.00
Robert S Kerr L&D	0	0.00
W D Mayo L&D	0	0.00
Webbers Falls L&D	0	0.00
Newt Graham L&D	0	0.00
Chouteau L&D	0	0.00

Table 32: Projects single dimensional value for energy production

Project	Evaluation Measure Score (Kilowatts)	Value (0-100)
Keystone	70,000	47.30
Oologah	0	0.00
Pensacola Dam	96,000	64.86
Markham Ferry Dam	0	0.00
Fort Gibson	45,000	30.41
Tenkiller Ferry	39,100	26.42
Eufaula	90,000	60.81
Kaw	25,600	17.30
Hulah	0	0.00
Copan	0	0.00
Wister	0	0.00
Blue Mountain	0	0.00
Nimrod	0	0.00
NorrellL&D	0	0.00
Arkansas L&D 2	108,000	72.97
Emmett Sanders L&D	0	0.00
Joe Hardin L&D	0	0.00
Arkansas L&D 5	0	0.00
David D Terry L&D	0	0.00
Toad Suck Ferry L&D	0	0.00
Murray L&D	39,000	26.35
Dardanelle L&D	148,000	100.00
Arthur V Ormond L&D	32,400	21.89
Ozark-JetaTaylor L&D	0	0.00
James W Trimble L&D	32,400	21.89
Robert S Kerr L&D	110,000	74.32
W D Mayo L&D	0	0.00
Webbers Falls L&D	60,000	40.54
Newt Graham L&D	0	0.00
Chouteau L&D	0	0.00

Table 33: Projects single dimensional value for recreation

Project	Evaluation Measure Score (number of visitors)	Value (0-100)
Keystone	1,062,635	40.58
Oologah	894,978	34.03
Pensacola Dam	167,467	5.61
Markham Ferry Dam	167,467	5.61
Fort Gibson	1,677,535	64.59
Tenkiller Ferry	2,583,915	100.00
Eufaula	2,466,286	95.40
Kaw	155,102	5.13
Hulah	59,350	1.39
Copan	52,311	1.12
Wister	205,815	7.11
Blue Mountain	405,025	14.89
Nimrod	226,048	7.90
Norrell L&D	23,702	0.00
Arkansas L&D 2	142,694	4.65
Emmett Sanders L&D	256,564	9.09
Joe Hardin L&D	38,506	0.58
Arkansas L&D 5	163,320	5.45
David D Terry L&D	1,256,852	48.16
Toad Suck Ferry L&D	146,983	4.81
Murray L&D	461,504	17.10
Dardanelle L&D	1,304,569	50.03
Arthur V Ormond L&D	74,187	1.97
Ozark-JetaTaylor L&D	519,159	19.35
James W Trimble L&D	473,808	17.58
Robert S Kerr L&D	271,719	9.68
W D Mayo L&D	48,921	0.98
Webbers Falls L&D	663,913	25.00
Newt Graham L&D	123,019	3.88
Chouteau L&D	95,036	2.79

Appendix B: One way Sensitivity Analysis Results

Table 34: One way sensitivity analysis of environmental agencies importance

Project	**Environmental Agencies Assessment**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Keystone	36.8	37.0	37.2	37.3	37.5	37.6	37.7	37.9	38.0	38.1
Oologah	23.0	23.0	23.1	23.1	23.2	23.2	23.2	23.3	23.3	23.3
Pensacola Dam	27.4	27.6	27.9	28.1	28.3	28.5	28.7	28.9	29.1	29.3
Markham Ferry Dam	15.0	15.4	15.7	16.1	16.4	16.7	17.0	17.3	17.6	17.8
Fort Gibson	28.8	28.8	28.9	28.9	29.0	29.0	29.0	29.1	29.1	29.1
Tenkiller Ferry	27.1	27.2	27.3	27.3	27.4	27.5	27.5	27.6	27.6	27.7
Eufaula	51.0	51.2	51.4	51.5	51.7	51.8	51.9	52.1	52.2	52.3
Kaw	25.3	25.5	25.7	25.9	26.0	26.2	26.4	26.5	26.6	26.8
Hulah	10.6	10.8	11.0	11.2	11.4	11.6	11.8	12.0	12.1	12.3
Copan	9.3	9.6	9.8	10.0	10.2	10.4	10.5	10.7	10.9	11.0
Wister	8.8	8.9	9.0	9.0	9.1	9.1	9.2	9.2	9.3	9.3
Blue Mountain	12.1	12.3	12.5	12.7	12.9	13.1	13.3	13.5	13.6	13.8
Nimrod	7.9	7.9	8.0	8.0	8.1	8.2	8.2	8.3	8.3	8.4
NorrellL&D	26.7	26.6	26.5	26.5	26.4	26.3	26.3	26.2	26.2	26.1
Arkansas L&D 2	38.6	38.5	38.4	38.3	38.2	38.1	38.0	37.9	37.8	37.7
Emmett Sanders L&D	27.2	27.1	27.1	27.0	27.0	26.9	26.9	26.8	26.8	26.7
Joe Hardin L&D	25.9	25.9	25.8	25.7	25.7	25.6	25.6	25.5	25.5	25.5
Arkansas L&D 5	25.7	25.7	25.6	25.6	25.6	25.5	25.5	25.4	25.4	25.4
David D Terry L&D	30.7	30.6	30.6	30.6	30.6	30.5	30.5	30.5	30.5	30.4
Toad Suck Ferry L&D	21.9	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0
Murray L&D	27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4	27.4
Dardanelle L&D	58.1	58.2	58.2	58.2	58.3	58.3	58.3	58.4	58.4	58.4
Arthur V Ormond L&D	24.9	24.9	24.8	24.8	24.8	24.8	24.8	24.8	24.8	24.8
Ozark-JetaTaylor L&D	22.1	22.1	22.2	22.2	22.2	22.3	22.3	22.3	22.3	22.4
James W Trimble L&D	25.3	25.3	25.3	25.4	25.4	25.4	25.4	25.4	25.4	25.5
Robert S Kerr L&D	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3	31.3
W D Mayo L&D	14.4	14.3	14.2	14.1	14.0	14.0	13.9	13.8	13.7	13.6
Webbers Falls L&D	27.0	27.1	27.1	27.2	27.2	27.2	27.3	27.3	27.3	27.4
Newt Graham L&D	12.3	12.2	12.1	12.1	12.0	12.0	11.9	11.9	11.8	11.8
Chouteau L&D	12.1	12.1	12.0	11.9	11.9	11.8	11.8	11.7	11.7	11.6

Table 35: One way sensitivity analysis of cargo shippers/cargo carriers importance

Project	**Cargo Shippers/Cargo Carries Assessment**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Keystone	38.2	38.1	38.0	38.0	37.9	37.8	37.8	37.7	37.7	37.6
Oologah	23.6	23.6	23.5	23.5	23.4	23.4	23.3	23.3	23.2	23.2
Pensacola Dam	28.7	28.7	28.6	28.6	28.6	28.6	28.6	28.6	28.5	28.5
Markham Ferry Dam	17.6	17.4	17.3	17.2	17.1	17.0	16.9	16.9	16.8	16.7
Fort Gibson	30.0	29.8	29.7	29.6	29.5	29.4	29.3	29.2	29.1	29.0
Tenkiller Ferry	29.4	29.1	28.9	28.7	28.4	28.2	28.0	27.8	27.6	27.5
Eufaula	53.3	53.1	52.9	52.7	52.6	52.4	52.2	52.1	51.9	51.8
Kaw	26.3	26.3	26.3	26.3	26.3	26.2	26.2	26.2	26.2	26.2
Hulah	12.0	12.0	11.9	11.9	11.8	11.8	11.7	11.7	11.7	11.6
Copan	10.8	10.7	10.7	10.6	10.6	10.5	10.5	10.4	10.4	10.4
Wister	9.3	9.3	9.2	9.2	9.2	9.2	9.2	9.2	9.1	9.1
Blue Mountain	13.8	13.7	13.7	13.6	13.5	13.4	13.3	13.3	13.2	13.1
Nimrod	8.3	8.3	8.3	8.3	8.3	8.2	8.2	8.2	8.2	8.2
NorrellL&D	24.3	24.6	24.8	25.1	25.3	25.6	25.8	26.0	26.2	26.3
Arkansas L&D 2	35.7	36.0	36.3	36.6	36.9	37.1	37.4	37.6	37.8	38.1
Emmett Sanders L&D	25.1	25.4	25.6	25.8	26.0	26.2	26.4	26.6	26.8	26.9
Joe Hardin L&D	23.7	24.0	24.2	24.5	24.7	24.9	25.1	25.3	25.5	25.6
Arkansas L&D 5	23.8	24.0	24.3	24.5	24.7	24.9	25.0	25.2	25.4	25.5
David D Terry L&D	29.8	29.9	30.0	30.1	30.1	30.2	30.3	30.4	30.5	30.5
Toad Suck Ferry L&D	20.7	20.9	21.0	21.2	21.3	21.5	21.6	21.7	21.9	22.0
Murray L&D	26.2	26.4	26.5	26.7	26.8	26.9	27.1	27.2	27.3	27.4
Dardanelle L&D	57.7	57.8	57.9	58.0	58.0	58.1	58.1	58.2	58.2	58.3
Arthur V Ormond L&D	23.4	23.6	23.8	23.9	24.1	24.3	24.4	24.6	24.7	24.8
Ozark-JetaTaylor L&D	21.5	21.6	21.7	21.8	21.9	22.0	22.1	22.1	22.2	22.3
James W Trimble L&D	24.5	24.6	24.7	24.8	24.9	25.0	25.1	25.2	25.3	25.4
Robert S Kerr L&D	30.1	30.2	30.4	30.6	30.7	30.8	31.0	31.1	31.2	31.3
W D Mayo L&D	12.6	12.8	13.0	13.1	13.3	13.4	13.6	13.7	13.8	14.0
Webbers Falls L&D	26.6	26.7	26.8	26.8	26.9	27.0	27.1	27.1	27.2	27.2
Newt Graham L&D	11.0	11.1	11.3	11.4	11.5	11.6	11.7	11.8	11.9	12.0
Chouteau L&D	10.8	11.0	11.1	11.2	11.3	11.4	11.5	11.6	11.7	11.8

Table 36: One way sensitivity analysis of port authorities/terminal owners' importance

Project	**Port Authorities/Terminal Owners Assessment**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Keystone	36.9	37.0	37.1	37.2	37.2	37.3	37.4	37.5	37.5	37.6
Oologah	22.2	22.3	22.4	22.6	22.7	22.8	22.9	23.0	23.1	23.2
Pensacola Dam	28.9	28.8	28.8	28.7	28.7	28.7	28.6	28.6	28.6	28.5
Markham Ferry Dam	16.1	16.1	16.2	16.3	16.4	16.4	16.5	16.6	16.6	16.7
Fort Gibson	28.0	28.1	28.3	28.4	28.5	28.6	28.7	28.8	28.9	29.0
Tenkiller Ferry	26.2	26.4	26.6	26.7	26.9	27.0	27.1	27.2	27.3	27.5
Eufaula	50.4	50.6	50.8	51.0	51.1	51.3	51.4	51.5	51.7	51.8
Kaw	25.8	25.8	25.9	25.9	26.0	26.0	26.1	26.1	26.2	26.2
Hulah	11.2	11.2	11.3	11.4	11.4	11.5	11.5	11.5	11.6	11.6
Copan	10.0	10.0	10.1	10.1	10.2	10.2	10.2	10.3	10.3	10.4
Wister	8.7	8.8	8.8	8.9	8.9	9.0	9.0	9.1	9.1	9.1
Blue Mountain	12.5	12.6	12.7	12.8	12.8	12.9	13.0	13.0	13.1	13.1
Nimrod	7.8	7.8	7.9	7.9	8.0	8.0	8.0	8.1	8.1	8.2
NorrellL&D	24.0	24.3	24.6	24.9	25.2	25.4	25.7	25.9	26.1	26.3
Arkansas L&D 2	36.9	37.0	37.2	37.3	37.5	37.6	37.7	37.8	37.9	38.1
Emmett Sanders L&D	24.5	24.8	25.1	25.4	25.7	26.0	26.2	26.5	26.7	26.9
Joe Hardin L&D	23.3	23.6	23.9	24.2	24.5	24.7	25.0	25.2	25.4	25.6
Arkansas L&D 5	23.2	23.5	23.8	24.1	24.4	24.6	24.9	25.1	25.3	25.5
David D Terry L&D	27.7	28.1	28.5	28.8	29.1	29.4	29.7	30.0	30.3	30.5
Toad Suck Ferry L&D	20.1	20.3	20.6	20.8	21.0	21.2	21.4	21.6	21.8	22.0
Murray L&D	25.8	26.0	26.2	26.4	26.6	26.8	26.9	27.1	27.2	27.4
Dardanelle L&D	60.2	59.9	59.7	59.5	59.2	59.0	58.8	58.6	58.5	58.3
Arthur V Ormond L&D	23.4	23.6	23.8	23.9	24.1	24.3	24.4	24.6	24.7	24.8
Ozark-JetaTaylor L&D	20.4	20.6	20.9	21.1	21.3	21.5	21.7	21.9	22.1	22.3
James W Trimble L&D	23.9	24.1	24.3	24.5	24.6	24.8	25.0	25.1	25.3	25.4
Robert S Kerr L&D	31.0	31.0	31.1	31.1	31.1	31.2	31.2	31.3	31.3	31.3
W D Mayo L&D	12.6	12.8	12.9	13.1	13.3	13.4	13.6	13.7	13.8	14.0
Webbers Falls L&D	26.2	26.3	26.4	26.6	26.7	26.8	26.9	27.0	27.1	27.2
Newt Graham L&D	10.8	11.0	11.1	11.3	11.4	11.5	11.6	11.8	11.9	12.0
Chouteau L&D	10.7	10.8	11.0	11.1	11.3	11.4	11.5	11.6	11.7	11.8

Table 37: One way sensitivity analysis of department of parks and tourism importance

Project	**Department of Parks and Tourism Assessment**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Keystone	38.6	38.4	38.2	38.0	37.8	37.6	37.4	37.3	37.1	37.0
Oologah	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2
Pensacola Dam	30.4	30.0	29.6	29.2	28.9	28.5	28.2	27.9	27.6	27.3
Markham Ferry Dam	18.2	17.9	17.6	17.3	17.0	16.7	16.4	16.2	16.0	15.7
Fort Gibson	28.8	28.8	28.9	28.9	29.0	29.0	29.0	29.1	29.1	29.1
Tenkiller Ferry	26.6	26.8	27.0	27.2	27.3	27.5	27.6	27.7	27.9	28.0
Eufaula	52.2	52.1	52.0	51.9	51.9	51.8	51.7	51.7	51.6	51.6
Kaw	27.4	27.1	26.9	26.6	26.4	26.2	26.0	25.8	25.6	25.4
Hulah	12.6	12.4	12.2	12.0	11.8	11.6	11.5	11.3	11.1	11.0
Copan	11.3	11.1	10.9	10.7	10.5	10.4	10.2	10.0	9.9	9.8
Wister	9.4	9.3	9.3	9.2	9.2	9.1	9.1	9.0	9.0	9.0
Blue Mountain	13.9	13.7	13.6	13.4	13.3	13.1	13.0	12.9	12.8	12.6
Nimrod	8.4	8.3	8.3	8.2	8.2	8.2	8.1	8.1	8.0	8.0
NorrellL&D	27.6	27.3	27.0	26.8	26.6	26.3	26.1	25.9	25.7	25.5
Arkansas L&D 2	40.0	39.5	39.1	38.8	38.4	38.1	37.7	37.4	37.1	36.8
Emmett Sanders L&D	28.0	27.8	27.5	27.3	27.1	26.9	26.7	26.5	26.4	26.2
Joe Hardin L&D	26.8	26.6	26.3	26.1	25.9	25.6	25.4	25.2	25.0	24.9
Arkansas L&D 5	26.6	26.4	26.2	25.9	25.7	25.5	25.3	25.1	25.0	24.8
David D Terry L&D	31.0	30.9	30.8	30.7	30.6	30.5	30.4	30.4	30.3	30.2
Toad Suck Ferry L&D	23.1	22.8	22.6	22.4	22.2	22.0	21.8	21.6	21.4	21.3
Murray L&D	28.5	28.3	28.0	27.8	27.6	27.4	27.2	27.0	26.8	26.6
Dardanelle L&D	59.9	59.5	59.2	58.9	58.6	58.3	58.0	57.8	57.5	57.3
Arthur V Ormond L&D	26.2	25.9	25.6	25.3	25.1	24.8	24.6	24.4	24.2	24.0
Ozark-JetaTaylor L&D	23.1	22.9	22.7	22.6	22.4	22.3	22.1	22.0	21.9	21.7
James W Trimble L&D	26.5	26.2	26.0	25.8	25.6	25.4	25.2	25.0	24.8	24.7
Robert S Kerr L&D	33.0	32.7	32.3	32.0	31.6	31.3	31.0	30.7	30.5	30.2
W D Mayo L&D	14.4	14.3	14.2	14.1	14.0	14.0	13.9	13.8	13.7	13.6
Webbers Falls L&D	28.4	28.1	27.9	27.6	27.4	27.2	27.0	26.8	26.7	26.5
Newt Graham L&D	12.4	12.3	12.2	12.1	12.0	12.0	11.9	11.8	11.8	11.7
Chouteau L&D	12.2	12.1	12.1	12.0	11.9	11.8	11.7	11.7	11.6	11.6

Table 38: One way sensitivity analysis of utility companies' importance

Project	**Utility Companies Assessment**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Keystone	37.8	37.8	37.7	37.7	37.7	37.7	37.6	37.6	37.6	37.6
Oologah	24.3	24.1	24.0	23.8	23.7	23.6	23.4	23.3	23.2	23.1
Pensacola Dam	27.1	27.3	27.5	27.7	27.9	28.1	28.2	28.4	28.5	28.7
Markham Ferry Dam	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
Fort Gibson	30.0	29.9	29.7	29.6	29.5	29.3	29.2	29.1	29.0	28.9
Tenkiller Ferry	29.0	28.8	28.6	28.4	28.2	28.0	27.8	27.6	27.5	27.3
Eufaula	52.9	52.7	52.6	52.4	52.3	52.2	52.0	51.9	51.8	51.7
Kaw	26.1	26.1	26.1	26.1	26.2	26.2	26.2	26.2	26.2	26.2
Hulah	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6
Copan	10.3	10.3	10.3	10.3	10.3	10.4	10.4	10.4	10.4	10.4
Wister	9.4	9.4	9.3	9.3	9.3	9.2	9.2	9.2	9.1	9.1
Blue Mountain	13.4	13.4	13.3	13.3	13.3	13.2	13.2	13.2	13.1	13.1
Nimrod	8.5	8.4	8.4	8.3	8.3	8.3	8.2	8.2	8.2	8.1
NorrellL&D	28.0	27.7	27.5	27.3	27.1	26.9	26.7	26.5	26.3	26.2
Arkansas L&D 2	37.9	37.9	38.0	38.0	38.0	38.0	38.0	38.0	38.1	38.1
Emmett Sanders L&D	28.7	28.4	28.2	27.9	27.7	27.5	27.3	27.1	26.9	26.7
Joe Hardin L&D	27.2	27.0	26.8	26.5	26.3	26.2	26.0	25.8	25.6	25.5
Arkansas L&D 5	27.1	26.9	26.7	26.4	26.2	26.0	25.9	25.7	25.5	25.4
David D Terry L&D	33.0	32.6	32.3	31.9	31.6	31.3	31.0	30.8	30.5	30.3
Toad Suck Ferry L&D	23.2	23.0	22.9	22.7	22.5	22.4	22.2	22.1	22.0	21.9
Murray L&D	28.2	28.1	28.0	27.9	27.7	27.7	27.6	27.5	27.4	27.3
Dardanelle L&D	55.5	55.9	56.3	56.7	57.0	57.4	57.7	58.0	58.3	58.6
Arthur V Ormond L&D	25.5	25.4	25.3	25.2	25.1	25.0	25.0	24.9	24.8	24.8
Ozark-JetaTaylor L&D	23.7	23.5	23.3	23.1	22.9	22.7	22.6	22.4	22.3	22.1
James W Trimble L&D	26.2	26.1	26.0	25.9	25.8	25.7	25.6	25.5	25.4	25.3
Robert S Kerr L&D	30.5	30.7	30.8	30.9	31.0	31.1	31.2	31.2	31.3	31.4
W D Mayo L&D	15.0	14.8	14.7	14.6	14.4	14.3	14.2	14.1	14.0	13.8
Webbers Falls L&D	27.5	27.5	27.4	27.4	27.4	27.3	27.3	27.3	27.2	27.2
Newt Graham L&D	12.8	12.7	12.6	12.5	12.4	12.3	12.2	12.1	12.0	11.9
Chouteau L&D	12.7	12.5	12.4	12.3	12.2	12.1	12.0	11.9	11.8	11.7

Table 39: One way sensitivity analysis of local communities' importance

Project	**Local Communities Assessment**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Keystone	37.4	37.5	37.5	37.6	37.7	37.7	37.8	37.8	37.9	37.9
Oologah	23.0	23.1	23.1	23.2	23.3	23.3	23.4	23.4	23.5	23.5
Pensacola Dam	28.6	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5
Markham Ferry Dam	16.8	16.7	16.7	16.7	16.7	16.7	16.7	16.6	16.6	16.6
Fort Gibson	28.6	28.7	28.9	29.0	29.1	29.2	29.4	29.5	29.6	29.7
Tenkiller Ferry	26.8	27.0	27.2	27.5	27.7	27.9	28.1	28.3	28.4	28.6
Eufaula	51.2	51.4	51.6	51.8	52.0	52.1	52.3	52.5	52.6	52.8
Kaw	26.3	26.2	26.2	26.2	26.2	26.2	26.2	26.1	26.1	26.1
Hulah	11.7	11.7	11.6	11.6	11.6	11.6	11.6	11.6	11.5	11.5
Copan	10.4	10.4	10.4	10.4	10.3	10.3	10.3	10.3	10.3	10.3
Wister	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.2	9.2
Blue Mountain	13.1	13.1	13.1	13.1	13.1	13.2	13.2	13.2	13.2	13.2
Nimrod	8.1	8.1	8.1	8.2	8.2	8.2	8.2	8.2	8.2	8.2
NorrellL&D	27.0	26.8	26.5	26.3	26.2	26.0	25.8	25.6	25.5	25.3
Arkansas L&D 2	38.6	38.4	38.2	38.1	37.9	37.7	37.6	37.4	37.3	37.1
Emmett Sanders L&D	27.4	27.3	27.1	26.9	26.8	26.6	26.4	26.3	26.2	26.0
Joe Hardin L&D	26.2	26.0	25.8	25.6	25.5	25.3	25.1	25.0	24.8	24.7
Arkansas L&D 5	26.1	25.9	25.7	25.5	25.4	25.2	25.1	24.9	24.8	24.6
David D Terry L&D	30.7	30.7	30.6	30.5	30.5	30.4	30.3	30.3	30.2	30.2
Toad Suck Ferry L&D	22.4	22.3	22.1	22.0	21.8	21.7	21.6	21.5	21.4	21.3
Murray L&D	27.7	27.6	27.5	27.4	27.3	27.2	27.1	27.0	26.9	26.8
Dardanelle L&D	58.2	58.3	58.3	58.3	58.3	58.3	58.4	58.4	58.4	58.4
Arthur V Ormond L&D	25.3	25.1	25.0	24.8	24.7	24.6	24.4	24.3	24.2	24.1
Ozark-JetaTaylor L&D	22.6	22.5	22.4	22.3	22.2	22.1	22.0	21.9	21.9	21.8
James W Trimble L&D	25.7	25.6	25.5	25.4	25.3	25.2	25.1	25.1	25.0	24.9
Robert S Kerr L&D	31.6	31.5	31.4	31.3	31.2	31.1	31.1	31.0	30.9	30.8
W D Mayo L&D	14.3	14.2	14.1	14.0	13.8	13.7	13.6	13.6	13.5	13.4
Webbers Falls L&D	27.4	27.3	27.3	27.2	27.2	27.1	27.1	27.0	27.0	26.9
Newt Graham L&D	12.2	12.1	12.1	12.0	11.9	11.8	11.7	11.7	11.6	11.5
Chouteau L&D	12.1	12.0	11.9	11.8	11.7	11.7	11.6	11.5	11.4	11.4