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Flood-Induced Disruption of an Inland Waterway Transportation System and Regional Economic Impacts

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Abstract: Record flooding in Spring 2019 caused Oklahoma's only inland navigable waterway to close. Closure disrupted the supply chains of agricultural and manufacturing industries. This research quantified the economic loss experienced by the region's economy due to the disruption of waterway transportation services. We used a multi-regional input–output model to analyze impacts for the state's congressional districts. The study found expected losses in employment of 63 to 750 jobs, \$14.5 million to \$165 million in output, and \$5.7 million to \$68.7 million in value-added to the economy, depending on the expected duration of closure and on assumptions regarding the sourcing of intermediate goods and services. Economic impacts were disproportionately experienced in different congressional districts and across economic sectors, depending on how tightly integrated those districts were to the manufacturing or agricultural sectors.

Keywords: waterway transportation; flood disruption; input–output model; congressional district

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1. Introduction

Extreme weather events such as floods and earthquakes can cause disruptions of navigable waterways through port closures and can result in economic losses [1–3]. Damaged infrastructure causes direct economic losses through needed repairs, but also indirect costs borne by businesses whose supply chains are interrupted, whose customers cannot purchase goods, and whose employee's commute to work is impeded. Port closures and channel disruption caused by natural events may take years to repair, triggering additional delays, instigating supply chain bottlenecks, and increasing the financial costs of doing business from demurrage and other port service payments [4,5]. Depending on the origin, density, and material composition of freight, some businesses can quickly switch to other transportation modes if waterways close, but other businesses may lack the capacity to adapt their supply chains quickly enough to manage the extra costs brought on by water transportation interruptions [6].

Metropolitan and rural economies depend on inland waterway systems in the United States (US) for receiving intermediate goods and for exporting final products to other regions [7,8]. The US Army Corp of Engineers (USACE) built inland waterways, locks, and dams in the 1930s. These infrastructures are aged well beyond their 50-year life expectancy. Yet, waterway infrastructure, its maintenance, and improvement are crucial for sustaining supply chain operations, but their maintenance is costly [9]. Congressional funding of civil work performed by the USACE increased from \$4.72 billion in the fiscal year 2013 to \$7.65 billion in 2020. A 2021 \$1.7 trillion infrastructure bill that included \$17 billion to upgrade ports, locks, and dams received bipartisan passage. The US has about 15,000 miles of inland waterways shared by 38 states, which encompasses 239 locks for transporting commerce. Understanding the economic impact of inland waterway disruption provides ex-ante information to private business, policymakers, and funding managers in their supply chain planning efforts.

The McClellan–Kerr Arkansas River Navigation System (MKARNS) is one of the largest inland waterway systems in the US. The MKARNS links rural communities and metropolitan regions of the Central Great Plains (CGP) to the Mississippi River. This navigation system serves a 12-state region including Arkansas, Oklahoma, Kansas, Texas, Colorado, Missouri, Nebraska, Minnesota, South Dakota, North Dakota, Montana, and Idaho. The USACE built the MKARNS in 1970. The MKARNS courses through the states of Oklahoma and Arkansas to the Mississippi River; it plays an important role in the transportation of goods into and out of the CGP. The system supports multiple activities, including transportation, recreation, flood control, and hydroelectric generation [5,10,11]. Major commodities transported on the MKARNS include sand and gravel, steel and iron, agricultural chemicals, and minerals [11]. According to [11], tonnage along the MKARNS totaled 11.5 million tons value at $4.7 billion in 2017. All public ports along OK-MKARNS are managed by Oklahoma's Public Port Authority (OPPA). The state of Oklahoma created the OPAA, which is considered a public agency of the state.

In spring 2019, the OK-MKARNS ceased operations due to the record flooding event on the Arkansas River. Channels became unnavigable and required dredging after flood waters subsided. All port operations were interrupted until late fall 2019; repairs to flood-damaged channels continued into 2020. Port closures disrupted the transportation of goods for months, resulting in loss of industry output, jobs, and economic value.

This research estimates the effects of a flood disruption in the head portion of the MKARNS, located in Oklahoma (OK-MKARNS hereafter). This is the first study to document the impact of the 2019 flood on this region's inland waterway using input–output methodology. The OK-MKARNS begins at the Tulsa Port of Catoosa (TPOC) and flows southeast through Arkansas for 445 miles to the Mississippi River (Figure 1). TPOC is an international port, home to the US foreign trade zone 53. There are smaller public ports on the OK-MKARNS located south of the TPOC, including the Ports of Muskogee, Keota, and others.

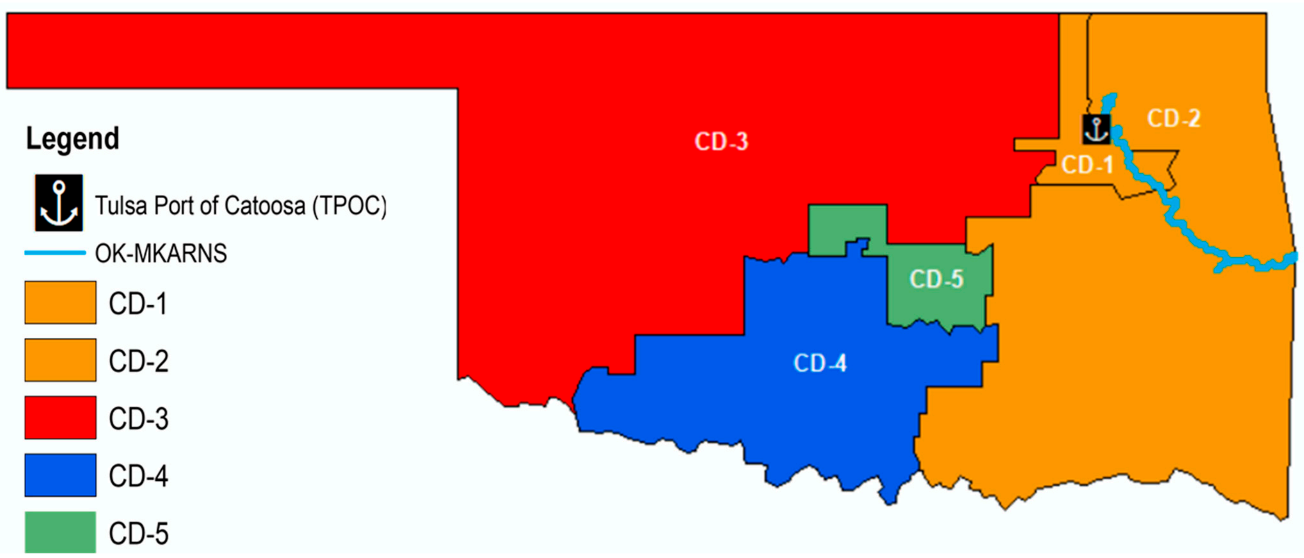

Figure 1. Study Region.

We estimated the impact of the TPOC and OK-MKARNS' closure caused by the 2019 flood on the economies of Oklahoma's congressional districts. The analysis uses the IMpact Analysis for PLANning (IMPLAN) [12,13] data and a multi-regional input–output (MRIO) model to determine (1) the economic contribution of the Oklahoma water transportation sector to the state's economy, and (2) an analysis of the direct, indirect, and induced economic impacts of the system's closure.

2. Previous Research

Refs. [14,15] categorized the methods used to measure the impact of natural disasters on economies into traditional and non-traditional approaches. Traditional approaches focus on direct and indirect economic losses from natural hazards. Direct economic impacts include observable damage or loss of on-site business. Indirect economic impacts include the downstream effects on off-site business through the transactional linkages. Input–output (IO) models [16] or computable general equilibrium (CGE) models (e.g., [17]) are frequently used in disaster economic impact studies that use the so-called traditional approach. Both IO and CGE models include all economic sectors (i.e., industries, government, and households) and transactional linkages between these sectors to provide ex-ante ranges of economic losses experienced by an economy [15,18]. IO and CGE models have been widely used to analyze the economic impacts of earthquakes (e.g., [19–22]), rainstorms and flooding (e.g., [23–25]), droughts (e.g., [26–29]), and infrastructure failure (e.g., [30–32]).

IO and CGE approaches capture the economic loss solely through business transactions and welfare transfers, but non-traditional approaches also consider system resilience assessments and how social-behavioral norms and system linkages contribute to economic loss [15]. System resilience assessments include the economic sectoral impacts from natural hazards, and how the performance and functionality of the social and institutional systems, psychology, ecological systems, and engineering affect economic loss caused by disasters. Because of their holistic perspective, non-traditional approaches have the potential to broaden understanding of costs and benefits of resilience strategies. This broader vantage leads to a more general problem scope required by private and public sectors for the development and implementation of recovery plans following a disaster [33,34]. For example, Ref. [35] investigated if tourism was an economic recovery strategy following earthquake based on regional economic resilience index. Non-traditional approaches also attempt to explain how natural hazards affect social behavior during and after a disaster (e.g., [36–38]). However, research that estimates the indirect economic impacts from social behavior following a natural hazard-induced disaster is generally limited to conceptual analysis [15,39]. This limitation is likely due to the difficulties of quantifying what is meant by 'resilience' (a socially constructed term arising from cultural context), and how this conceptual context bridges behavioral norms with economic systems.

These broader issues relating to social-economic institutions and behavioral norms are beyond the scope of this research mainly due to data limitations and funding constraints. Instead, this study uses a methodology that closely aligns with traditional natural hazards-induced disaster impact methodology, IO modeling, to estimate the direct and indirect economic losses due to the waterway transportation disruption of 2019. The IO approach is limited in scope and only focuses on changes in employment, industry output, and value added to the economy. It is incapable of incorporating institutional or behavioral norm constraints in the final analysis. Discussion of the IO modeling procedures are summarized in Section 3.

Previous Studies on the MKARNS Waterway

Early studies of the MKARNS's economic impact focused largely on its costs and benefits as a public infrastructure project (e.g., [10,40]). More recent studies estimated holding, demurrage penalties, and transportation costs by simulating disruption scenarios along portions of or the entire MKARNS waterway to aid operational and maintenance planning [19,41–44]. Refs. [19,41] used MRIO modelling to quantify the economic impact from inland port disruptions across multiple states. Existing research confirms that the MKARNS is a significant component of the nation's business sales and US gross domestic product (GDP). Complete closure of the MKARNS would result in an estimated decrease of at least $4.1 billion to US business sales [5]. Maintenance, disrepair, and disruption of navigable inland waterway infrastructure on the MKARNS have increasingly received attention. Canal banks continue to age and are less resilient to the effects of floods; channels require more frequent dredging [5].

A few studies focused on the TPOC and OK-MKARNS closure to demonstrate the economic importance of transportation through inland waterways and ports. Ref. [19] focused on losses in production in Oklahoma and cargo final destination states' (Alabama, Arkansas, Illinois, Iowa, Kentucky, Louisiana, Mississippi, Ohio, and Texas) economies, assuming different TPOC closure periods. The authors of [45] estimated that closure of the TPOC and OK-MKARNS could result in direct economic losses of $111.8 million and $72.9 million in indirect economic losses across 10 states due to a 2-week shutdown. Both studies only examined economic impacts at the state level.

The 2019 flood provides an opportunity to conduct an event study of TPOC and OK-MKARNS waterway disruption. No previous research has estimated the regional economic impacts of the 2019 OK-MKARNS flood disruption. This research differs from previous studies by focusing on the economic contribution of the OK-MKARNS and the flood's impact on total industry output (TIO), the economic value the navigation system adds to the region, and employment at the state's congressional district levels because of their role in representative fiscal policy and creating legislation for spending on infrastructure.

3. Data and Methods

Economic data on Oklahoma's industrial sector employment, regional production functions, final demand, and total industry output is from the state's IMPLAN database [13]. The 546 industry sectors IMPLAN uses were aggregated into 37 sectors to reflect the major economic activities in Oklahoma (aggregation scheme, Appendix A). The main industries of Oklahoma's economy are natural gas and petroleum (15%), financial, insurance and real estate (FIRE, 13%), and manufacturing (11%) (Table 1). Agriculture accounted for 3% of the state's TIO, but in 2019, Oklahoma ranked fifth among all other states in terms of farm numbers, fifth in cattle production, and fourth in the production of wheat [46].

Table 1. Oklahoma 2019 Total Industrial Output (TIO) by Industry Sector and Congressional districts ($ million).

Industry Sectors	Congressional Districts			
	CD-1 &CD-2 [a,b]	CD-3 [a]	CD-4 [a]	CD-5 [a]
Agriculture Inputs	1233	909	417	494
Animal Processing	1534	1596	319	386
Animal Production, except cattle and poultry and eggs	235	663	104	10
Beef Cattle Ranching and Farming	1096	1628	535	69
Breweries, Wineries, Distilleries	80	54	9	69
Commercial Fishing and Hunting	1	1		
Construction	6921	3697	2952	4862
Cotton Farming	1	212	78	2
Dairy Cattle and Milk Production	39	43	40	6
Dairy Processing	102	152	198	209
Financial, Insurance, and Real Estate	20,810	8177	7661	17,616
Food Manufacturing	1476	481	397	979
Fruit and Vegetable Farming	10	5	3	2
Government	13,517	6115	8768	10,477
Grain Farming	33	484	35	2
Greenhouse, Nursery, and Floriculture Production	104	28	18	14
Manufacturing	22,924	7432	5397	9034
Milling	1181	252	59	167
Mining	364	16	8	281
Miscellaneous	14,061	4634	5983	13,191
Natural Gas and Petroleum	21,415	12,462	9961	18,293
Oilseed Farming	46	97	4	1
Other Agriculture and Food Manufacturing	353	265	140	253
Other Transportation	7607	707	520	2188
Poultry and Egg Production	835	7	1	2

Table 1. *Cont.*

Industry Sectors	Congressional Districts			
	CD-1 &CD-2 [a,b]	CD-3 [a]	CD-4 [a]	CD-5 [a]
Primary Forestry	45	11	18	12
Rail Transportation	767	243	104	176
Retail Trade	6397	2813	2553	4583
Secondary Forestry	2612	99	326	454
Services	25,677	7773	7408	25,734
Textiles	91	21	76	68
Tree Nut Farming	8	1	5	1
Truck Transportation	1856	1129	610	1252
Utilities	5435	2262	1222	2419
Warehousing and Storage	568	85	293	605
Water Transportation	5	4	2	1
Wholesale	6680	3539	1851	6755
Total	166,119	68,097	58,075	120,667

[a] CD = congressional district; [b] Congressional districts 1 and 2 are combined into one region.

There are five congressional districts (CDs) in Oklahoma (Figure 1). The economic sectors and corresponding direct requirements matrix for the five CDs were assembled in IMPLAN, and labeled CD-1, CD-2, CD-3, CD-4, and CD-5. The OK-MKARNS flows through Congressional District 1 (CD-1, the Tulsa metropolitan statistical area) and Congressional District 2 (CD-2) before reaching Arkansas. The CD-2 includes counties in the state's eastern region spanning from the northern state line with Kansas to the southern state border with Texas and extends to the boundaries of the Oklahoma City metropolitan area. Port closures have direct impacts on both the CD-1 and CD-2's economies. Therefore, the CD-1 and CD-2 were combined into one region, CD-1&CD-2 hereafter, because the waterway flows through both districts. CD-3 covers most of the northwest portion and the southwest corner of the state. CD-4 is located in the southern part of the state. CD-5 is the three-county Oklahoma City metroplex. Most of the state's population lives in CD-1, CD-4, and CD-5.

CD-1&CD-2 has the highest TIO compared with other districts (Table 1), mainly because their economies were combined since they both include the MKARNS. For this reason, CD-1&CD-2& also have the largest total industry output (TIO, millions of dollars) for water transportation (about $5 million). CD-5's water transportation sector is the smallest (TIO, $1 million), but its other transportation sector is largest in terms of TIO ($2188 million). This is because CD-5 is a core metropolitan region with the smallest agricultural inputs and processing sector. However, the main commodities that moved through Oklahoma's water transportation systems are agricultural inputs, crops, and chemical fertilizers.

3.1. Multiregional Input–Output (MRIO) Model

Ref. [16] developed input–output (IO) analysis. Standard IO procedures quantify interdependencies between economic sectors through transaction tables. Transaction tables are composed of monetary transactions between sectors, final demand for goods, and value-added to the economy. Final demand is the sum of household consumption, government purchases, investment, and exports. Value-added to the economy includes proprietor income, other property income, taxes on production and imports, and employee compensation. Value-added is a proxy for an industry's contribution to the gross domestic product (GDP) net expenditures on intermediate inputs [47]. Each row of the transaction table depicts the relationship between inter-sectoral transactions. Table columns denote expenditures and inter-sectoral sales by the rows.

The IO model transaction table can be reduced to a system of linear equations:

$$X_i - \sum_j a_{ij} X_j = Y_i \qquad \forall i \tag{1}$$

where X_i and Y_i are the output and final demand, both denominated in dollars, of sector i (j aliases i). The parameter a_{ij} is a technical coefficient that indicates how many current units of output in sector i are required to produce one currency unit of output in sector j.

The technical coefficients, a_{ij}, are calculated as:

$$a_{ij} = \frac{z_{ij}}{X_j} \qquad \forall\, i, j \tag{2}$$

where X_j is the output of sector j, and Z_{ij} is the monetary (dollar) value of transactions from sector i to sector j to produce X_j. In matrix form, the IO model is:

$$X - AX = Y \tag{3}$$

where matrix A includes the technical coefficients, X is a vector of total industry outputs, and Y is a vector of the final demands. Equation (3) can also be transformed to Equation (4) through the matrix inversion $(I - A)^{-1}$, also known as the "Leontief inverse". The sum of the columns of this matrix yield multipliers. Multipliers measure the change in economic activity of a sector, given a $1-increase in demand for a good produced by the sector. This matrix represents the marginal change in the TIO, given a one-unit change in final demand. The complete system is:

$$X = (I - A)^{-1}Y \tag{4}$$

In a single-region input–output model, direct, indirect, and induced effects are captured in a region's economy but any effects that leave the region are leakages. A leakage is any money that exits the study region.

A multi-regional input–output (MRIO) model is an extension of the IO model. The MRIO includes interindustry transactions between trading regions. MRIO models recover leakages that are otherwise experienced in single-region IO models [47]. We used IMPLAN's modeling system to construct an MRIO model for Oklahoma's congressional districts. All prices are in 2020 dollars. There are four regions considered in the MRIO model: CD-1&CD-2 (combined CD-1 and CD-2), CD-3, CD-4, and CD-5. The MRIO model allows us to see if and how the impact of TPOC and the OK-MKARNS disruption (i.e., delay) in combined congressional district CD-1&CD-2 is affecting itself and other congressional districts in Oklahoma.

3.2. Economic Contribution Analysis

We estimate first the economic contribution of the OK-MKARNS to Oklahoma's economy and its congressional districts. Economic contribution analyses proceed by removing the forward (downstream) and backward (upstream) linkage between this economic sector and other sectors of the economy and then measuring the loss from its removal through multipliers [47–49] (A step-by-step example of the procedure is found here: https://support.implan.com/hc/en-us/articles/115009542247-IMPLAN-Pro-Multi-Industry-Contribution-Analysis (accessed on 22 June 2019)).

Figure 2 depicts the forward and backward linkages between water transportation and other sectors that define Oklahoma's economy. Inspection of the backward linkages highlights the key sectors supporting economic activity in the water transportation sector. Perhaps unsurprisingly, the magnitude of the backward link between the finance, insurance, and real estate (FIRE) and water transportation is relatively large since insurance would cover any losses incurred during warehousing or transportation of goods. Forward links from the water transportation sector to services, natural gas and petroleum, rail transport, mining, construction, truck transport, wholesale, retail, utilities, and governmental sectors underscore the role of the OK-MKARN navigation services in its support of their economic output. The vacuum that remains after the removal of the water transportation sector from

Oklahoma's economy quantifies the overall contribution of the sector to the region's output, employment, and value-added.

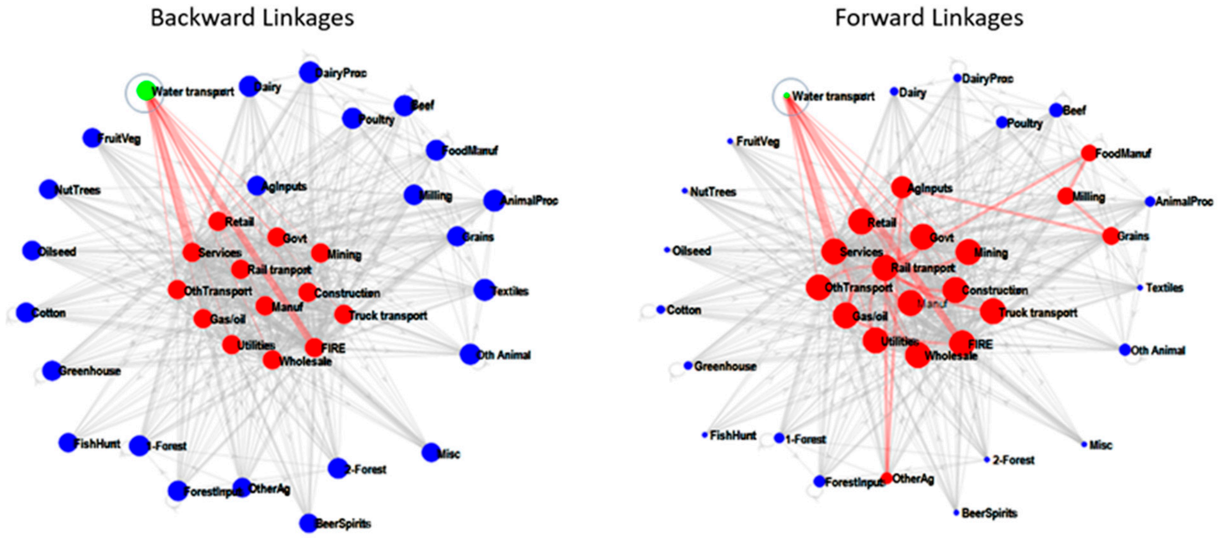

Figure 2. Water transportation backward linkages and forward linkages to other industry sectors in Oklahoma.

The contribution of the water transportation sector is calculated with an adjustment factor that preserves the output values in the transactions table while removing the water transportation sector's forward and backwards linkages [47]. In the case of the water transportation sector, the adjustment factor is the reciprocal of the water transportation sector's multiplier, and the direct contribution of the water transportation sector is the TIO $\times$ the adjustment factor [50]. The adjustment factor can also be used to quantify indirect effects (i.e., purchases from supporting industries) and induced effects (i.e., employee household spending) to all other industry sectors of the economy that result from water transportation. This type of analysis quantifies the direct, indirect, and induced effects from the removal of the water transportation sector on the state's jobs, TIO, and value added, resulting in a state total and totals for each industry sector.

3.3. Impact Analysis

The OK-MKARNS disruption results in economic shocks that have direct effects on combined region CD-1&CD-2's economy (Figure 3). The MRIO model captures the indirect and induced effects experienced in CD-3, CD-4, and CD-5 through feedback paths (Figure 3). Feedback paths map trade flows between regions through business-to-business transactions and household spending cycles between all four regions. The effects continue to cycle until all transactions and spending rounds cease. The economic shocks encompass changes in TIO for the water transportation, agricultural inputs, grain farming, oilseed farming, other agriculture and food manufacturing, manufacturing, construction, mining, and natural gas and petroleum sectors (Figure 4).

We analyzed the OK-MKARNS disruption on the regional economy under two assumptions pertaining to local purchases and sales by adjusting the regional purchasing coefficient (RPC) The RPC determines how much the total demand of a commodity or service in a region is met by supply of the commodity or service in the same region [47]. The first assumption sets the RPC to '0' for each affected sector in the combined region CD-1&CD-2, home to the OK-MKARNS system. Under this assumption, when the water transportation sector in region CD-1&CD-2 is disrupted, the industry is forced to source all their demands outside of the combined region CD-1&CD-2.

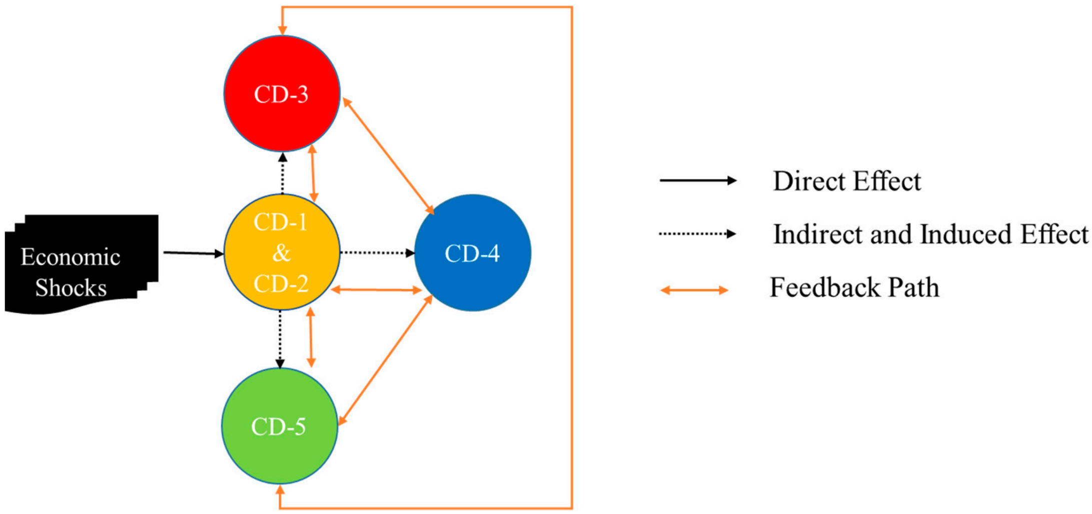

Figure 3. Flows of direct, indirect, induced, and feedback effects.

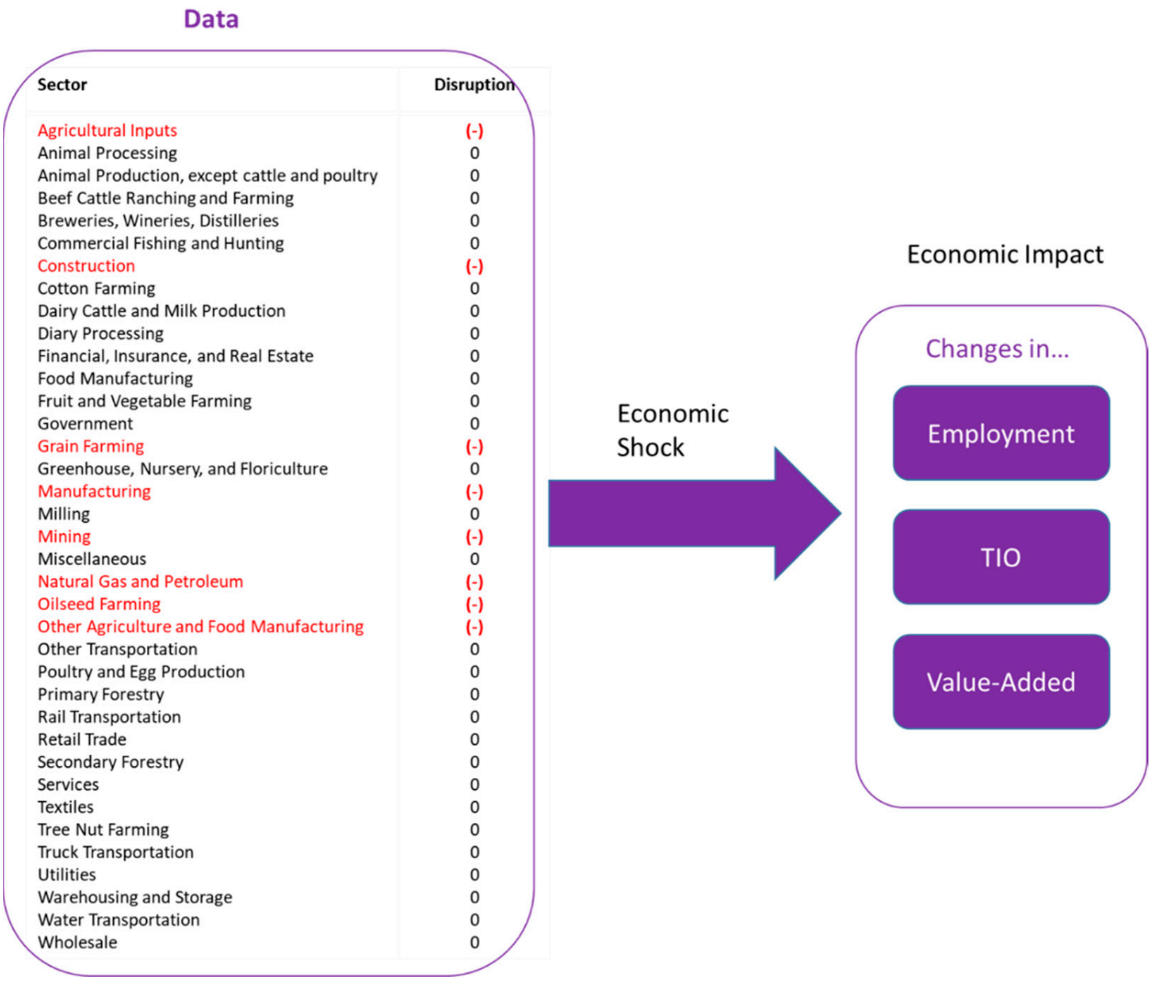

Figure 4. Scheme of economic shock and changes in employment, TIO, and value-added.

The second assumption uses an RPC linked to IMPLAN's social accounts matrix (SAM), implying that a portion of the sector's demand can be met with local supplies from the combined region CD-1&CD-2, while the remainder will be sourced from other congressional districts (CD-3, CD-4, and CD-5). The economic impacts on the combined region CD-1&CD-2 calculated under the first assumption will be smaller (more conservative) than those generated under the second assumption (less conservative) because the first assumption results in much higher leakage than the second assumption. Using these two assumptions provides a lower and upper range for the impact scenarios.

3.4. Commodity Volumes Moved through OK-MKARNS and the Disruption Costs

The 2018 commodity tonnage that moved on the OK-MKARNS were obtained from TPOC operators (Table 2). TPOC classified the goods transported through the OK-MKARNS waterway into 12 categories: chemical fertilizers, coal and coke, food and farm products, iron and steel, manufacturing equipment, minerals and building, miscellaneous products, other chemicals, petroleum products, sand, gravel, and rock (Table 2). These categories were apportioned across the aggregated 37 industry sectors. In 2018, the largest tonnage of commodity transported on the OK-MKARNS was the agricultural inputs sector (over 1.9 million tons), followed by oilseed and grain farming.

Table 2. Tonnage of Commodities Through TPOC in 2018 and Reclassification into Industry.

Industry Sectors	**TPOC Commodity [a]**	**Tonnage**
Agriculture Inputs	Chemical Fertilizers	1,955,104
Grain Farming	Grain	841,880
Oilseed Farming	Soybeans	881,902
Other Agriculture and Food Manufacturing	Food and Farm Products	240,500
Manufacturing	Manufacturing Equipment	2680
	Other Chemicals	218,263
	Iron and Steel (1) [b]	422,947
Construction	Iron and Steel (2) [b]	172,753
Mining	Coal and Coke	358,500
	Minerals and Building Products	131,282
	Sand, Gravel, and Rock	147,000
Natural Gas and Petroleum	Petroleum Products	99,000

[a] Category of commodities that are through. [b] A portion of iron and steel (i.e., Iron and Steel (1)) were classified into manufacturing and the rest (Iron and Steel (2)) were classified into construction.

Most TPOC commodity categories could be directly linked to a specific industry in IMPLAN. For example, the TPOC commodities of coal and coke; minerals and building materials (e.g., cement); and sand, gravel, and rock were reclassified into the sector of 'Mining'. However, some of the commodity categories overlapped with one or more of the 37 industry aggregation categories. For these industries, a weight was calculated using the ratio of the total industry output (TIO) of the industry to the total TIO of all related industries. For example, "iron and steel" could be allocated to either construction or manufacturing. Therefore, a weight for "iron and steel" in construction and a weight for "iron and steel" in manufacturing were calculated as follows. The TIO for construction was $18 billion, and the TIO for manufacturing was $45 billion. The $18 billion figure was divided by the combined TIO of construction and manufacturing ($63 billion), which resulted in a construction weight of 0.29. This process was repeated for manufacturing. Next, the total value of the "iron and steel" tonnage reported by TPOC was multiplied by their respective weights. Lastly, the share-weighted values were allocated to the manufacturing and construction industry sectors (Table 2).

Disruption costs per tonnage by commodity and by disruption length were obtained from the delay costs estimated by [5] (Table 3). The total amount of tonnage delayed was assumed to be equivalent to the amount of tonnage that would normally flow through the system during the period. Tonnage per month was assumed to be 1/12 of the total tonnage for the year. There are likely seasonal fluctuations in tonnage that flows through the OK-

MKARNS, but assuming consistent tonnage per month allows the results to be applied to other closure situations that may occur at different times of the year other than the 2019 flood. If there is a 2-month delay scenario, the cost of delay is estimated by multiplying the 2-month delay cost per ton by the tonnage delayed per month. For example, 2-month delay costs for the industry "Chemical Fertilizer" are $11.25 per ton. This number is multiplied by the 2-month tonnage of chemical fertilizers, which yields the total delay cost. The delay costs for these industries are used as shocks caused by disruption. The delay costs from [5] were inflated to 2019 US dollars.

Table 3. Costs by Commodity and Length of Disruption ($ per tonnage).

TPOC Commodity	2-Month [a]	4-Month [b]	6-Month [a]
Chemical Fertilizers	11.25	24.82	38.39
Grain	7.41	19.17	30.92
Soybeans [c]	7.41	19.17	30.92
Food and Farm Products	6.84	18.49	30.13
Manufacturing Equipment	34.00	72.02	109.63
Other Chemicals	10.01	22.74	35.47
Iron and Steel	13.06	28.18	43.29
Coal and Coke	5.23	16.67	28.10
Minerals and Building Products	10.07	22.89	35.71
Sand, Gravel, and Rock	0.55	3.03	5.50
Petroleum Products	10.31	23.21	36.11

[a]: Source: [5]. [b]: Cost of 4-month delay is an average between 2 months and 6 months delay. [c]: Soybean delay costs were missing in [5]. We assumed soybean had the same delay costs as grain.

4. Results and Discussion

4.1. Economic Contribution

The contribution of the water transportation sector to Oklahoma's economy is estimated to be employment of 38 jobs, $9.6 million in industry output, and $2.2 million in value-added (Table 4). The indirect and induced employment, TIO, and value-added generated from water transportation are mainly in the "Natural Gas and Petroleum", "Services", "Other Transportation", "Retail Trade", FIRE, and "Government Sectors" (Tables 5–7). The reason these sectors had the largest indirect and induced effects is because of the size of their transactions with water transportation.

Table 4. Contribution of the OK-MKARNS to Oklahoma Economy.

	Employment	Value-Added ($ millions)	Total Industry Output (TIO) ($ millions)
Direct	10	−0.6	4.5
Indirect	24	2.5	4.5
Induced	4	0.3	0.5
Total	38	2.2	9.6
Multiplier	**3.88**	**−3.34**	**2.10**

The significance of the water transportation industry's contribution to the Oklahoma economy is evident in the employment and TIO multipliers. For every job in the water transportation industry, an additional 3.88 total jobs are generated in across all regions. A 1-dollar increase in demand for water transportation services generates an additional $2.1 − $1 = $1.1 of regional economic activity. Mining is the only industry in Oklahoma that creates larger indirect and induced values than the water transportation industry for each dollar of output, with a multiplier of $2.71 − $1 = $1.71. Thus, while the water transportation sector's aggregate TIO value is comparatively small, its multiplier is relatively larger and comparable with the mining sector. The relatively large size of the water transportation sector's multiplier is indicative of its role in terms of capacitating the supply chains of other sectors. The value-added multiplier for the water transportation industry is negative. This occurs because the sector's proprietor's income was negative. Proprietor's income is a proxy for profits. In years of lower prices, or higher operational costs, an industry's operating surplus (profit) may be lower than its operating expenses. In addition, the OK-MKARNS system is an imperfect public good. This means that the navigation system is subject to congestion because it can be used by anyone. The public ports are not privately owned companies with profit maximizing objectives. If other value-added components fail to counterbalance operating losses, then the multiplier will be negative.

Table 5. Contribution of the water transportation to employment by industry (number of jobs).

Industry Sectors	Direct	Indirect	Induced	Total
Oilseed Farming				
Grain Farming				
Fruit and Vegetable Farming				
Tree Nut Farming				
Greenhouse, Nursery, and Floriculture Production				
Cotton Farming				
Beef Cattle Ranching and Farming				
Dairy Cattle and Milk Production				
Poultry and Egg Production				
Animal Production, except cattle and poultry and eggs				
Primary Forestry				
Commercial Fishing and Hunting				
Natural Gas and Petroleum		1.21	0.02	1.23
Mining		0.01		0.01
Services		6.47	1.21	7.68
Utilities		0.05	0.01	0.06
Construction		0.64	0.06	0.70
Textiles				
Milling				
Food Manufacturing		0.01		0.02
Dairy Processing				
Animal Processing				
Breweries, Wineries, Distilleries				
Secondary Forestry		0.01		0.01
Agriculture Inputs			0.01	0.01
Other Agriculture		0.19	0.04	0.23
Wholesale		0.67	0.07	0.74
Retail Trade		0.79	0.77	1.56
Rail Transportation		0.01		0.01
Water Transportation	9.68			9.68
Truck Transportation		0.28	0.03	0.31
Other Transportation		2.09	0.02	2.12
Warehousing and Storage		0.60	0.03	0.63
Financial, Insurance, and Real Estate		3.15	0.54	3.70
Miscellaneous		1.29	0.69	1.98
Government		6.38	0.38	6.76
Manufacturing		0.13	0.01	0.14

Table 6. Contribution of the water transportation to TIO by industry ($ thousands).

Industry Sectors	Direct	Indirect	Induced	Total
Oilseed Farming				
Grain Farming				
Fruit and Vegetable Farming				
Tree Nut Farming				
Greenhouse, Nursery, and Floriculture Production				
Cotton Farming				

Table 6. *Cont.*

Industry Sectors	Direct	Indirect	Induced	Total
Beef Cattle Ranching and Farming				
Dairy Cattle and Milk Production				
Poultry and Egg Production				
Animal Production, except cattle and poultry and eggs				
Primary Forestry				
Commercial Fishing and Hunting				
Natural Gas and Petroleum		731	13	744
Mining		1		1
Services		679	119	797
Utilities		47	10	58
Construction		83	8	91
Textiles				
Milling				1
Food Manufacturing		5	1	6
Dairy Processing		1		1
Animal Processing		1	1	2
Breweries, Wineries, Distilleries				
Secondary Forestry		3	1	4
Agriculture Inputs		1	2	3
Other Agriculture		6	1	7
Wholesale		195	21	216
Retail Trade		66	63	129
Rail Transportation		7	1	8
Water Transportation	4542			4542
Truck Transportation		49	5	54
Other Transportation		675	7	681
Warehousing and Storage		62	3	66
Financial, Insurance, and Real Estate		888	153	1041
Miscellaneous		147	74	221
Government		780	48	828
Manufacturing		55	3	58

Table 7. Contribution of the water transportation to value-added by industry ($ thousands).

Industry Sectors	Direct	Indirect	Induced	Total
Oilseed Farming				
Grain Farming				
Fruit and Vegetable Farming				
Tree Nut Farming				
Greenhouse, Nursery, and Floriculture Production				
Cotton Farming				
Beef Cattle Ranching and Farming				
Dairy Cattle and Milk Production				
Poultry and Egg Production				
Animal Production, except cattle and poultry and eggs				
Primary Forestry				
Commercial Fishing and Hunting				
Natural Gas and Petroleum		246	4	250
Mining				
Services		372	63	435
Utilities		17	3	20
Construction		36	3	40
Textiles				
Milling				
Food Manufacturing		1		2
Dairy Processing				
Animal Processing				

Table 7. *Cont.*

Industry Sectors	Direct	Indirect	Induced	Total
Breweries, Wineries, Distilleries				
Secondary Forestry		1		1
Agriculture Inputs			1	1
Other Agriculture		3	1	4
Wholesale		111	12	123
Retail Trade		37	35	72
Rail Transportation		5	1	5
Water Transportation	−646			−646
Truck Transportation		24	2	26
Other Transportation		546	5	551
Warehousing and Storage		26	1	28
Financial, Insurance, and Real Estate		455	78	533
Miscellaneous		72	36	108
Government		553	34	587
Manufacturing		16	1	17

Compared to other industries in the region, "Mining" (employment multiplier, 6.54) and "Utilities" (employment multiplier, 4.35) are the only other industries with employment multipliers larger than the water transportation sector (Appendix B). Water transportation has a negative direct value-added, but it creates enough indirect and induced value-added to have the fifth largest value-added multiplier behind "Poultry and Egg Production", "Dairy Cattle and Milk Production", "Mining", and "Animal Processing". The water transportation industry does not have the largest total impact numbers by indicator compared to other industries, but it does make a notable contribution through the multiplier effect observed in the indirect and induced effects for each indicator. Again, this is indicative of the essential transportation services the system provides as supply chain support for other industries.

4.2. Regional Economic Impacts

Water transportation disruptions result in lost jobs and a decrease in output and value-added across all regions, including CD-1&CD-2, CD-3, CD-4, and CD-5 (Tables 8–10). The direct effects are compartmentalized in CD-1&CD-2 since this is where the flood events exerted their impact on the water transportation system. Employment and TIO decreased in all regions.

For CD-1&CD-2, a 2-month disruption in water transportation results in a loss of 34 direct jobs and ranged between 28–33 in indirect and induced jobs, depending on the RPC assumptions. When the RPC was set to zero (i.e., high leakage), the economic impact to the region CD-1&CD-2 was smaller. This occurred because only a portion of final demand could be met from supplies inside of the region. The increased disruption periods of 4- and 6-months brought with them larger negative effects on employment (161 and 381 jobs, respectively). Induced job losses ranged between 126 to 150 (4-month delay) and 293 to 350 (6-month delay). Job losses in other regions were relatively small. Less than one job was lost in other regions when the disruption length was two months. When the disruption length was longer, the most affected region in terms of job loss was CD-3. This is the largest congressional district and a major agricultural producer. Industries most affected include "Grain Farming", "Agriculture Inputs", "Oilseed Farming", "Services", and "FIRE". "Grain Farming", "Agriculture Inputs", and "Oilseed Farming" were directly impacted by the waterway's closure because they are industries that normally use the OK-MKARNS to receive fertilizer and ship grains and oilseed. Agriculture exports are important to Oklahoma's economy, with 4.7% of the 2017 US wheat exports (Grain Farming) originating from Oklahoma [46]. "Services" and "FIRE" incurred relatively larger indirect and induced losses. CD-4 was the least impacted region. This region is a large metropolitan area and does not directly depend on water transport for transportation needs.

Table 8. Impact on loss in employment under different length of water transportation disruption.

Length of Disruption	Regions	Direct	Indirect [a]	Induced [a]	Total [a,b]
2-Month	CD-1&CD-2	−34.06	[−14.83, −18.45]	[−13.19, −15.05]	[−62.09, −67.56]
	CD-3		[−0.32, −0.34]	[−0.45, −0.49]	[−0.78, −0.83]
	CD-4		[−0.13, −0.14]	[−0.06, −0.06]	[−0.19, −0.21]
	CD-5		[−0.29, −0.31]	[−0.15, −0.16]	[−0.43, −0.47]
	Total	−34.06	[−15.57, −19.24]	[−13.85, −15.76]	[−63.49, −69.07]
4-Month	CD-1&CD-2	−161.33	[−61.70, −77.70]	[−64.23, −72.75]	[−287.26, −311.78]
	CD-3		[−1.58, −1.65]	[−2.13, −2.33]	[−3.71, −3.98]
	CD-4		[−0.66, −0.71]	[−0.36, −0.40]	[−1.02, −1.11]
	CD-5		[−1.38, −1.46]	[−0.80, −0.87]	[−2.17, −2.34]
	Total	−161.33	[−65.32, −81.52]	[−67.52, −76.35]	[−294.16, −319.21]
6-Month	CD-1&CD-2	−381.8	[−140.61, −177.75]	[−153.13, −173.13]	[−675.54, −732.68]
	CD-3		[−3.75, −3.93]	[−5.03, −5.49]	[−8.78, −9.42]
	CD-4		[−1.58, −1.71]	[−0.90, −1.00]	[−2.48, −2.71]
	CD-5		[−3.26, −3.46]	[−1.96, −2.14]	[−5.22, −5.61]
	Total	−381.8	[−149.2, −186.85]	[−161.02, −181.76]	[−692.02, −750.42]

[a] The first entry in the bracket ('[ ]') is calculated with the RPC equals to zero I, and the second entry in the blanket is calculated with the RPC equals to MPLAN SAM. [b] Total is the sum of direct, indirect, and induced.

Table 9. Impact on decrease in TIO under different length of water transportation disruption ($ millions).

Length of Disruption	Regions	Direct	Indirect [a]	Induced [a]	Total [a,b]
2-Month	CD-1&CD-2	−9.2	[−3.1, −4.0]	[−1.9, −2.3]	[−14.3, −15.5]
	CD-3		[−0.08, −0.09]	[−0.06, −0.07]	[−0.1, −0.2]
	CD-4		[−0.03, −0.03]	[−0.01, −0.01]	[−0.04, −0.04]
	CD-5		[−0.08, −0.09]	[−0.02, −0.03]	[−0.1, −0.1]
	Total	−9.2	[−3.29, −4.21]	[−1.99, −2.41]	[−14.54, −15.84]
4-Month	CD-1&CD-2	−41.5	[−13.0, −16.9]	[−9.5, −10.9]	[−64.0, −69.3]
	CD-3		[−0.4, −0.4]	[−0.3, −0.3]	[−0.7, −0.7]
	CD-4		[−0.1, −0.2]	[−0.05, −0.05]	[−0.2, −0.2]
	CD-5		[−0.4, −0.4]	[−0.1, −0.1]	[−0.5, −0.5]
	Total	−41.5	[−13.9, −17.9]	[−9.95, −11.35]	[−65.4, −70.7]
6-Month	CD-1&CD-2	−96.8	[−29.7, −38.7]	[−22.6, −26.0]	[−149.1, −161.5]
	CD-3		[−0.9, −1.0]	[−0.7, −0.8]	[−1.6, −1.7]
	CD-4		[−0.3, −0.4]	[−0.1, −0.1]	[−0.4, -0.5]
	CD−5		[−0.9, −0.9]	[−0.3, −0.4]	[−1.2, −1.3]
	Total	−96.8	[−31.8, −41.0]	[−23.7, −27.3]	[−152.3, −165.0]

[a] The first entry in the bracket ('[ ]') is calculated with the RPC equals to zero I, and the second entry in the blanket is calculated with the RPC equals to MPLAN SAM. [b] Total is the sum of direct, indirect, and induced.

The impact of the flood event on TIO and the value-added follows a pattern similar to employment (Tables 8 and 9). The direct impact on TIO is a loss of $41.5 million in CD-1&CD-2 when for a 4-month disruption, while it increases to $96.8 million when the system is inoperable for 6-months (Table 8). Induced and indirect impacts are mainly experienced in CD-1&CD-2, while CD-3 has a higher induced and indirect TIO loss range compared with CD-4 and CD-5. Many of CD-3's agricultural related industries rely on water transportation. The loss in value-added ranges from $26.88 to $29.29 million when the disruption length is 4-month. The range in losses reaches up to $63.2 to $68.7 million when the system is shut down for 6-months.

The estimated economic impact from this research is different from [5,45]. Ref. [5] estimated a 6-month traffic disruption on the MKARNS would cause a loss of 230 jobs, $48.8 million in TIO, and $23.9 million in value-added. Ref. [45] reported that loss in output for a two-week closure of the MKARNS was $22 million for Oklahoma. Differences in these estimates from the current analysis is due to differences in the scope of the region.

Refs. [5,45] analyzed the MKARNS system and surrounding states, including Kansas, Arkansas, Texas, Missouri, and Oklahoma. Although their estimates for Oklahoma were smaller, their total estimates including all the regions in their studies were larger, which is likely attributable to a larger study region.

Table 10. Impact on decrease in value-added under different length of water transportation disruption ($ millions).

Length of Disruption	Regions	Direct	Indirect [a]	Induced [a]	Total [a,b]
2-Month	CD-1&CD-2	−2.8	[−1.7, −2.1]	[−1.1, −1.2]	[−5.6, −6.2]
	CD-3		[−0.04, −0.04]	[−0.03, −0.04]	[−0.07, −0.07]
	CD-4		[−0.01, −0.01]	[−0.004, −0.004]	[−0.01, −0.02]
	CD-5		[−0.04, −0.04]	[−0.01, −0.01]	[−0.05, −0.06]
	Total	−2.8	[−1.79, −2.19]	[−1.14, −1.25]	[−5.73, −6.35]
4-Month	CD-1&CD-2	−13.8	[−7.1, −8.7]	[−5.2, −5.9]	[−26.2, −28.5]
	CD-3		[−0.2, −0.2]	[−0.2, −0.2]	[−0.3, −0.4]
	CD-4		[−0.05, −0.06]	[−0.02, −0.03]	[−0.08, −0.09]
	CD-5		[−0.2, −0.2]	[−0.07, −0.08]	[−0.3, −0.3]
	Total	−13.8	[−7.55, −9.16]	[−5.49, −6.21]	[−26.88, −29.29]
6-Month	CD-1&CD-2	−33	[−16.2, −19.8]	[−12.4, −14.1]	[−61.6, −67.0]
	CD-3		[−0.4, −0.4]	[−0.4, −0.4]	[−0.8, −0.8]
	CD-4		[−0.1, −0.1]	[−0.06, −0.07]	[−0.2, −0.2]
	CD-5		[−0.4, −0.5]	[−0.2, −0.2]	[−0.6, −0.7]
	Total	−33	[−17.1, −20.8]	[−13.06, −14.77]	[−63.2, −68.7]

[a] The first entry in the bracket ('[ ]') is calculated with the RPC equal to zero I, and the second entry in the blanket is calculated with the RPC equals to MPLAN SAM. [b] Total is the sum of direct, indirect, and induced.

5. Conclusions and Future Research

The prospect of more frequent and intense flooding events is a cause for concern over economic and social losses related to supply-chain bottlenecks caused by transportation disruptions. The unprecedented flooding events of 2019 shut down the Central Great Plain's gateway to the Mississippi River and international commerce—the McClellan–Kerr Arkansas River Navigation System. This study's main contribution was quantifying the economic impacts of this disruption of Oklahoma's regional economy. The total economic contribution of the water transportation is relatively small compared to other sectors, but its multiplier effects are substantial and comparable to the state's largest economic sectors, such as mining, natural gas, and petroleum production. This result is mainly due to the water transportation services the region's other major economic sectors, particularly agriculture, mining, and manufacturing.

The disruption of the OK-MKARNS also had regional economic impact on industries and regions that depend either directly or indirectly on OK-MKARNS waterborne transportation services. The multi-regional input and output results show that the economic impact of the waterway's disruption increases nonlinearly as the duration of closure is extended. Regions whose economies rely more on the agricultural sector are most affected. This research investigated three disruption lengths. The results indicate significant losses throughout the state, with losses increasing as the duration of the disruption increased. Findings suggest that disruption in Oklahoma's water transportation system had greater indirect and induced impacts on the productivity of agriculture-producing regions compared to other, more densely populated locations.

There are limitations to this research. Only economic impact of floods on Oklahoma's economy and its congressional districts were estimated. Estimates may therefore be lower than the actual economic losses because businesses in other neighboring states, such as Arkansas, Colorado, and Kansas, are likely affected by the OK-MKARNS closure. Future studies may benefit by incorporating the economic contribution and losses in other states if such data becomes available. Another limitation is lack of flexibility on transportation mode changes under the prolonged interruption scenarios. Business could find alternative transportation if the waterway transportation is shut down or in congestion for longer periods. Lastly, the IO modelling assumptions presume that (1) industry supply is perfectly elastic and that any changes in final demand will always be met, and (2) industry production functions are fixed-proportion technology ('Leontief technology' assumption). These assumptions are likely to hold in the short-term (~1 to 2 years), but not over longer (~5+ years) periods. It is generally advisable to provide a range of expected impacts, as was done in this study. Evaluating the impacts at lower and upper bounds provides some indication of model uncertainty. A more flexible modeling approach might entail the use of a CGE model, which relaxes the fixed-proportion technology and perfectly elastic supply assumptions. Development of a CGE model would be a logical next step for this research.

Ref. [51] defines an 'impure' public good as one that simultaneously provides access to several users but is subject to congestion. Defined this way, the Oklahoma water transportation (i.e., TPOC and OK-MKARNS), and other transportation infrastructure, are impure public goods. The benefits entities receive from impure public goods diminish as congestion increases. The causes of congestion vary from the obvious case of many users accessing the good to more subtle causes related to maintenance and repair. The 2019 flood's magnitude caused the extended closure, but so did the condition of the waterway's channels and locks. What remains unknown is whether increasing the waterway's resiliency to extreme flooding events through continued maintenance would have shortened the closure period. More frequent waterway maintenance and repair of the waterway would require fiscal budgeting through legislation, or an increased use of the waterway's transportation services by agricultural, mining, and manufacturing industries. An obstacle a government faces in maintaining a public good and sustaining a level of service provided is household and other stakeholder's willingness to pay for the good. Toward this end, future analyses could collect primary data on waterway beneficiaries' knowledge of the OK-MKARNS use and existence value. Future analysis could also focus on estimating the flood impacts using a computable general equilibrium model, which would allow for greater flexibility in the economic modeling assumptions such as sourcing behavior.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Industry Aggregation.

Aggregated Industry	Industry in Aggregation
Oilseed farming	Oilseed farming
Grain farming	Grain farming
Fruit and vegetable farming	Vegetable and melon, and other fruit farming
Tree nut farming	Tree nut farming

Table A1. *Cont.*

Aggregated Industry	Industry in Aggregation
Greenhouse, nursery, and floriculture production	Greenhouse, nursery, and floriculture production
Cotton farming	Cotton farming
Beef cattle ranching and farming	Beef cattle ranching and farming, including feedlots and dual-purpose ranching and farming
Dairy cattle and milk production	Dairy cattle and milk production
Poultry and egg production	Poultry and egg production
Animal production	Animal production, except cattle and poultry and eggs
Primary forestry	Forestry, forest products, and timber tract production; Commercial logging
Commercial fishing and hunting	Commercial fishing, hunting, and trapping
Natural Gas and Petroleum	Oil and gas extraction; drilling oil and gas wells; support activities for oil and gas operations; petroleum refineries; industrial gas manufacturing
Mining	All commercial mining and other nonmetallic minerals; drilling oil and gas wells; supportive activities for oil and gas operation
Services	All services
Utilities	Electric power generation, transmission and distribution; natural gas distribution; water, sewage, and other systems
Construction	All constructions, maintenance and repair
Textiles	All textiles
Milling	Flour and rice milling, malt manufacturing; wet corn milling; soybean and other oilseed processing; fats and oils refining and blending; sugar cane mills and refining
Food manufacturing	All food manufacturing
Dairy processing	Cheese and dairy production
Animal processing	Poultry processing; animal, except poultry, slaughtering; meat processed from carcasses; rendering and meat byproduct processing; seafood product preparation and packaging; leather and hide tanning and finishing
Breweries, wineries, distilleries	Breweries; wineries; distilleries
Secondary forestry	Furniture, wood work manufacturing; and all other converted paper product manufacturing
Agriculture inputs	Support activities for agriculture and forestry; other animal food, fertilizer, pesticide and other agricultural chemical manufacturing; farm machinery and equipment, lawn and garden equipment manufacturing
Other agriculture	Tobacco, sugarcane, and sugar beet farming; all other crop farming; Landscape and horticultural services
Wholesale	Wholesale
Retail trade	Dealers; retail stores
Rail transportation	Rail transportation
Water transportation	Water transportation
Truck transportation	Truck transportation
Other transportation	Air transportation; transit, ground passenger, pipeline, scenic and sightseeing transportation; support activities for transportation; couriers and messengers; warehousing and storage

Table A1. *Cont.*

Aggregated Industry	Industry in Aggregation
Warehousing	Warehousing
Financial, Insurance, Real Estate	Depository and non-depository credit intermediation; brokerage; financial vehicles; insurance carriers, agencies, brokerage, and related activities; Real estate and owner-occupied dwellings
Miscellaneous	All other industries (used goods, scrap, religious, business, and social organizations)
Government	Schools, local and federal electric utilities; transit, state and local government enterprises; local and federal employment and payroll of state and federal government, rest of the world adjustment
Manufacturing	Non-food manufacturing (not including agricultural and forestry input- or output-related manufacturing)

Appendix B

Table A2. Multipliers by Industry.

Industry	Output Multiplier	Employment Multiplier	Value-AddedMultiplier
Oilseed Farming	1.62	3.10	1.47
Grain Farming	1.84	2.32	2.12
Fruit and Vegetable Farming	1.59	1.36	1.95
Tree Nut Farming	1.61	1.16	1.68
Greenhouse, Nursery, and Floriculture Production	1.59	1.44	1.89
Cotton Farming	1.51	1.43	1.67
Beef Cattle Ranching and Farming	1.54	1.25	1.95
Dairy Cattle and Milk Production	1.68	2.64	3.72
Poultry and Egg Production	1.53	2.35	5.07
Animal Production, except cattle and poultry and eggs	1.42	1.21	1.29
Primary Forestry	1.56	1.20	1.65
Commercial Fishing and Hunting	1.41	1.09	1.38
Natural Gas and Petroleum	1.48	2.68	1.64
Mining	2.71	3.27	3.48
Services	1.45	1.31	1.43
Utilities	1.56	4.35	1.96
Construction	1.69	1.62	1.82
Textiles	1.48	1.44	1.84
Milling	1.38	6.54	2.63
Food Manufacturing	1.46	1.93	1.91
Dairy Processing	1.59	3.11	2.76
Animal Processing	1.71	3.44	3.37
Breweries, Wineries, Distilleries	1.48	2.18	1.82
Secondary Forestry	1.50	2.35	1.79
Agriculture Inputs	1.66	1.99	2.20
Other Agriculture	1.73	1.16	1.78
Wholesale	1.59	2.23	1.56
Retail Trade	1.73	1.38	1.69
Rail Transportation	1.48	3.13	1.38
Water Transportation	2.10	3.88	−3.31 [a]
Truck Transportation	1.89	1.92	2.03
Other Transportation	1.70	3.00	1.45
Warehousing and Storage	1.81	1.51	1.96
Financial, Insurance, and Real Estate	1.30	1.64	1.32
Miscellaneous	1.53	1.37	1.57

Table A2. *Cont.*

Industry	Output Multiplier	Employment Multiplier	Value-AddedMultiplier
Government	1.59	1.42	1.38
Manufacturing	1.45	2.14	1.85

[a] The value-added multiplier for the water transportation industry is negative. This occurs because the positive total value added ($2.2 million) is divided by the negative direct value added of $0.6 million (Table 4). The direct effect is negative because the OK-MKARNS has a large negative proprietor income. In bad years of lower prices or higher operational costs, an industry's operating surplus (profit) may be lower than operating expenses. If other value-added components fail to counterbalance operating losses, then the calculated multiplier will be negative.

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