Gulf Intracoastal Waterway
Coastal Resilience Study, Texas

Economic Appendix A

DRAFT

Texas Gulf Coast

Matagorda County, Texas

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US Army Corps of Engineers ®
Galveston District

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List of Acronyms

AIS	Automatic Identification System
AISAP	Automatic Identification System Analysis Package
BCR	Benefit Cost Ratio
BRFG	Brazos River Flood Gates
CBA	Cost Benefit Analysis
CRL	Colorado River Locks
CRS	Coastal Resilience Study
DOE	Department of Energy
EIA	Energy Information Association
ERDC	Engineer Research and Development Center
FWOP	Future Without Project
FWP	Future With Project
FY	Fiscal Year
GICA	Gulf Intracoastal Canal Association
GIWW	Gulf Intracoastal Waterway
ICA	Incremental Cost Analysis
LPMS	Lock Performance Monitoring System
MC	Marginal Cost
MLLW	Mean Lower Low Water
MSL	Mean Sea Level
NED	National Economic Development
OCE	Office of the Chief of Engineers
O&M	Operations and Maintenance
PA	Placement Area
PCXIN-RED	Planning Center of Expertise for Inland Navigation and Risk Informed Economics Division
SWG	Southwest Galveston District
TXDOT	Texas Department of Transportation
USACE	US Army Corps of Engineers
USCG	US Coast Guard
USFWS	US Fish and Wildlife Service
WCSC	Waterborne Commerce Statistics Center
WOPC	Without Project Condition
WPC	With Project Condition

1.0 INTRODUCTION

Conducting a study on resilience offers computational challenges to come up with meaningful results. For this particular study, after much consideration in various approaches, it was determined that a combination of a traditional benefit cost calculation, a tradeoff analysis, and a modified cost effectiveness and incremental cost analysis was the most appropriate approach. Each of those pose challenges of themselves, but when assessed as a whole and coupled with qualitative analysis, the results of the analysis are strengthened.

Traditional benefit cost calculations use transportation cost savings and the cost of construction and maintenance to determine a benefit cost ratio.

Tradeoff analysis compares a list of various options and considers beneficial and adverse responses to each option.

Cost effectiveness compares the annual costs and benefits of plans under consideration to identify the least cost plan alternative for each possible level of environmental output, and for any level of investment, the maximum level of output is identified.

Incremental cost analysis of the cost-effective plans is conducted to reveal changes in costs as output levels are increased. Results from both analyses are presented graphically to help planners and decision makers select plans. For each of the best buy plans identified through incremental cost analysis, an "is it worth it?" analysis is then conducted for each incremental measure or plan to justify the incremental cost per unit of output to arrive at a recommended plan.

Qualitative assessments include information that is known or likely to occur, but perhaps is difficult to quantify the magnitude. This information could be acquired through interviews, professional knowledge and experience, or observational data.

2.0 OVERVIEW OF THE GIWW

The Gulf Intracoastal Waterway (GIWW) is a man-made shallow draft waterway that is over 100-years old and traces the U.S. coast along the Gulf of Mexico 1,100 miles from Appalachia Bay near St. Marks, FL, to the United States-Mexico border at Brownsville, TX. The GIWW is authorized as part of the Inland Waterways System to provide navigation through a 12-foot deep by 125-foot-wide channel. The GIWW is a critical part of our nation's infrastructure and confers wide-ranging benefits on national and state economies. The waterway is important not only to American commerce, but it supports a variety of other public purposes including flood control and water-based recreational activities.

The Texas section of the GIWW has two controlled systems, the Brazos River Floodgates and the Colorado River Locks. The East and West Brazos River Floodgates are located at GIWW West mile 404.1, and the East and West Colorado River locks are located at GIWW West mile 444.8. The Brazos River Floodgates and the Colorado River Locks are located along the intersections of the GIWW with the Brazos River in Brazoria County and Colorado River in Matagorda County, respectfully.

2.1 SUMMARY OF GEOGRAPHICAL LOCATION

The project area encompasses approximately 85 miles of the Texas portion of the GIWW in Brazoria and Matagorda Counties, Texas. The study area is generally bounded between Port O'Connor, Texas and Galveston, Texas. The portion of the GIWW in Texas is authorized to 125-feet wide and -13 feet mean lower low water (MLLW) for approximately 406 miles along the coast. Maintenance material is placed into confined upland placement areas (PAs), open water unconfined PAs, side-cast along the channel and placed on partially confined barrier islands. Fringe barrier islands that originally buffered the GIWW from Gulf of Mexico currents and waves is eroding or in many cases has eroded away leaving the channel exposed to cross currents and wave action. In other areas there are breaches between features such as the GIWW and lakes or bays. The map below shows the general study area location.

Figure 1 - GIWW CRS Study Area (Brazoria and Matagorda Counties, Texas)

The study area was divided into several areas sectioned by zones. Each zone shared similar navigational characteristics. As the navigational conditions changed, a new zone was identified. In the entire study area, 18 zones were created, but the zones of primary focus included zones 11 through 18, as shown in the map below.

The screening of the zones are explained in the Main Report as well as the Plan Formulation appendix. In short, the zones less than zone 11 are found in Brazoria County and were not identified as problem areas amongst the users of the channel, or the problems identified in those zones are being addressed in other projects. Zones 11, 15, and 17 were initially of interest but were also screened when it was recognized that the issues are also being addressed in other projects. The remaining zones of interest for this study is Zone 12, 13, 14, 16, and 18. Sections 4, 5, and 6 in this appendix expound upon the details within zones 11 through 18.

Figure 2 - Zones within the Study Area

2.2 PLANNED PROJECTS IN THE STUDY AREA

Two major projects are planned in the study area that have direct overlap with the economics on this study: The Brazos River Floodgates and Colorado River Locks project, and the Coastal Texas project. For study purposes, it is assumed these projects will be built and therefore is included in the Future Without Project condition. Multiple other projects are being studied as well in the area and the fringes outside of the scope of this project.

The Brazos River Floodgates project consists of flood gates on each side of the Brazos River that are 75 feet wide by 750 feet long. The Colorado River Locks project consists of two lock chambers on each side of the Colorado River consisting of two sector gates, each gate creates a chamber 75 feet wide by 1,200 feet long. Both projects serve to control flood flows from the Brazos and Colorado Rivers to the GIWW, improve navigation safety by controlling traffic flow and currents at the intersection with the GIWW, and aid in preventing sand and silt deposition into the GIWW. The Colorado River is within the boundaries of this project, but the modifications to that project will not contribute to the benefits on this project.

The Coastal Texas project includes a study area covering the entire Texas Gulf Coast from the mouth of the Sabine River to the mouth of the Rio Grande, and includes the Gulf and tidal waters, barrier islands, estuaries, coastal wetlands, rivers and streams and adjacent areas that make up the interrelated ecosystem along the coast of Texas. The study area encompasses 18 coastal counties along the Gulf Coast and bayfronts. The study area has been divided into four regions loosely based on major bay systems and habitats. The project design includes design of hurricane levee systems and development of features along the existing levee systems which are anticipated to require redundancy, resiliency, and/or robustness to prevent failure during storm events. Additionally, there are life safety concerns which must be addressed so the project will likely involve features that could be a concern to human life/safety assurance. Coastal Texas is addressing some areas along the GIWW that affect navigation and shoaling, and these areas will be discussed in more detail later in the report. Since Coastal Texas is assumed to be completed at the onset of this project, features included in that study are considered in place as part of the Future Without Project condition and the benefits of the Coastal Texas project is not included in this study.

2.3 DEFINING RESILIENCY

This project focuses on the resiliency of the GIWW. Resiliency can have different meanings to different individuals and contexts. Resiliency, by definition according to the Merriam-Webster dictionary, is the ability to recover from or adjust easily to adversity or change. Dissecting this definition, resiliency has four components: recovering or adjusting (the response), and adversity or change (the phenomenon).

The GIWW has the proven ability to recover from adversity. Hurricanes and coastal storms frequently strike the study area. When these storms hit, usually traffic continues to flow, but may have temporary delays. For example, at areas along the GIWW where it intersects with a river (Brazos River at mile 404, and Colorado River at mile 444), the river may have increased flows making it more difficult to cross and creating shoaling issues. Other examples include areas of open bay water, where cross winds or increased wave action may pose navigational challenges, such as along Matagorda Bay.

The GIWW also has the ability to adjust to change. Historically when shocks to the market have affected industries, traffic on the GIWW has the ability to adapt very quickly. For instance, when the Eagle Ford Shale play was discovered in 2012, there was a large untapped oil and gas reserve that led to an explosion of drilling and activity. An oil export ban was imposed on the U.S. in 1975 and was still in effect. Most of the oil consumed in the U.S. was imported because it was cheaper to import than to drill and transport oil that originated from the U.S. The discovery of Eagle Ford, and the changes in regulations regarding fracking, made U.S. oil much more competitive. The oil companies began lightly refining the oil to convert it into condensate for export. Beginning in December 2015, the crude oil export ban was lifted, and the oil could directly be exported without the need to convert it into condensate. With this sudden increase in supply of oil desiring to be transported for export, proper infrastructure was not in place to accommodate the volumes of oil needing to be distributed. Pipelines needed to be built, but it would take several years before they would be operational. Truck and rail were potential options, but were more costly and would create congestion on the roads. The GIWW was a viable low-cost option, and could accommodate the increased volumes needed. As pipelines came online after 2018, transport by pipelines became the preferred method, and tonnage of crude oil declined (see Figure 3-2). With the GIWW in place, it allowed a smoother transition to the sudden market shock, and the overall U.S. economy benefitted from otherwise what would have been several years of missed opportunity in trade. The full benefits to the U.S. economy of having the GIWW available for such a market adjustment is incalculable.

Another recent example that illustrates the ability of the channel to adjust to change includes the pandemic in 2020. The coronavirus that led to the U.S. lockdowns for a couple months in 2020 caused demand for crude oil to plummet, thereby dropping prices to record lows. Drilling and transport of crude oil decreased significantly, and starting operations back up after a shutdown is not an easy feat. Pipelines are more difficult to start up again than using the GIWW. As the demand returned with the re-opening of businesses in the U.S., the market adapted very well, and the GIWW traffic was able to continue remarkably well thereby enabling the industry to recover rather quickly.

These are just a few examples illustrating that despite abrupt changes to the markets and economy, the GIWW is a necessary channel that enables the distribution of goods to continue. The channel has proven to be remarkably resilient.

However, the GIWW has some areas for improvement to enhance its resiliency. For example, as stated above, wind and wave action can pose navigational challenges. Cross currents and water velocities, especially at the mouth of rivers, can also impede traffic. A narrow channel at areas of frequent congestion cause transport delays. Increased shoaling, typically due to storms, can also limit navigational fortitude. To the operators of the channel, a resilient channel means having a reliable waterway, and all of these events can impact the ability of the users to navigate through the channel safely and reliably.

These episodic events can be categorized as either disturbances or stressors. Disturbances are single events that disrupt a system. Disturbances primarily affect short term traffic levels. On the contrary, stressors impact the longer-term functionality of the system. Stressors would include excessive shoaling, low water events, high wind, wave action, and systemic bottlenecks. Disturbances are difficult to predict, and usually occur more ad hoc, whereas stressors can be largely mitigated if given the proper attention. Therefore, the desire of this study is to be proactive in minimizing the impacts that adverse events can cause for users to navigate through the channel safely and reliably, and the focus will be on stressors to the system.

In other Corps business lines, such as Flood Risk Management and Life Safety, projects are formulated based on the resiliency of the system. A levee system is designed based on a storm that is “unlikely” to happen, but if it does happen will cause enormous damage. It factors in risk, probabilities, and consequences of “unlikely” events.

In contrast, in many Corps navigation studies, the focus is on efficiency of the system. Efficiency, by definition according to Merriam-Webster, is the effective operation as measured by a comparison of production with cost (such as energy, time, and money). An efficient channel, under conventional thinking, would optimize the costs to benefits (maximum net benefits) using assumptions of convergence of the mean. That is, one would assume that the channel will continue to be fully operational, and traffic will continue to use the channel as it most often has historically in the past, and any “shocks” to the system are simply “outliers” and should be dismissed in the data and analysis.

Efficiency, therefore, includes the "most likely" foreseeable future, omitting any outliers that deviate from the mean.

Though this may be relevant in certain circumstances and studies, it does not capture the shocks to the system. In the case of the GIWW, these shocks may occur more frequently than other parts of the country. The Texas coast is one of the most hurricane and tropical storm prone areas in the U.S. The GIWW gets hit with a major hurricane several times per decade, which can severely impede navigation and disrupt supply chains. Widespread flooding is common, which increases velocities at the mouth of rivers. Also, the oil and gas industry is extremely volatile and dynamic, hinging on factors of oil prices, exchange rates, and economic strength/weakness on the demand side, and pumping ability, refining capacity, transportability, storage capacity, and geopolitical relationships on the supply side. Also, as previously stated, policy changes such as imposing an oil embargo, or lifting the embargo, poses additional shocks to the system. The implementation of fracking also affected traffic and commodities transported on the GIWW. To a lesser degree, urbanization, use of materials, and interest rates have also affected traffic and commodities on the channel.

The table below lists several events that have resulted in economic shocks and shifts to the oil markets over the past 50 years. Note this is only an abbreviated list. There have been policy changes, such as an oil embargo in 1973 and lifting of that embargo in 2015; conflicts such as the Vietnam War, Desert Storm, 9-11 and the aftermath; abrupt market changes and economic slumps such as the oil crisis in 1979, another one in 1986, Black Monday in 1987, housing crisis and Great Recession in 2008; and numerous hurricanes and tropical storms such as Hurricane Ike in 2008 and Hurricane Harvey in 2017.

Table 1 - Select Historical Shocks and Shifts to the Market Due to Episodic Events

Economic Period	Date	Event
Stagflation	1973	Oil Embargo
	1975	End of Vietnam War
	1979	Oil Crisis
Recession	1980-1983	Economic Downturn
Expansion	Mid-1980s	Savings and Loan Crisis
	1986	Oil Crisis
Recession	1987	Black Monday
Recession	1990-1991	Desert Storm
Recession	2000-2003	Dot com bubble burst
	2001	9-11 Attacks
Recession	2008	Housing Crisis, Hurricane Ike
Expansion	2012	Eagle Ford Shale Discovery
	2015	Oil Export Ban lifted
	2020	Coronavirus pandemic

Coastal climate in Texas is characterized by episodic storms and unusual weather events that are documented in the monthly report, "Storm Data." During 2015 to 2016, unusual weather events along the Texas coast included temperatures below freezing for several hours in Kenedy County, severe hailstorms in Harris and Jefferson counties, and tornadoes and severe flooding along most of the Texas coast caused by Hurricane Patricia, which crossed from the Pacific through Mexico during October 2015 (National Centers for Environmental Information, 2016).

The probability of hurricane landfall on the Texas Coast is about one every 6 years. (Roth, 2010). The most active area for hurricanes over the past 160 years is the upper Texas coast with 28 landfalls, followed by the mid Texas coast with 25 landfalls, and lastly the lower Texas coast with 16 landfalls. Hurricane Harvey was the costliest storm causing over $125B worth of damages, occurring nine years after Hurricane Ike (2008) in Texas with over $29.5 billion worth of damage (Table 2). The top four costliest storms for Texas have all occurred since 2000, one of which (Allison) only reached tropical storm status (Blake et al., 2011).

Table 2 Costliest Texas Storms (1900 – 2020)*

Name	Year	Category	Landfall	Cost of Damages
Harvey	2017	4	South Texas	$ 125.0 B
Ike	2008	2	Galveston	$ 29.5 B
Rita	2005	3	Sabine Pass	$ 12.0 B
Allison	2001	TS	Freeport	$ 9.0 B
Alicia	1983	3	Galveston	$ 2.0 B
Hanna	2020	1	South Padre Island	$ 1.2 B
Dolly	2008	1	South Padre Island	$ 1.1 B
Celia	1970	3	Corpus Christi	$ 930 M
Allen	1980	5	South Padre Island	$ 700 M

Source: Blake et al. (2011), Handbook of Texas Online (2017).
* Not adjusted for inflation and include adjusted National Flood Insurance Program flood damage amounts beginning in 1995.
TS = tropical storm

Given all these "outliers" throughout the years, the GIWW continues to perform remarkably well. However, the channel does have areas for improvement to be both more efficient and resilient.

On the surface, it may seem like the idea of efficiency and resiliency are in conflict with one another. For a system to be efficient, it must maximize net benefits given a certain set of parameters, and those parameters may disregard the outliers to the system. Meanwhile, resiliency hones in on those outliers, and ensures that supply chain disruptions are minimized through those events. A "black elephant" event, an event that is visible to everyone yet is ignored, such as hurricanes can greatly impact the navigability of the GIWW. A "black swan" event, an event that is unlikely and unexpected event with enormous ramifications, such as the Eagle Ford Shale discovery and the coronavirus pandemic are typically not included in Corps analyses, yet do happen. As mentioned above, there have been numerous black elephant and black swan events in the past five decades (a typical navigation study period is 50 years). To simply ignore them as non-existent does not accurately portray reality. Put another way, efficiency typically focuses on the area of the probability distribution containing one or two standard deviations, while resiliency focuses on the tails of the distribution. Quantifying efficiency relies on averages, while quantifying resiliency is more challenging due to its ad hoc nature of uncertainty surrounding the events.

Given the uncertainty, resiliency becomes a risk issue. Risk exists in being able to reasonably predict the future events and the extent of their ramifications. Since these events are somewhat less frequent and historically have been variable, it is more difficult to quantify than an efficiency calculation. Resiliency does play a role in maintaining efficiency though. Having the ability to adapt to storms, market shocks, and other events, a resilient channel enables industry to invest in infrastructure, business development, and operational efficiencies that help the businesses and economies thrive. In a sense, designing a resilient channel is like an insurance policy for the users of the channel and the broader economy. Events may be somewhat rare, but when they do occur, the goal is to minimize the impact so that the event doesn't become catastrophic.

To truly maximize the utility of the GIWW, one must maximize both efficiency and resiliency since the shocks can have a large overarching effect on the broader economy. For an economy to be resilient, the components of the supply chains must also be resilient. The GIWW is a key component of the supply chain in the oil and gas industry in the U.S.

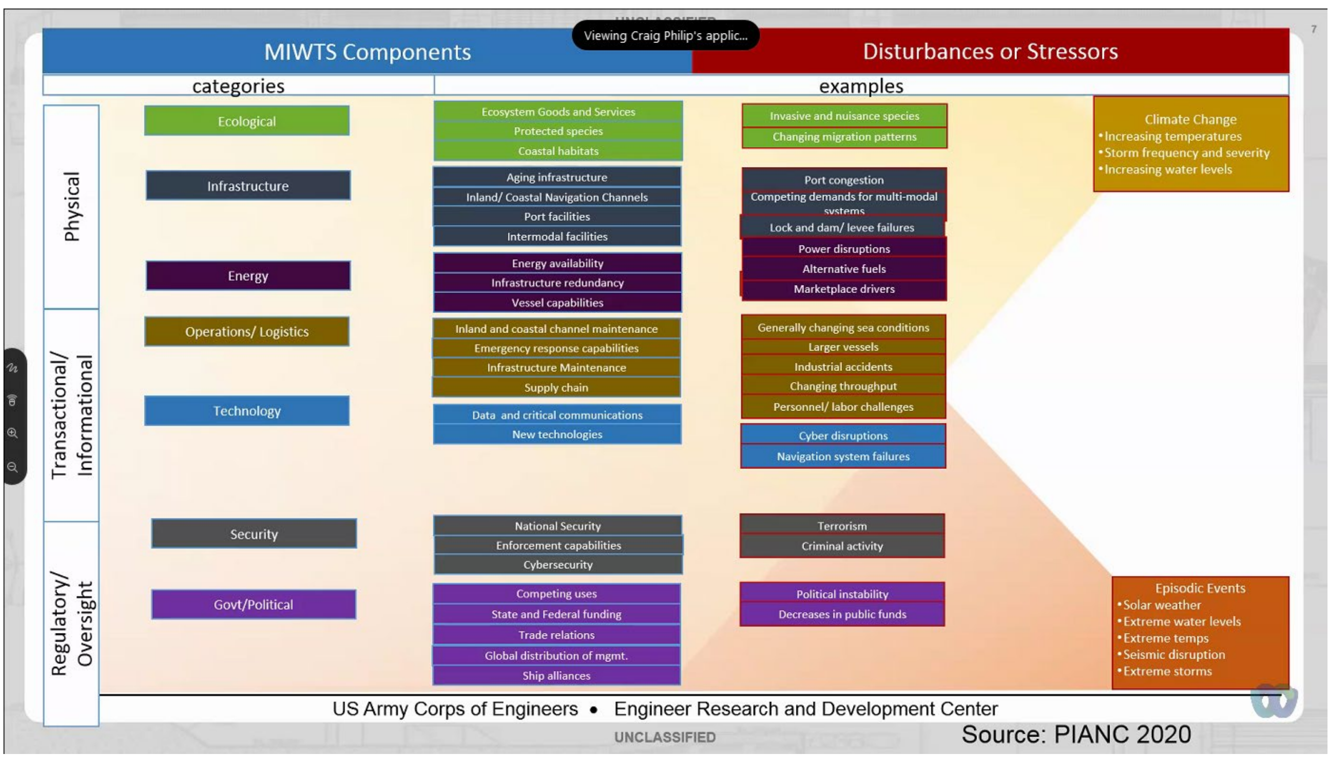

Figure 3 Resilience Components and Disturbances

3.0 HISTORICAL AND EXISTING TRAFFIC: THE IMPORTANCE OF THE GIWW

3.1 Delays

The Colorado River Locks were constructed in 1944 and the Brazos River Floodgates were completed in 1943 when barges were typically 26 feet to 35 feet wide. Both projects' chambers are 75 feet wide, and the maximum width they can accommodate are 55 feet, given the width of the average barge sizes prevent a wider tow without exceeding the limit. Today, it is standard for towboat operators to push at least two 35 feet dry cargo barges side by side, for a total width of 70 feet (rather than the historical practice of pulling two in-line barges of 35 feet wide). A typical tank barge measures 54 feet across, so tank barges must transit each lock and gate in single width. The need to break the tow causes significant time delays.

The current standard operating procedure for tow operators is to break their tow, tie the remaining tows to buoy(s), take a single barge through the gate/lock, get back into line to return back to their tied-up tow(s), connect another single barge, get back into the end of the line, and cross again with that single barge. The process continues until all of the barges in their full tow are reconnected and they can move on. This can take hours under normal conditions (i.e. good weather, no construction, no accidents, etc.). It can take days if there are any problems related to weather, construction, accidents, etc.

In addition, to regular delays caused by the breaking of tows, frequent accidents occur when tows strike the facilities while trying to line up to enter the floodgates after crossing the Brazos River. The Brazos Floodgates are only about 600 feet from the river and have about a sixty-degree bend on approach to the gate, therefore the towboat operators experience a difficult time to recover their course after struggling with the river currents. As a result, an average of approximately 56 accidents occur per year at the Brazos Floodgates (Brazos River Floodgate, Supervisory Mechanic). The Colorado River Locks do not experience as many accidents as the Brazos Floodgates because the lock is 1,200 feet from the river and has a straight approach across the GIWW. However, accidents still occur at an average of approximately 8 accidents per year (Colorado River Locks, Supervisory Mechanic). At either project location, when these accidents involve tank barges, there is also an increased risk for hazardous material spills.

Clearly the vast majority of the delays in the study area include crossing the Brazos River and Colorado River. However, additional delays do occur in other areas. Causes of delays could include storms, excessive winds, wave action, currents, depth limitations due to excessive shoaling and tide, groundings, accidents, and other unforeseen causes. Empty vessels are affected more by wind, waves, and currents, while shoaling and tide affect loaded vessels. According to the Gulf Intracoastal Canal Association (GICA), in areas where shoaling is increased, such as Caney Creek in Zone 12, users frequently schedule their vessels so that they reach Caney Creek during high tide. This is an area of concern that does not show up in the data per se, but does impact the reliability of navigation. Of course, given the delays a vessel may experience at Brazos River Flood Gates or Colorado River Locks, it is possible the vessels miss the high tide window at Caney Creek. If a vessel misses the high tide window, it may need to wait several hours until the tide returns enough that the vessel can cross Caney Creek. According to the operators, often the vessel waits at the moorings near Brazos River or Colorado River if buoys are available until they can reasonably time the crossing at Caney Creek. Again, it is difficult to capture the reason for the pause in the data for a particular vessel.

In the GIWW, open channels (no barrier island protection) have more impact on empty vessels than loaded ones. Winds in excess of 30-35 mph, and wave currents have a greater impact on the empty vessels so vessels need to travel faster to maintain control, or the wind and waves can cause delays. Loaded vessels are more affected by shoaling issues, for example cross currents increasing shoaling at Caney Creek. That area experiences shoaling at a greater rate than most parts of the channel, so as stated above, the users have to adjust their schedules to time their trip so that they cross Caney Creek at high tide. Also during the winter, the north wind pushes the water in Matagorda Bay toward the Gulf and water levels significantly decline, often below low tide levels. This makes loaded vessels difficult to transport goods when there's a strong north wind in winter. Loaded vessels travel a little slower than empty vessels. In current markets, loaded vessels are typically moving downbound while empties are moving upbound. At Caney Creek, traffic is slower possibly due to waiting to cross the bridge, though according to the users the bridge does not cause much of a delay. A more common reason for slower traffic and delays in crossing the creek is trying to time crossing Caney Creek at high tide for loaded vessels. In the dataset, upbound vessels experience greater delays at Caney Creek than downbound vessels. Several factors could affect this delay: cross current affecting empty vessels, construction of the bridge at Caney Creek, fog or visibility concerns especially during February, excessive shoaling or groundings, higher wind speeds, congestion, or traffic backup from Brazos River or Colorado River crossings.

When comparing the travel times in each zone, it was observed there are delays in Zone 15 when compared to Zone 14. Exposure to open water is the only significant difference the operators could identify between the two zones that would explain the difference in operational speed. During weather delays, the vessels will typically hold up at the moorings if they are available.

A short summary of causes of delays can be found in the table below.

Table 3 Causes of Delays by Zone

Zone	Cause of Delays
11	Eroding barrier island causes exposure to Gulf winds, and in future potentially Gulf currents. Downbound vessels appear to get backed up crossing Caney Creek or waiting for high tide. The TXDOT project addresses the concern of barrier islands.*
12	Crossing Caney Creek. Shoaling due to cross currents affects loaded vessels. Currents could also affect empty vessels. Some loaded vessels must wait for high tide. Congestion. Crossing the bridge may cause slight delays.
13	No barrier island exposes empty vessels to wind and waves. Upbound vessels appear to get backed up crossing Caney Creek.
14	Little or no apparent issues in terms of navigation in existing condition. Existing traffic in this zone is used as the baseline future condition to calculate navigation delays.
15	Open water affects empty vessels due to wind and wave. The Texas Coastal project addresses the concern.*
16	Some open water exposure affects empty vessels due to wind and waves. During times of high congestion, downbound vessels may get backed up in this zone crossing the Colorado River.
17	Traffic congestion crossing the Colorado River. The Brazos River Flood Gates and Colorado River Locks project addresses the concern.*
18	Open water affects empty vessels due to wind and waves. During times of high congestion, upbound vessels may get backed up in this zone crossing the Colorado River.

*Not included in this study

3.2 Traffic Commonality

The Brazos River Floodgates and Colorado River Locks are separated by 40 miles, with few commercial docks located between the projects. The average width of the GIWW between the Brazos and Colorado Rivers is estimated between 300-450 feet with the narrowest point being a 130 feet wide bridge underpass located at approximately mile 418 on the GIWW near Caney Creek. Several streams and rivers flow into the GIWW along this route, with a few areas of minor open water navigation. Aerial imagery shows multiple fleeting/mooring locations in between, but no infrastructure for loading or unloading barges along the GIWW.

According to lock operators, approximately 1 million tons on average utilizes one Colorado Lock and travels up the Colorado River without crossing the other lock in Zone 17. Table 4 shows the average annual tonnage at Brazos and Colorado from 2010 through 2014 and displays the high level of commonality between projects.

Table 4 Average Annual Tonnage Commonality

	Average Tonnage	Commonality
Brazos River Flood Gates	22,497,593	97%
Colorado River Locks	21,607,965	99%
Tonnage through Both	21,038,012	

As displayed in the above table, the Brazos and Colorado River have a significantly high level of traffic commonality. This suggests any substantial change at one location has the potential to alter traffic patterns or operations at the other location and the areas in between. For example, a significant delay at one river could be beneficial in reducing congestion within the zones between the rivers, but it could also mean the vessels experience further delays at Caney Creek because they missed the high tide window. Also, it is possible that with the widening of Brazos River Flood Gates or the Colorado River Locks, larger tows may desire to call on the system in zones less equipped to handle them.

A flotilla is a group of vessels traveling together as a single unit. For USACE purposes, a flotilla generally refers to a group of unpowered barges being pushed as a single unit by a powered towboat, and is interchangeable with the term “tow package.”

3.3 NED Evaluation

The purpose of a U. S. Army Corps of Engineers planning analysis “… is to estimate changes in national economic development that occur as a result of differences in project outputs with a plan, as opposed to national economic development without a plan”. This is accomplished through a federally mandated National Economic Development (NED) analysis which is “… generally defined as an economic cost-benefit analysis for plan formulation, evaluation, and selection that is used to evaluate the federal interest in pursuing a prospective project plan.” NED benefits are defined as “… increases in the net value of the national output of goods and services, expressed in monetary units …”

For a navigation project investment, NED benefits are composed primarily of the reductions in transportation costs attributable to the improved waterway system. The reduction in transportation costs is achieved through increased efficiency of existing waterway movements, shifts of waterway and overland traffic to more efficient modes and routes, and shifts to more efficient origin destination combinations. The "… basic economic benefit of a navigation project is the reduction in the value of resources required to transport commodities" remains the conceptual basis of NED benefits for inland navigation.

Traditionally, this primary benefit for barge transportation is calculated as the cost savings for barge shipment over the long-run least costly all-overland alternative routing. This benefit estimation is referred to as the waterway transportation rate-savings.

The primary guidance document that sets out principals and procedures for evaluating federal interest is the Principles and Guidelines (P&G). Corps guidance for implementing P&G is found in the Planning Guidance Notebook with additional discussions of NED analysis documented in the National Economic Development Procedures Overview Manual. For inland navigation analysis, the focus is on the evaluation and comparison of the existing waterway system with three basic alternative measures: 1) increase capacity (decrease transit times and thereby reduce delay costs); 2) increase reliability (replace or rehabilitate aging structures, thereby reduce the probability of structural failure and its consequences); and / or 3) reduce demand (e.g. congestion fees).

The alternative plan with the greatest net NED benefits is defined as the NED plan. NED analysis can be generally defined as an economic cost-benefit analysis (CBA). CBA is a well-established method for systematically organizing and comparing information between alternatives and aims to separate acceptable from unacceptable projects, and to rank the acceptable projects, to ensure that resources are invested wisely. Cost-benefit analysis remains the most important criterion in Corps planning studies.

To accomplish an incremental analysis, all alternatives must be measured against a common base. The future condition at the project (and in the system) without the investment(s) is referred to as the Without-Project Condition (WOPC) and the future condition with investment is referred to as the With-Project Condition (WPC). Identifying these future scenarios or conditions is central to the analysis framework. An economic analysis of these competing future conditions (over a 50-year analysis period) estimates the stream of benefits and costs associated with each respective future. The temporal aggregation of these cash flows necessitates discounting to complete the CBA.

NED benefits for a navigation project investment (WPC) are composed primarily of the reductions in transportation costs attributable to the availability of the improved waterway system. These reductions in transportation costs are achieved by increasing the efficiency of existing waterway movements, by providing for shifts of waterway and overland traffic to more efficient modes and routes, and by providing for shifts to more efficient origin destination combinations.

Basically, the economic analysis of waterway investments focuses on the evaluation and comparison of the costs and benefits of the existing waterway system by: 1) increasing capacity (decrease transit times and thereby reduce delay costs); and 2) increasing reliability (replace or rehabilitate barrier islands, thereby reduce the probability of impeding traffic and its consequences). In the WPCs, the creation of barrier islands leads to increased reliability and lower transportation costs through the GIWW primarily by allowing for increased speeds, thereby reducing the delays within the channel.

3.3.1 Data Sources

To successfully evaluate the role of an individual project to the larger inland waterways system, standardized data needs to be collected in a uniform manner across all USACE shallow-draft projects. This ensures not only that a standard suite of system planning models are able to be deployed, but that evaluation of projects is done on an apples-to-apples basis. The Lock Performance Monitoring System (LPMS) was established by the Office of the Chief of Engineers (OCE) established an OCE Task Group for Inland Waterways Systems Analysis to collect and display the required data to support such analyses. Reliable, comparable data from LPMS has not historically been the case for the Brazos River Floodgates and the Colorado River Locks in their relation to the other projects on the inland waterways system. Some of these inconsistencies can be attributed to the unique characteristics of these projects and how they are operated. It is beyond the scope of this document to explore how and why other data discrepancies not related to project characteristics were not collected in a manner consistent with other USACE navigation projects. Unfortunately, in this particular study, the LPMS data has limited utility and other data sources were required since the data could not be analyzed by each zone.

To capture benefits broken down by each zone, a dataset was needed that could be divided by geographic location and by travel time to capture speeds/delays in each reach. The Engineer Research and Development Center (ERDC) has a tool and dataset using Automatic Identification System (AIS) data to help delineate the data into a useful format. The Automatic Identification System Analysis Package (AISAP) by ERDC is a web-based tool for acquiring, analyzing, and visualizing near-real-time and archival data from the U.S. Coast Guard. The AISAP can be used to investigate questions of historical travel time, capacity limitation, and the effects of weather or accidents on the flow of freight through waterways. Although the dataset was helpful, data gaps still existed, and interviews of operators were needed to explain some observations in the data. Analysts with USACE's Planning Center of Expertise for Inland Navigation and Risk-Informed Economics Division (PCXIN-RED) were made aware of certain data limitations at the outset of this study and were included throughout the study process.

3.3.2 Stall/Stoppage Records

Stall/Stoppage records may offer insight into traffic delays experienced in the study area. Stall/Stoppage records are supposed to be recorded in LPMS whenever a vessel is prevented from transiting a project for a reason other than waiting for a vessel to finish the lockage process. The stall/stoppage record is supposed to begin with the first vessel that is prevented from transiting and should end when that vessel is finally able to transit. A reason-code is also to be recorded, which allows the data analyst to decipher if the closure was due to a weather-related incident such as fog, or if the closure was related to a mechanical issue with the lock.

Stall/Stoppages in LPMS are associated with the first towboat to become delayed at a project once the outage occurs. For instance a mechanical issue can occur hours before a towboat arrives, but is only recorded once that towboat arrives and becomes delayed. At the Brazos River Floodgates and Colorado River Locks, a further wrinkle exists given that data is recorded separately between each set of East/West structures. An issue may arise at the East gate of Brazos, but if the first towboat to be delayed by this issue is moving West to East, the outage will be associated with the West gate instead of the East gate. Summing the duration of outage across each structure for a project provides a more reasonable estimation of the downtime at the flood gates and locks.

At the Brazos River Floodgates and Colorado River Locks, these stall/stoppage records are recorded in LPMS, at best, sporadically. Estimates for closures based on known accident and repair durations, as well as notices to navigation issued by SWG suggest that the BRFG are effectively closed 50% of the time in recent years. Neither site's recorded stall/stoppage records reflect the level of closures cited by project staff. Therefore, the stall/stoppage records have limited value for this study.

These closures are identified as the largest impediment to the safe and efficient movement of commodities along this stretch of the GIWW. The team attempted to determine causes of delays external to this project, such as a mechanical issue or allision at Brazos River Flood Gates or Colorado River Locks. However, lack of data from the stall/stop records from LPMS, notices to navigation issued by SWG, and accident reports and groundings, provide challenges to identify cause and effect relationships to vessel delays in a particular zone. The analyst resorted to interviews to identify causes of delays and explanation of delay patterns. The interviews revealed that zone 15 speeds were reasonable to use for the FWOP, and zone 14 speeds were reasonable to use for the FWP in this study since the only distinguishable difference in travel times was the absence or presence of barrier islands in those zones. This is explained in more detail in the FWOP and FWP sections of this report.

3.3.3 System Analysis

The Gulf Intracoastal Waterway (GIWW) and inland waterway system is a network of locks, flood gates, and channel reaches. As a result, no navigation project stands in isolation from other projects in the system. The study area must extend to areas that would be directly, indirectly or cumulatively affected by the alternative plans. An improvement at one node in the system affects traffic levels past that node, and since that traffic can also transit other system nodes the performance at these other nodes changes, possibly affecting traffic levels unique to those nodes, and so on. The evaluation of the GIWW and inland navigation system equilibrium is a substantial computational problem given the mix of commodity flows, each transiting different locks and gates and each having their own set of economic properties.

3.4 Traffic Patterns

The following section details the number of vessels and types of commodities utilizing the Texas portion of the GIWW.

All commercial vessel operators are required to report their vessel trip details to USACE on a monthly basis. These data are recorded by the Waterborne Commerce Statistics Center (WCSC). The following graphs illustrate the historic tonnage that is annually transported on the GIWW.

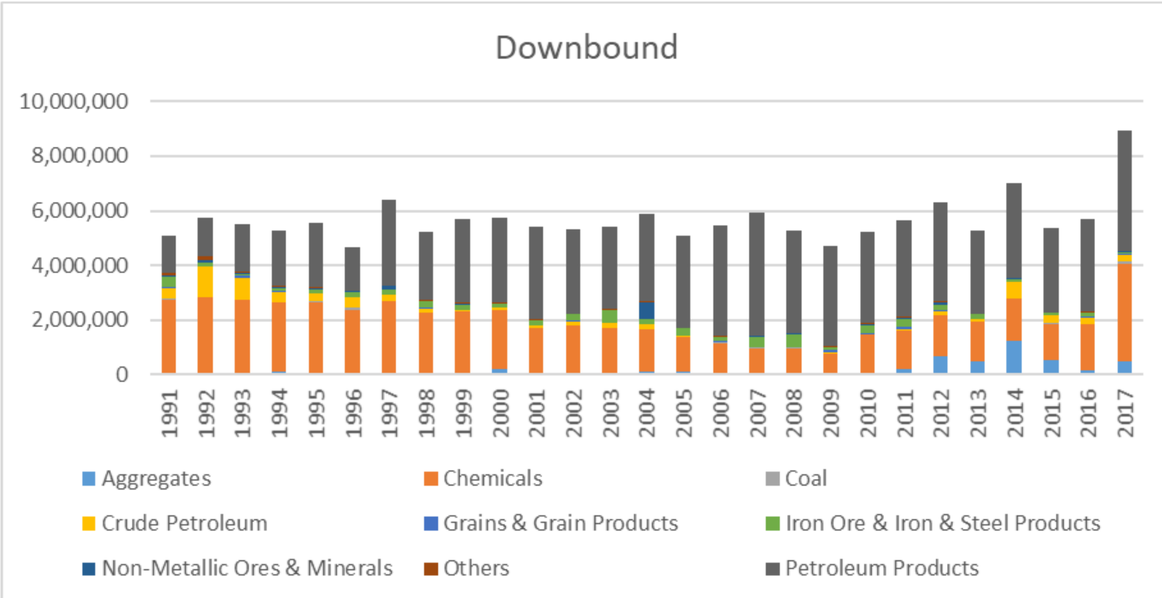

Figure 4 Downbound Traffic by Commodity
Source: Waterborne Commerce

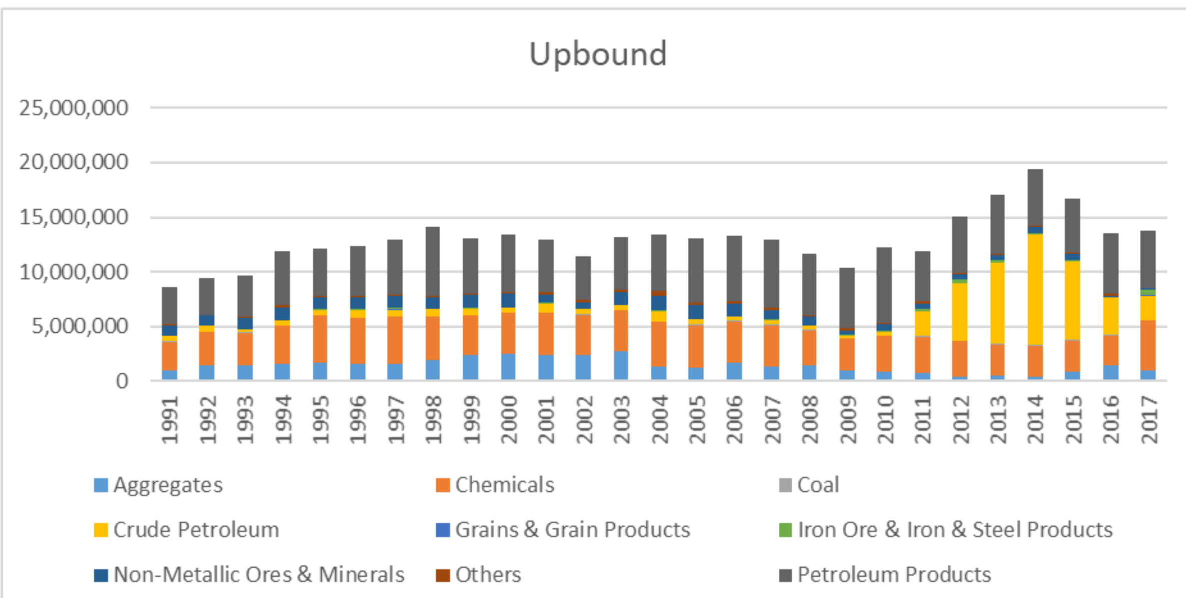

Figure 5 Upbound Traffic by Commodity
Source: Waterborne Commerce

Crude petroleum tonnage on the GIWW has fluctuated dramatically since 2010. In 2009 and 2010, the price of oil was low and pumping in West Texas was limited. As the price of oil climbed, additional wells came online. In 2012, a major discovery of oil and gas was found in the Eagle Ford shale play. Additional oil discoveries have been made in the Permian Basin since 2012. The infrastructure was not in place to accommodate the large increases in tonnages being transported. To capitalize on the market opportunities, initially, large quantities were trucked or railed to the coast to be refined or exported since the pipelines were already operating at capacity. Since water transport is significantly cheaper than truck or rail for longer distances, the preferred method of transport was to use the GIWW. As the market stabilized and additional pipelines came online, the demand to transport oil along the GIWW waned and has now returned to historical levels. If the GIWW was not a resilient channel and could adapt to sudden market changes, billions of dollars in economic activity would not have been realized in the past decade.

Table 5 displays vessel trips at the Brazos River Floodgates and Colorado River Locks as reported in WCS. These include empty and loaded trips for all towboats and self-propelled commercial vessels. The annual average vessel count in recent years between the two rivers is approximately 4,000 vessels per year traveling each direction upbound and downbound.

Table 5 Total Commercial Vessels through Brazos River Floodgates and Colorado River Locks

Year	Brazos River Flood Gates	Colorado River Locks
2013	9,252	8,835
2014	10,403	10,002
2015	8,646	8,153
2016	7,102	6,631
2018	7,996	7,996
2019	7,686	7,686
Annual Average	8,514	8,217

Source: Waterborne Commerce 2013-2016, AISAP 2018-2019

3.5 Forecasts

Given the recent market disruptions from the pandemic, determining a reasonable traffic forecast is challenging. In past studies, a forecast is usually derived by implementing a national or regional forecast published by Department of Energy and apply it to the base traffic levels. Base traffic is typically an average of the most recent 3- or 5-years tonnage. The traffic in 2020 and 2021, with all the supply chain disruptions, are probably not reflective of future years, and therefore are not considered as part of the base levels. Additionally, this project is primarily based on vessel delays, and therefore the benefits may not be highly correlated to tonnage growth as typical studies. In order to apply some form of growth to the analysis, benefits were calculated first, using existing delays as a base, and then a tonnage growth rate was applied to the benefits calculation to implement traffic growth. The growth rate applied is the same growth rate that was used in the BRFG-CRL study completed in 2019. For a detailed description of how that growth rate was developed, the Economic Appendix of the BRFG-CRL study can be reviewed. This document will only touch on the highlights. As noted above, chemicals, petroleum products, and crude petroleum are the primary commodities transported on the GIWW, so they were the focus of the growth forecasts.

The graph below shows the historical tonnage and forecasted tonnage for chemicals that were applied to the study. The recent volatility introduces a wide range of uncertainty to the baseline tonnage of which to apply the growth rate.

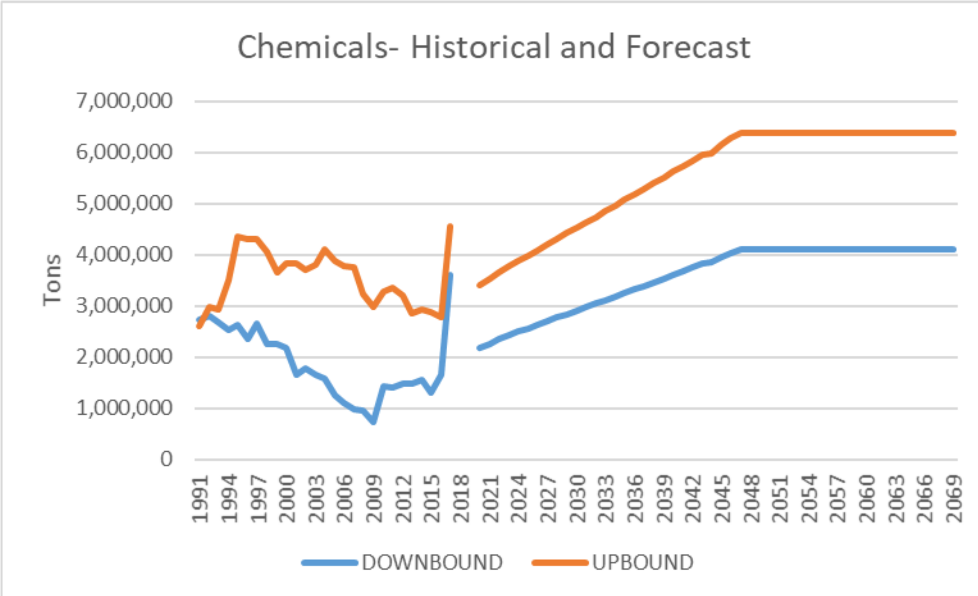

Figure 6 Chemicals Historical and Forecasted Tonnage

The table below displays the DOE EIA published forecast for petroleum products and crude petroleum.

Table 6 Projected Production of Crude Oil and Petroleum Products Southwestern United States

Petroleum Products	**2016**	**2020**	**2035**	**2040**	**2050**	**Percent Change**	**CAGR***
Reference case	14.81	17.87	19.37	19.75	19.27	30%	0.8%
High	14.81	20.57	23.62	22.41	20.93	41%	1.0%
Low	14.81	16.16	15.51	14.95	14.96	1%	0.03%
Crude Oil							
Reference case	2.11	3.29	3.99	4.25	4.11	95%	2.0%
High	2.11	4.63	5.36	4.9	4.28	103%	2.1%
Low	2.11	2.62	2.53	2.44	2.47	17%	0.46%

*Compound annual growth rate
Source: U.S. Energy Information Administration

Although much has changed since 1970, Texas continues to produce more crude oil than any other state or region of the U.S. Texas has held the top position in nearly every year since 1970, with the exception of 1988, when Alaska produced more than Texas, and from 1999 through 2011, when offshore production in the Gulf of Mexico was higher. Oil in Texas is coming primarily from two formations – the Eagle Ford Shale region west and southwest of San Antonio and the Permian Basin in central West Texas.

The oil markets have changed dramatically for the state of Texas in the past two decades. Twenty years ago, the majority of the oil was imported sour crude. Exporting oil was banned with few exceptions. The price of oil was also historically low. As the price of oil climbed, oil markets expanded in the U.S. Pumping has increased significantly in the past 10 years from the Permian Basin and the Eagle Ford

Shale play. The crude oil export ban was lifted in 2016 as well, thereby opening up new markets and increasing tonnage transported while pipelines were being built to accommodate the increased supply.

Since 2005 when the current surge started to the end of 2017, U.S. production of crude oil rose nearly 80 percent from about 5 million barrels per day to 9.4 million in 2017. EIA predicts that U.S. crude oil production will average 10.7 million barrels per day in 2018 and 11.7 million in 2019.

EIA's 2018 Annual Energy Outlook contains projections for changes in crude extraction in the U.S. on a regional basis. In total, U.S. oil output is expected to grow in the Southwest region (primarily Texas) accounting for the majority growth. EIA expect production in the region to increase by about 4.25 million barrels per day by 2040, and then slowly decline.

Regional production forecasts published by Department of Energy's Energy Information Administration (EIA) for crude oil and petroleum products were used. The growth rates from these forecasts were applied to the baseline traffic in the study. Given the recent volatility in recent years, projected baseline tonnage levels inherently incur a generous amount of uncertainty.

The following graphs show the historical tonnage and forecasted tonnage for crude oil and petroleum products.

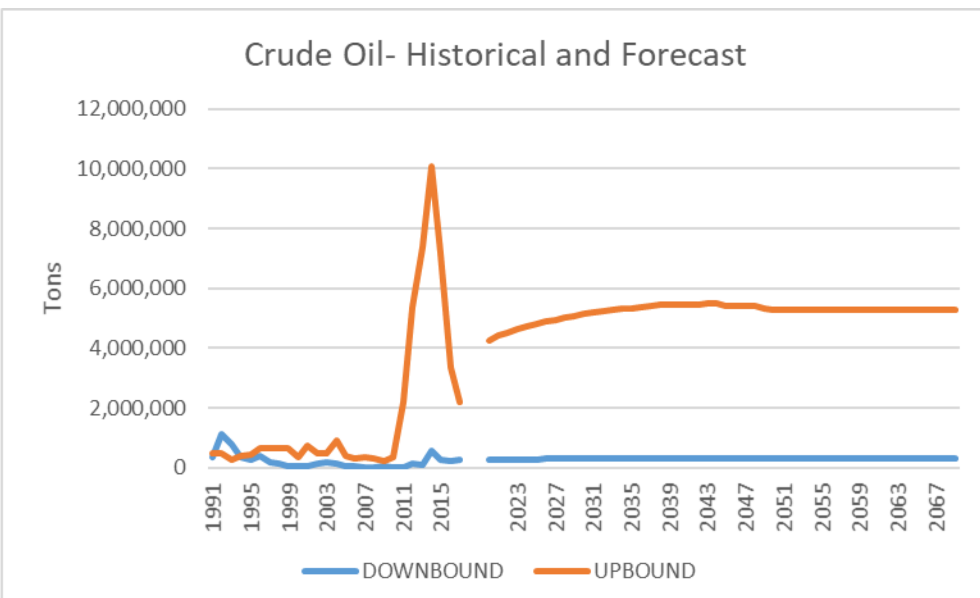

Figure 7 Crude Oil Historical and Forecasted Tonnage

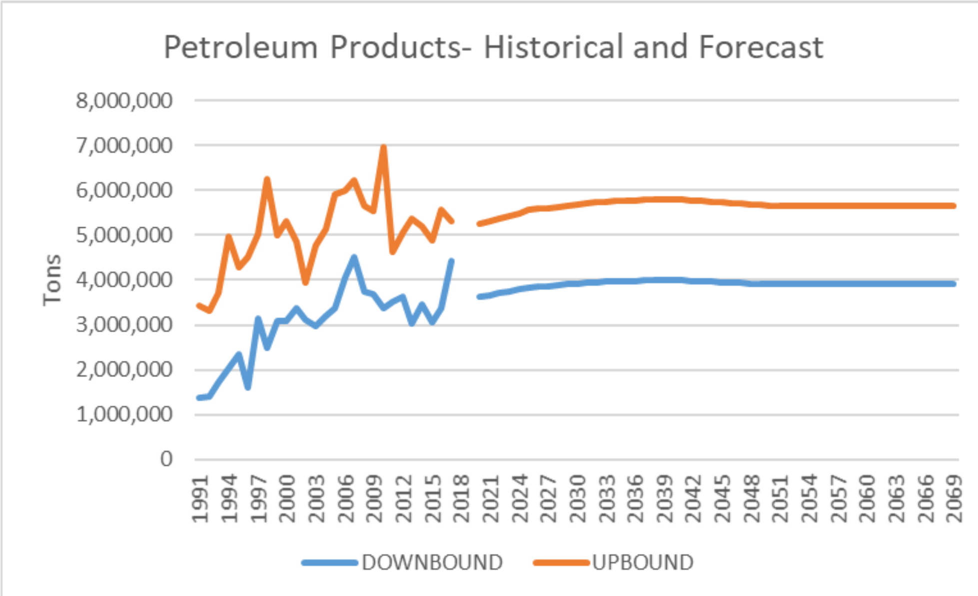

Figure 8 Petroleum Products Historical and Forecasted Tonnage

The tables below show historic tonnage and forecasted tonnage for each commodity and totals for both downbound traffic and upbound traffic.

Table 7 Downbound Historic Tonnage and Forecasted Tonnage (1,000s)

Year	Chemicals	Crude Petroleum	Petroleum Products	Other	Total	Index
1991	2,736	372	1,364	627	5,100	0.77
1995	2,627	271	2,333	307	5,540	0.83
2000	2,184	57	3,094	419	5,756	0.86
2005	1,268	46	3,370	412	5,099	0.77
2010	1,426	2	3,374	447	5,250	0.79
2015	1,317	253	3,056	721	5,348	0.80
2016	1,650	241	3,374	431	5,697	0.86
2017	3,601	281	4,426	629	8,937	1.34
Projections (Base Case)						
2020	2,189	258	3,618	595	6,662	1.00
2025	2,555	293	3,826	595	7,271	1.09
2030	2,905	313	3,922	595	7,736	1.16
2035	3,254	325	3,978	595	8,154	1.22
2040	3,607	333	3,999	595	8,535	1.28
2045	3,958	330	3,950	595	8,835	1.33
2050	4,094	322	3,901	595	8,913	1.34
2060	4,094	322	3,901	595	8,913	1.34
2070	4,094	322	3,901	595	8,913	1.34

2080	4,094	322	3,901	595	8,913	1.34

Table 8 Upbound Historical Tonnage and Forecasted Tonnage (1,000s)

Year	Chemicals	Crude Petroleum	Petroleum Products	Other	Total	Index
1991	2,617	472	3,431	2,091	8,613	0.59
1995	4,351	458	4,276	3,009	12,095	0.82
2000	3,829	380	5,307	3,963	13,479	0.92
2005	3,879	420	5,902	2,870	13,073	0.89
2010	3,278	369	6,952	1,704	12,304	0.84
2015	2,890	7,149	4,889	1,728	16,657	1.14
2016	2,773	3,362	5,561	1,854	13,551	0.92
2017	4,564	2,205	5,308	1,700	13,777	0.94
Projections (Base Case)						
2020	3,409	4,238	5,253	1,762	14,663	1.00
2025	3,979	4,813	5,554	1,762	16,109	1.10
2030	4,523	5,138	5,693	1,762	17,118	1.17
2035	5,067	5,336	5,775	1,762	17,941	1.22
2040	5,616	5,469	5,805	1,762	18,653	1.27
2045	6,163	5,425	5,734	1,762	19,085	1.30
2050	6,374	5,284	5,662	1,762	19,084	1.30
2055	6,374	5,284	5,662	1,762	19,084	1.30
2060	6,374	5,284	5,662	1,762	19,084	1.30
2065	6,374	5,284	5,662	1,762	19,084	1.30
2070	6,374	5,284	5,662	1,762	19,084	1.30
2075	6,374	5,284	5,662	1,762	19,084	1.30
2080	6,374	5,284	5,662	1,762	19,084	1.30

The graph below illustrates the growth rates applied to the benefits calculations. The growth rates were based on total tonnage, separated by upbound traffic and downbound traffic.

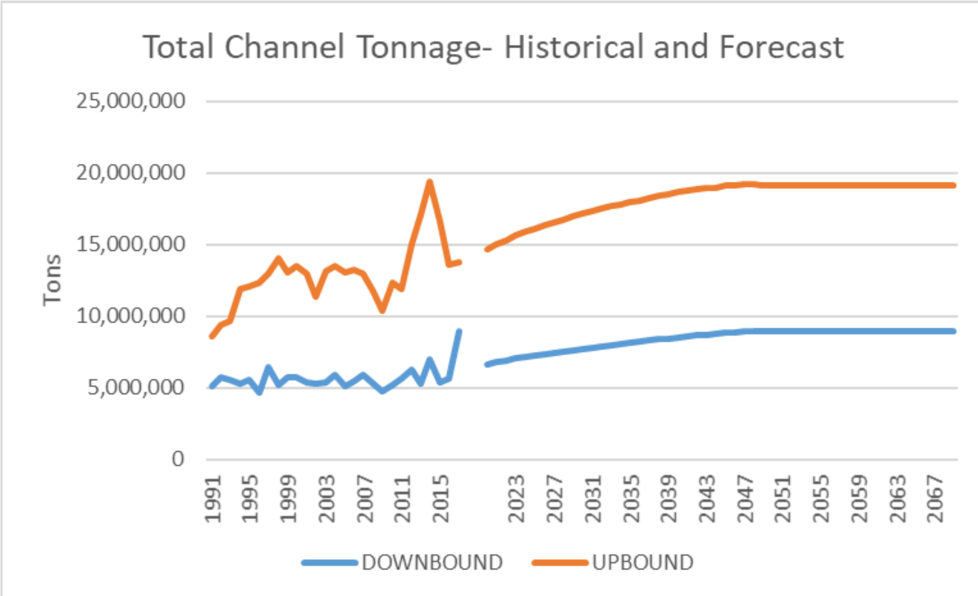

Figure 9 Total Channel Historical and Forecasted Tonnage

4.0 FUTURE WITHOUT PROJECT CONDITION

The conditions observed presently are expected to continue in the future without project condition. As traffic increases, delays are expected to increase proportionally. However, the delays may not be a linear increase and may increase exponentially as traffic increases, similar to congestion on an interstate following properties of fluid mechanics. Once the traffic reaches a certain threshold, which is unknown on the GIWW without further study, the congestion builds and delays are prolonged for each vessel. For simplicity in this analysis, average delays are expected to remain constant over time per vessel.

A caveat to the above assumption is that the erosion expected to occur will affect future traffic that is not reflective in the existing data. As barrier islands wither away, the channel becomes more vulnerable to the elements, and traffic could be impacted significantly. For example, wind may have a more frequent disturbance to traffic. Waves and currents could also impact future navigation. Increased shoaling could prompt more frequent light loading until emergency dredging can occur.

The table below provides descriptions for the FWOP condition for the zones of interest for this study. Zones 11, 15, and 17 were not included as part of this study because those areas are being addressed in Coastal Texas, as well as Brazos River Flood Gates and Colorado River Locks studies. This study assumes that those two projects are already constructed by the year 2030. If either project is not completed by 2030, there will likely be slight changes to the modeled hydrology which will in turn affect shoaling rates and locations, possibly placement of material, and dredging costs. The benefits are not anticipated to substantially change. To achieve optimal effectiveness toward resiliency in the GIWW, all three projects will need to be completed.

Table 9 FWOP Condition by Zone

Zone	FWOP Condition (beginning year 2030)
12	Scouring hole on west side of Caney Creek. Shoaling high spots on east of Caney Creek. Cross currents. Channel landside breakwater included in Coastal Texas study.
13	Barrier Island completely gone by 2030. Channel landside breakwater included in Coastal Texas study.
14	Channel landside breakwater included in Coastal Texas study.
16	Barrier Island completely gone by 2030.
18	Barrier Island breached around year 2035. Little barrier island left by 2040 in portion of Zone 18.

The following tables show delays experienced in 2018 and 2019, which are expected to continue or get worse in the future. The data illuminate some noteworthy observations.

First, February experiences the fewest number of vessels per month. This could be due to market factors and seasonality of the industry. However, as the data also shows, February is also the month with the greatest delays per vessel. With greater delays, product is more expensive to transport. Industry could be adjusting its operations either by using other modes for part of their transport, or making adjustments and transporting some of the February product in January or March when the channel is more reliable and has fewer delays.

Second, generally the winter months experience greater delays than the summer months. This could be due to several factors, including fog, strong north winds, and shoaling, among others.

Third, Zone 11 Downbound, Zone 12 both directions, and Zone 13 Upbound experience higher delays in the month of May. This appears to be due to upbound traffic crossing Caney Creek. The month of May experiences higher rainfall totals, thereby increasing current flow crossing Caney Creek and making navigability more challenging. A wider channel in this locale would likely help alleviate some of the navigability challenges.

Fourth, Zone 14 is an extremely reliable area presently. The entire year, the average travel time only varied by 8 minutes in either direction. According to the channel users, this is attributable to the presence of barrier islands providing shelter for the vessels from the elements. In contrast, Zone 15, which has no barrier island presently, varied 20 minutes in average travel time. That is a greater variance than any other zone, with the exception of delays crossing Caney Creek or the Colorado River. Hence, the lack of barrier islands present much more vulnerability to the channel than the presence of barrier islands.

Fifth, downbound traffic in Zone 18 appear to have a wide variance of travel times, with the month of February being the greatest and the summer months being the least. There could be a number of factors for increased travel times in this zone. As vessels approach Matagorda Bay, wind, waves, currents, fog, and shoaling could pose impediments to smooth navigation.

Table 10 Average Number of Vessels Per Month

	Upbound	
	2018	2019
January	334	356
February	285	257
March	345	328
April	311	319
May	347	298
June	291	339
July	346	328
August	404	337
September	347	331
October	311	370
November	318	339
December	332	226

	Downbound	
	2018	2019
January	327	338
February	295	254
March	329	325
April	328	323
May	331	306
June	303	342
July	348	330
August	405	318
September	347	355
October	327	363
November	317	350
December	348	229

Table 11 Average Travel Time in Each Zone of Interest Per Vessel

	Upbound	Downbound
January	77	72
February	89	87
March	74	67
April	70	72
May	79	72
June	67	69
July	65	65
August	65	65
September	66	62
October	67	74
November	76	77
December	77	79
Total	873	862
Annual Total	349	345

Table 12 Average Travel Time Per Vessel by Zone, 2018-2019

	11		12		13		14		15		16		17		18		Average	
	Upbound	Downbound	Upbound	Downbound	Upbound	Downbound	Upbound	Downbound	Upbound	Downbound	Upbound	Downbound	Upbound	Downbound	Upbound	Downbound	Upbound	Downbound
January	82	88	49	35	60	37	36	32	42	41	102	139	255	245	141	119	96	92
February	92	123	82	40	80	51	40	38	49	45	107	115	269	257	137	191	107	107
March	76	100	52	35	61	38	38	32	44	38	95	98	219	216	123	133	88	86
April	69	93	55	37	59	39	33	33	40	39	88	98	225	233	114	154	85	91
May	69	106	67	38	69	42	32	31	42	40	95	116	246	258	133	130	94	95
June	65	79	51	35	49	42	32	30	40	38	85	119	261	259	120	119	88	90
July	63	84	49	38	54	43	32	30	41	38	81	101	238	234	108	116	83	86
August	64	85	53	37	55	41	32	30	43	39	80	102	220	227	107	114	82	84
September	67	89	56	34	55	39	33	30	42	38	80	91	185	190	105	116	78	78
October	63	84	47	34	49	37	35	30	40	45	92	143	308	275	113	127	93	97
November	71	101	52	36	57	43	34	37	43	57	102	123	275	242	136	147	96	98
December	75	90	56	40	55	43	37	34	41	41	104	140	298	267	132	141	100	99
Total	856	1,121	666	439	703	495	413	386	506	499	1,111	1,385	2,999	2,904	1,469	1,606	1,090	1,105
Annual Total	343	448	267	176	281	198	165	155	202	200	444	554	1,199	1,161	587	643	436	442
Variance	29	43	35	6	31	14	9	8	10	20	27	52	123	86	36	78	37	38

5.0 FUTURE WITH PROJECT CONDITION

The future with project condition is anticipated to alleviate transportation delays within the various zones, excluding crossing the Brazos River and Colorado River. In analyzing the data, transportation through Zone 14 experienced minimal delays and speeds averaged 5.7 to 6.0 miles per hour. As previously mentioned, Zone 14 already has some barrier islands for protection and has minimal shoaling issues, so this zone is fairly reliable for navigation presently. Therefore, with the measures identified and implemented, it is anticipated that these average speeds can be reached in all the zones addressed in this project and that minimal delays will occur. The difference in transportation costs between applying what is observed today in each zone adjusted for barrier island degradation, and the transportation costs of a channel with optimal speeds accounts for the benefits.

6.0 ALTERNATIVES

Several alternatives were evaluated in the initial phase of this project. They are listed below. For a detailed discussion on the screening process, refer to the main report.

Table 13 Alternatives Screening

Alt #	Description	Anticipated Effectiveness	Status
1	No Action	Existing	Baseline
2	Non-Structural	Limited resilience	Screened
3	Shoreline Stabilization	Potential solutions	Keep
4	Alt 2 + Sediment Placement	Limited effectiveness	Screened
5	Alt 4 + Channel Modification	Moderate effectiveness	Screened
6	Alt 3 + Alt 4	Combination provides potential	Keep
7	Alt 3 + Alt 5	Costly, real estate challenges	Screened

Alternative 3 Shoreline Stabilization – This alternative address some of the shoaling problems by reducing sediment flowing into the channel from eroding shorelines, upland sediment placement areas, and barriers which are caused by vessel-induced and wind-driven waves.

Alternative 6 Sediment Placement, Non-structural, and Shoreline Stabilization – This alternative is the combination of alternative 3 and natural stabilization measures such as placement of dredged material and marsh plantings.

The following is a breakdown of alternatives carried forward by zone and increments for each alternative:

6.1 Zone 12

Increment 1 – Channel Bayside Breakwater (yellow lines in above figure) which will be constructed about 7 feet above the mean sea-level (MSL) elevation. Channel Landside Breakwaters are excluded from this zone because they are included as part of the Coastal Texas Protection and Restoration Study.

Increment 2 – In addition to what is described in increment 1 above, channel widening will be done by removing material on the landside just east of the opening of the breakwaters (red line in above figure).

Increment 3 – In addition to what is described in increment 2 above, sediment trap(s) will also be located east of the breakwater opening from mile marker 420 to 420.5, station 694+000 to 696+000.

Alternative 6

None – Screened as requested by USFWS for Section 7 Threatened and Endangered Species due to this area being a critical habitat. Negative environmental impacts of sediment placement outweigh benefits.

6.2 Zone 13

Increment 1 – Channel Bayside Breakwater (blue line in above figure) will be constructed about 7 feet above the MSL elevation. There are no further increments for this alternative because the barrier islands will be completely eroded away and/or submerged by 2030 which is the proposed start date of construction. Also, Channel Landside Breakwaters are excluded from this zone because they are included as part of the Coastal Texas Protection and Restoration Study.

Increment 1 – The Channel Bayside Breakwater (blue line in above figure) and the Bayside Breakwater (light blue line in above figure) will both be constructed to be about 3 feet above the MSL elevation, and sediment placement and marsh planting (green hatching) to fill the area between the two breakwaters which is about 405 acres. Also, there will be an earthen berm (light green line in above figure) just on the inside of the Channel Bayside Breakwater.

6.3 Zone 14

Increment 1 – Bayside Breakwater (yellow line in above figure) will be constructed about 5 feet above the MSL elevation, and Channel Bayside Breakwater (red line in above figure) will be constructed about 3 feet above MSL elevation. Channel Landside Breakwaters are excluded from this zone because they are included as part of the Coastal Texas Protection and Restoration Study.

Increment 1 – The Channel Bayside Breakwater and Bayside Breakwater (blue line in above figure) will both be constructed to be about 3 feet above the MSL elevation, and sediment placement and marsh planting will fill the inside area (green hatching in above figure). Also, there will be an earthen berm just on the inside of the Channel Bayside Breakwater (purple line in above figure).

6.4 Zone 16

Increment 1 – Bayside Breakwater (light blue line in above figure) will be constructed about 5 feet above the MSL elevation. The Channel Bayside and Landside Breakwaters were screened earlier in the study due to the shoaling rate not being significant enough from the H&H analyses. This can be further evaluated later to confirm whether there is a need for Channel Landside Breakwaters for PA 105.

Increment 1 – The Bayside Breakwater (blue line in above figure) will be constructed in the same location as alternative 3 but at a height of about 3 feet above the MSL elevation, and sediment placement and marsh planting will fill the area in PA 105 and on the edge of PA 106 (green hatching in above figure). Also, there will be a small earthen berm on the inside of the curved edge of the Bayside Breakwater wrapping around to the channel side (light green line in above figure).

6.5 Zone 18

Increment 1 – The Bayside Breakwater (light blue line in above figure) will be constructed about 5 feet above the MSL elevation.

Increment 2 – In addition to what is described above in increment 1, the Channel Bayside Breakwater (yellow line in above figure) will be constructed about 3 feet above MSL elevation.

Increment 3 – In addition to what is described above in increment 2, the Channel Landside Breakwater (orange lines in above figure) will be constructed about 3 feet above MSL elevation, and reef balls (magenta lines in above figure) will be placed in portions along the Channel Landside Breakwater.

Increment 1 – The Bayside Breakwater (blue line in above figure) will be constructed about 3 feet above the MSL elevation, and sediment placement and marsh planting will fill the area inside (green hatching in above figure).

Increment 2 – In addition to what is described above in increment 1, the Channel Landside Breakwater (orange lines in above figure) will be constructed about 3 feet above MSL elevation, and reef balls (magenta lines in above figure) will be placed in portions along the Channel Landside Breakwater. There are no berms in this zone because there will not be enough barrier islands left by 2030 for protection.

7.0 BENEFITS AND COSTS

The true benefits of having a reliable channel is immeasurable and difficult to quantify. As stated throughout this document, the oil and gas, and the chemical industries rely on the GIWW as a means of transporting goods to its facilities. In turn, their products are widely used across the United States. A reliable GIWW translates into a reliable gasoline stream to gas stations, reliable supplies of oil and diesel fuel for construction, and reliable supply of components to manufacture plastics used across a gamut of industries. A disruption in the supply chain distribution leads to disruptions in operations and potential shortages either locally or nationally.

Additionally, with a reliable channel, there is likely to be additional industry development due to assurances of a dependable means of transport. That spawns infrastructure investments, thereby growing not only the regional economy but the national economy as well since many of these companies are nationwide or worldwide (reference Section 9).

However, per ER 1105-2-100, none of these tertiary effects were computed in the benefits calculations, only transportation cost savings within given zones. The transportation cost savings are based on a reduction of delays within each zone.

The true transportation cost savings are also difficult to quantify because there are known phenomena that are not captured in the data itself. For example, in discussing with industry, they are aware of the shoaling issues at Caney Creek, and that if they desire to transport with no time restrictions they may need to light-load or else they face the potential of groundings. As a result, some vessels may choose to light-load. However, another adjustment made is that industry will adjust the scheduling so that vessels will reach Caney Creek at high tide. Instead of leaving the dock when the operator is ready, they are delayed at the dock because of an issue at Caney Creek. There is also extra cost in terms of labor for scheduling. This is not captured in the data nor the transportation delay benefits.

7.1 Benefits

The methodology for calculating transportation cost savings benefits in this study is very straightforward. Data showing each vessel transit over a period of January 2018 to August 2020 was collected using the tool AISAP developed by ERDC. It compiles the vessel records using AIS data so that vessel speeds and time traveled across each zone can be acquired. Those time stamps and speeds for each vessel in each zone were used to compute vessel delays by subtracting the amount of time it should have reasonably taken the vessel to transit that zone based on other non-impeded vessels from the time it actually took to transit that zone. It was assumed that if a transit in a particular zone exceeded 1000 minutes (16 hours 40 minutes), it was due to factors external to this project, such as an allision at BRFG causing traffic to backup or a channel closure. The data revealed that the fastest speeds occurred in zone 14, and the slowest speeds excluding crossings at Caney Creek and the Colorado River occurred in zone 15. When operators were asked what could cause that difference in speeds, they indicated the notable difference is the presence of a barrier island in zone 14 and the absence of a barrier island in zone 15. Therefore, the minimum speeds of each representative zone or of zone 15 were used for the FWOP condition for all zones. Based on those speeds, transportation costs were calculated as a function of time traveled across the zone, distance traveled, and vessel operating costs. The FWP condition was calculated in a similar manner, except the variable change is the time traveled across the zone. The difference between the FWOP and the FWP for each vessel is the benefits.

A growth rate was applied to the transportation cost savings (reference Forecasts section). Once the benefits were computed for the FWOP and FWP conditions, accounting for the growth rates, the benefits were discounted to get a single average annual benefits figure for each zone.

Table 14 Average Vessel Speeds By Zone

Zone	Mile Markers (East border)	Channel Miles	MPH Actual (Upbound)	MPH Actual (Downbound)	MPH FWOP (Upbound)	MPH FWOP (Downbound)	MPH FWP Optimal (Upbound- Zone 14)	MPH FWP Optimal (Downbound- Zone 14)
11	412.4	7.1	6.1	4.6	4.7	4.6	5.7	6.0
12	419.5	2.4	2.6	3.9	2.6	3.9	5.7	6.0
13	421.9	3.6	3.7	5.2	3.7	4.8	5.7	6.0
14	425.5	3.2	5.7	6.0	4.7	4.8	5.7	6.0
15	428.7	3.3	4.7	4.8	4.7	4.8	5.7	6.0
16	432.0	7.6	5.0	4.0	4.7	4.0	5.7	6.0
17	439.6	5.2	1.3	1.3	1.3	1.3	5.7	6.0
18	444.8	11.0	5.5	5.0	4.7	4.8	5.7	6.0

Table 15 Transportation Costs By Zone Per Vessel

Zone	Transportation Cost By Reach Per Vessel- Actual (Upbound)	Transportation Cost By Reach Per Vessel- Actual (Downbound)	Transportation Cost By Reach Per Vessel- FWOP (Upbound)	Transportation Cost By Reach Per Vessel- FWOP (Downbound)	Transportation Cost By Reach Per Vessel- Optimal (Upbound)	Transportation Cost By Reach Per Vessel- Optimal (Downbound)
11	$ 312	$ 410	$ 401	$ 410	$ 335	$ 315
12	$ 244	$ 163	$ 244	$ 163	$ 113	$ 106
13	$ 259	$ 183	$ 259	$ 200	$ 170	$ 160
14	$ 151	$ 142	$ 181	$ 177	$ 151	$ 142
15	$ 187	$ 183	$ 187	$ 183	$ 156	$ 146
16	$ 405	$ 504	$ 430	$ 504	$ 359	$ 337
17	$ 1,094	$ 1,071	$ 1,094	$ 1,071	$ 246	$ 231
18	$ 537	$ 585	$ 622	$ 610	$ 520	$ 488

7.2 Costs

The costs are determined based on the cost of construction of the alternatives and increments, cyclical dredging costs, and levee lifts throughout the 50-year period of analysis. For details how the costs were derived, refer to the Main Report and the Engineering Appendix. The benefits and costs are expressed in October 2021 dollars with a federal discount rate of 2.25% to determine average annual figures.

Table 16 Construction Costs

Increment Reference #	Zone	Increment	Construction Cost	IDC	Total Cost with IDC	Average Annual Cost
1	12	12.3.1	$ 12,023,356	$ -	$ 12,023,356	$ 403,003
2	12	12.3.2	$ 17,703,372	$ -	$ 17,703,372	$ 593,388
3	13	13.3.1	$ 39,124,868	$ -	$ 39,124,868	$ 1,311,401
4	14	14.3.1	$ 19,984,666	$ -	$ 19,984,666	$ 669,853
5	16	16.3.1	$ 44,785,997	$ -	$ 44,785,997	$ 1,501,153
6	18	18.3.1	$ 82,176,857	$ -	$ 82,176,857	$ 2,754,433
7	18	18.3.2	$ 180,051,373	$ -	$ 180,051,373	$ 6,035,027
9	18	18.3.3	$ 224,478,370	$ -	$ 224,478,370	$ 7,524,147
11	13	13.6.1	$ 60,907,295	$ -	$ 60,907,295	$ 2,041,513
12	14	14.6.1	$ 15,746,397	$ -	$ 15,746,397	$ 527,793
13	16	16.6.1	$ 32,337,806	$ -	$ 32,337,806	$ 1,083,910
14	18	18.6.1	$ 125,078,779	$ -	$ 125,078,779	$ 4,192,435
15	18	18.6.2	$ 175,347,581	$ -	$ 175,347,581	$ 5,877,363

Table 17 Levee Lift O&M Average Annual Costs By Zone and Increment

Levee Lift O&M Cost Savings						
Inc Ref #	**12**	**13**	**14**	**16**	**18**	**Total**
WOPC	$ 449,426	$ 670,193	$ 678,711	$ 654,234	$ 1,549,612	$ 4,002,176
1	$ 310,229	$ 668,956	$ 677,414	$ 655,104	$ 1,504,497	$ 3,816,199
2	$ 401,461	$ 668,956	$ 677,414	$ 655,104	$ 1,504,497	$ 3,907,431
3	$ 449,426	$ 584,122	$ 677,414	$ 655,104	$ 1,504,497	$ 3,870,562
4	$ 449,426	$ 668,956	$ 584,335	$ 655,104	$ 1,504,497	$ 3,862,317
5	$ 449,426	$ 668,956	$ 677,414	$ 517,792	$ 1,504,497	$ 3,818,084
6	$ 449,426	$ 668,956	$ 677,414	$ 655,104	$ 1,275,904	$ 3,726,803
7	$ 449,426	$ 668,956	$ 677,414	$ 664,982	$ 1,800,056	$ 4,260,834
9	$ 449,426	$ 668,956	$ 677,414	$ 655,104	$ 2,133,314	$ 4,584,213
11	$ 416,063	$ 631,685	$ 641,926	$ 655,104	$ 1,504,497	$ 3,849,274
12	$ 453,927	$ 500,827	$ 282,136	$ 655,104	$ 1,504,497	$ 3,396,490
13	$ 449,426	$ 602,828	$ 441,190	$ 323,420	$ 1,504,497	$ 3,321,361
14	$ 449,426	$ 564,984	$ 641,194	$ 652,552	$ 1,197,459	$ 3,505,615
15	$ 449,658	$ 564,984	$ 641,194	$ 652,552	$ 1,520,370	$ 3,828,758
16	$ 309,495	$ 561,597	$ 643,988	$ 514,428	$ 1,460,484	$ 3,489,992
18	$ 315,852	$ 631,685	$ 282,136	$ 323,420	$ 1,460,484	$ 3,013,577
19	$ 309,495	$ 561,597	$ 643,988	$ 514,428	$ 2,091,403	$ 4,120,910
20	$ 315,852	$ 631,685	$ 282,136	$ 323,420	$ 1,520,370	$ 3,073,462

Table 18 Dredging O&M Average Annual Costs By Zone and Increment

Dredging O&M Cost Savings						
Inc Ref #	12	13	14	16	18	Total
WOPC	$ 2,094,362	$ 823,831	$ 883,685	$ 1,072,080	$ 4,990,428	$ 9,864,386
1	$ 2,078,209	$ 798,259	$ 867,204	$ 1,071,184	$ 4,973,711	$ 9,788,566
2	$ 2,131,964	$ 798,259	$ 867,204	$ 1,071,184	$ 4,973,711	$ 9,842,322
3	$ 2,097,268	$ 792,080	$ 867,178	$ 1,071,184	$ 4,973,711	$ 9,801,421
4	$ 2,096,837	$ 798,259	$ 866,345	$ 1,071,184	$ 4,973,711	$ 9,806,335
5	$ 2,096,837	$ 798,259	$ 867,211	$ 1,008,864	$ 4,973,711	$ 9,744,881
6	$ 2,096,837	$ 798,259	$ 867,211	$ 1,071,184	$ 3,655,804	$ 8,489,293
7	$ 2,098,033	$ 798,259	$ 867,211	$ 1,071,184	$ 3,277,189	$ 8,111,874
9	$ 2,096,837	$ 798,259	$ 867,211	$ 1,071,184	$ 2,869,608	$ 7,703,097
11	$ 2,097,268	$ 792,080	$ 867,178	$ 1,071,184	$ 4,973,711	$ 9,801,421
12	$ 2,094,595	$ 798,259	$ 866,331	$ 1,071,184	$ 4,973,711	$ 9,804,079
13	$ 2,096,837	$ 798,259	$ 867,204	$ 1,008,864	$ 4,973,711	$ 9,744,875
14	$ 2,096,837	$ 798,259	$ 867,204	$ 1,071,184	$ 1,467,140	$ 6,300,623
15	$ 2,096,837	$ 798,259	$ 867,204	$ 1,071,184	$ 2,141,863	$ 6,975,346
16	$ 1,597,201	$ 681,382	$ 751,863	$ 894,163	$ 4,090,645	$ 8,015,255
18	$ 1,597,201	$ 681,382	$ 751,863	$ 894,163	$ 4,085,950	$ 8,010,560
19	$ 1,597,201	$ 681,382	$ 751,863	$ 894,163	$ 2,663,920	$ 6,588,530
20	$ 1,597,201	$ 681,382	$ 751,863	$ 894,163	$ 1,872,163	$ 5,796,774

The tables below display the benefits, costs, net benefits, and benefit cost ratio for each zone. The left column signifies the zone, alternative, and increment (e.g. 12.3.1, 12.3.2, etc.). The total is a culmination of the most economical increments for each zone.

Table 19 Alternative 3 Economic Results

Alternative 3	Average Annual Benefits	Average Annual Costs	Net Benefits	BCR
Zone 12				
12.3.1	$ 1,088,797	$ 403,003	$ 685,794	2.70
12.3.2	$ 943,810	$ 593,388	$ 350,422	1.59
Zone 13				
13.3.1	$ 745,579	$ 1,311,401	$ (565,822)	0.57
Zone 14				
14.3.1	$ 436,911	$ 669,853	$ (232,943)	0.65
Zone 16				
16.3.1	$ 877,597	$ 1,501,153	$ (623,556)	0.58
Zone 18				
18.3.1	$ 2,411,466	$ 2,754,433	$ (342,967)	0.88
18.3.2	$ 2,254,855	$ 6,035,027	$ (3,780,172)	0.37
18.3.3	$ 2,340,252	$ 7,524,147	$ (5,183,894)	0.31
Total	$ 5,560,350	$ 6,639,844	$ (1,079,494)	0.84

Table 20 Alternative 6 Economic Results

Alternative 6	Average Annual Benefits	Average Annual Costs	Net Benefits	BCR
Zone 13				
13.6.1	$ 766,867	$ 2,041,513	$ (1,274,646)	0.38
Zone 14				
14.6.1	$ 904,994	$ 527,793	$ 377,200	1.71
Zone 16				
16.6.1	$ 1,374,328	$ 1,083,910	$ 290,417	1.27
Zone 18				
18.6.1	$ 4,821,324	$ 4,192,435	$ 628,889	1.15
18.6.2	$ 3,823,458	$ 5,877,363	$ (2,053,905)	0.65
Total	$ 7,867,513	$ 7,845,652	$ 21,861	1.00

8.0 TRADEOFF ANALYSIS

As stated above, the benefits do not capture all the benefits to having a reliable channel. Similarly, this is a resilience study, and therefore selecting the plan that yields the highest net benefits based on transportation delay savings may or may not be the best selection to achieve the study objective of navigation resiliency from episodic disturbances, nor reduce safety risks for vessels operating within the GIWW navigation system. An additional step was taken in this study of conducting a tradeoff analysis to pursue opportunities to address resiliency and safety to navigation. The measures used to achieve these goals are mostly in the form of barrier islands. The metrics used for the tradeoff analysis include: acres of reduced erosion from barrier islands, and linear feet of channel protection by use of barrier islands. One caveat to these metrics is that Caney Creek (zone 12) has different hydrology and therefore these metrics are not as relevant when comparing zone 12 to other zones.

The following table shows the economic factors as well as the resiliency metrics. The shaded green areas are included in the NED plan. Both 12.3.1 and 12.3.2 are shaded because either one could be included in the NED plan. Although 12.3.2 has fewer net benefits presently, the team recognizes that if other benefits were included in the calculations, it is possible that 12.3.2 net benefits will exceed 12.3.1. Further refinement will occur to bring greater granularity to the results.

Table 21 Economic and Resiliency Metrics Results by Zone

Increment	Benefits				Costs		Annualized Net Benefits	BCR						
	Transportation Savings	AAEQ Transportation Savings	Average Annual O&M Costs Savings	Total Benefits	Total Project First Costs	Average Annual Project First Costs			Acres of Barrier Island Erosion Reduced by 2080	Annualized Cost per Acre of Erosion Reduced	Incremental Cost/ Incremental Acre	Linear Feet of Channel Exposure Reduced by 2080	Annualized Cost per Linear Foot of Channel Protected	Incremental Cost/ Incremental Linear Foot
Zone 12														
12.3.1	$ 24,675,220	$ 827,000	$ 261,797	$ 1,088,797	$ 12,023,356	$ 403,003	$ 685,794	2.7	16	$ 25,950	$ 25,950	951	$ 424	$ 424
12.3.2	$ 24,675,220	$ 827,000	$ 116,810	$ 943,810	$ 17,703,372	$ 593,388	$ 350,422	1.6	16	$ 38,209	#DIV/0!	951	$ 624	#DIV/0!
Zone 13														
13.3.1	$ 16,437,347	$ 551,000	$ 194,579	$ 745,579	$ 39,124,868	$ 1,311,401	$ (565,822)	0.6	3	$ 393,814	$ 393,814	19,000	$ 69	$ 69
13.6.1	$ 16,437,347	$ 551,000	$ 215,867	$ 766,867	$ 60,907,295	$ 2,041,513	$ (1,274,646)	0.4	438	$ 4,664	$ 1,681	19,000	$ 107	#DIV/0!
Zone 14														
14.3.1	$ 7,123,093	$ 239,000	$ 197,911	$ 436,911	$ 19,984,666	$ 669,853	$ (232,943)	0.7	25	$ 26,859	$ (1,602)	4,329	$ 155	$ 155
14.6.1	$ 7,123,093	$ 239,000	$ 665,994	$ 904,994	$ 15,746,397	$ 527,793	$ 377,200	1.7	114	$ 4,645	$ 4,645	4,329	$ 122	#DIV/0!
Zone 16														
16.3.1	$ 17,133,617	$ 574,000	$ 303,597	$ 877,597	$ 44,785,997	$ 1,501,153	$ (623,556)	0.6	165	$ 9,106	$ (1,976)	7,704	$ 195	$ 195
16.6.1	$ 17,133,617	$ 574,000	$ 800,328	$ 1,374,328	$ 32,337,806	$ 1,083,910	$ 290,417	1.3	376	$ 2,883	$ 2,883	7,704	$ 141	#DIV/0!
Zone 18														
18.3.1	$ 22,706,827	$ 761,000	$ 1,650,466	$ 2,411,466	$ 82,176,857	$ 2,754,433	$ (342,967)	0.9	348	$ 7,924	$ 7,924	33,115	$ 83	$ 83
18.3.2	$ 22,706,827	$ 761,000	$ 1,493,855	$ 2,254,855	$ 180,051,373	$ 6,035,027	$ (3,780,172)	0.4	426	$ 14,161	$ (215)	33,115	$ 182	#DIV/0!
18.3.3	$ 22,706,827	$ 761,000	$ 1,579,252	$ 2,340,252	$ 224,478,370	$ 7,524,147	$ (5,183,894)	0.3	426	$ 17,655	#DIV/0!	33,115	$ 227	#DIV/0!
18.6.1	$ 22,706,827	$ 761,000	$ 4,060,324	$ 4,821,324	$ 125,078,779	$ 4,192,435	$ 628,889	1.2	1161	$ 3,611	$ 1,768	33,115	$ 127	#DIV/0!
18.6.2	$ 22,706,827	$ 761,000	$ 3,062,458	$ 3,823,458	$ 175,347,581	$ 5,877,363	$ (2,053,905)	0.7	1161	$ 5,063	#DIV/0!	33,115	$ 177	#DIV/0!

8.1 Cost Effectiveness

In reviewing the various alternative and increment combinations, given that the alternatives are mutually exclusive within each zone and between zones, determining the cost effectiveness was straightforward with the exception of zone 12 at Caney Creek. In zone 12, alternative 3 increment 1 appears to be the most cost effective with a higher BCR than increment 2. However, as stated above, the widening in increment 2 provides additional benefits that are more difficult to quantify, potentially allowing it to be more cost effective. In zone 13, neither alternatives have a BCR above unity but alternative 3 is slightly more cost effective than alternative 6. In zones 14 and zones 16, alternative 6 is more cost effective. In zone 18, alternative 6 increment 1 is clearly the most cost effective.

Each zone was assessed independently. Increments 12.3.1 and 12.3.2 are inconclusive at this point in the study. Zone 13 is not economically justified based on transportation delay savings. Zone 14 and Zone 16 are only economical for alternative 6, and Zone 18 only has 18.6.1 that is economically feasible.

When considering resiliency metrics, 13.6.1 was included since it provides more acres. Additionally, 18.3.1 was included due to the number of acres, and 18.3.2 was also included since it was preferred to 18.3.3. Increment 2 provided the same acres as increment 3 but at less cost.

8.2 Incremental Analysis and Best Buy Plans

Incremental cost analysis (ICA) was conducted on each of the cost-effective plans. ICA compares the incremental cost per incremental benefit among the plans to identify plans that maximize the last dollar spent. Starting with the no action plan, the incremental cost per incremental benefit is calculated from the no action for each cost-effective plan. The plan with the least incremental cost per incremental output is identified as the first of the “with-project” best buy plans. Then starting with that plan, the incremental cost per incremental benefit is calculated between that plan and each remaining cost-effective plan, and the one with the least incremental cost per incremental benefit is identified as the next plan in the array of best buy plans. This process continues until there are there are no remaining plans. The last plan in the best buy array is the plan that contains all the management measures being analyzed.

Table 22 Incremental Analysis Using Acres

Description	Increment	Average Annual Cost	Acres	Incremental Cost	Incremental Acres	Incremental Cost Per Incremental Acre
Most Acres	18.6.1	$ 4,192,435	1161	$ -	0	
Cost Effective	12.3.1	$ 403,003	16	$ -	0	
O&M Savings	14.6.1	$ 527,793	114	$ -	0	
Least Cost Combo	12.3.1 - 14.6.1	$ 930,797	129	$ 403,003	16	$ 25,950
NED - 18	12.3.1 - 14.6.1 - 16.6.1	$ 2,014,707	505	$ 1,083,910	376	$ 2,883
Resilience - 18	12.3.2 - 13.6.1 - 14.6.1 - 16.6.1	$ 4,246,604	943	$ 2,231,897	438	$ 5,099
NED	12.3.1 - 14.6.1 - 16.6.1 - 18.6.1	$ 6,207,142	1666	$ 4,192,435	1161	$ 3,611
Resilience	12.3.2 - 13.6.1 - 14.6.1 - 16.6.1 - 18.6.1	$ 8,439,040	2104	$ 4,192,435	1161	$ 3,611

Table 23 Incremental Analysis Using Linear Feet

Description	Increment	Average Annual Cost	Linear Feet	Incremental Cost	Incremental Feet	Incremental Cost Per Incremental Foot
Most Acres	18.6.1	$ 4,192,435	33,115	$ -	0	
Cost Effective	12.3.1	$ 403,003	951	$ -	0	
O&M Savings	14.6.1	$ 527,793	4,329	$ -	0	
Least Cost Combo	12.3.1 - 14.6.1	$ 930,797	5,280	$ 403,003	951	$ 424
NED - 18	12.3.1 - 14.6.1 - 16.6.1	$ 2,014,707	12,984	$ 1,083,910	7,704	$ 141
Resilience - 18	12.3.2 - 13.6.1 - 14.6.1 - 16.6.1	$ 4,246,604	31,984	$ 2,231,897	19,000	$ 117
NED	12.3.1 - 14.6.1 - 16.6.1 - 18.6.1	$ 6,207,142	46,099	$ 4,192,435	33,115	$ 127
Resilience	12.3.2 - 13.6.1 - 14.6.1 - 16.6.1 - 18.6.1	$ 8,439,040	65,099	$ 4,192,435	33,115	$ 127

9.1 Caney Creek

Caney Creek introduces some interesting idiosyncrasies to the analysis that are not captured in the benefit numbers. This area is known to experience vessel groundings due to excessive shoaling.

The US Coast Guard collects data on groundings. The USCG was consulted, and recorded groundings in their database for 2018-2020 are included in the following table.

Table 24 List of Groundings Recorded by US Coast Guard, 2018-2020

Date	Vessel Class	Vessel Type	Damage Status
12/14/2019	Towing Vessel	General	Damaged
02/07/2020	Towing Vessel	General	Damaged
02/07/2020	Towing Vessel	General	Damaged
02/08/2020	Towing Vessel	General	Undamaged
05/30/2020	Barge	Bulk Liquid Cargo	Undamaged
07/28/2020	Barge	Bulk Liquid Cargo	Undamaged
07/30/2020	Barge	General	Undamaged
07/30/2020	Barge	General	Undamaged
07/30/2020	Barge	General	Undamaged
07/30/2020	Barge	General	Undamaged
07/30/2020	Barge	General	Undamaged
07/30/2020	Barge	General	Undamaged
07/30/2020	Barge	General	Undamaged

The Corps of Engineers Operations branch also has a record of groundings. The data from Operations and the records from USCG do not coincide very well. Operations records show groundings occurred both in 2018 and 2019 after storms passed through. Consequently, the Corps surveyed twice and observed the shoal was moving. It was dredged in early FY2021.

The discrepancy could be accounted for by the way the information is gathered. The USCG is notified of groundings when industry self-reports the groundings to the USCG. There is a disincentive for industry to officially report groundings to the USCG, and therefore likely only the more severe groundings get reported where it shuts down the channel or causes damage to a vessel. On the contrary, Operations is notified of groundings either by industry or via GICA notifications. Industry has an interest in informing GICA about groundings so that the channel can be dredged out of cycle by the Corps. Likewise, the Corps has an interest in recording it so that they know what areas need the attention.

Emergency dredging contracts are issued on a regular basis with the current conditions at Caney Creek. When storms strike, the excessive currents increase the shoaling in the area and can cause impediments to navigation. To alleviate the problem, emergency dredging must occur out of the regular dredging cycle to help open up the channel again. Such contracts were issued in June 2015 with work completed September 2015, August 2017 following Hurricane Harvey with work completed October 2017, and additional contracts issued in 2018, 2019, and early 2021. To save on mobilization and demobilization, on-going contracts were modified rather than executing a stand-along contract. This out of cycle dredging is not only costly in terms of mobilization and demobilization, but also causes disruptions to regular traffic flows. It is unknown to what extent the disruptions to the users affect overall business operations. Industry has already pointed out to us that they schedule vessels to arrive at Caney Creek during high tide, which takes additional manpower and coordination. Computing the full business effects is beyond the scope of this study, but undoubtedly the shoaling has an effect on their business practices.

It is anticipated that Increment 12.3.2, to include channel widening at Caney Creek, will help alleviate some of these concerns and will reap additional benefits not captured in 12.3.1, as well as yield additional O&M cost savings. Based on current figures, if 12.3.2 can reduce an average of $340,000 in damages due to groundings per year, 12.3.2 will prove to be a more economical choice than 12.3.1.

9.2 Potential Additional Benefits

In addition to the emergency dredging that occurs at Caney Creek, emergency dredging has occurred in other parts of the GIWW within the study area. Post Hurricane Harvey, three contracts were modified to conduct emergency dredging at the Colorado River Locks and East Matagorda Bay. These two shoals shut down the GIWW completely for about two weeks. The channel was able to be incrementally opened in stages over the next 2-3 weeks after that.

9.2.1 Theoretical Construct

Markets are very dynamic and complex. Countless factors can have an effect on a market, and the supply chain that feeds that market in turn can also be influenced by these factors. The oil and gas industry is largely an input into other industries, and therefore has additional market influences. That contributes to the volatility particularly within the oil and gas industry. Certain markets have more stable and constant demand, such as residential energy, while others vary in demand such manufacturing.

The modes of feeding this supply chain in the Texas Gulf Coast are limited. Essentially, the modes of transport include the GIWW, pipeline, truck, or rail. Pipelines are generally cheapest but often operate at capacity already, and certain materials cannot be transported by pipeline. Generally, the next cheapest option is by waterway. Rail can sometimes be cheaper, depending on the distance traveled and the route. Truck is almost inevitably higher cost and causes congestion on roads. Hence, generally the preferred method of transport is the GIWW when pipelines are not available.

The substitution effects on modes of transport are complex, but can be explained through fundamental economics graphs. Economists use indifference curves to illustrate a theoretical concept known as utility. Traditionally, utility plots the combination of commodities that an individual would accept to maintain a given level of satisfaction. These plots make up an indifference curve. Utility and indifference curves are used by economists to understand the underpinnings of demand curves in the supply and demand analysis that is used to analyze the workings of goods markets.

Adopting this concept, but applying it to the modes of transporting goods, we get the following graph. When the marginal cost of transporting by waterway is high, the users will likely shift to other methods of transport. When the marginal cost of transporting by other means is high comparatively to waterway, the users will shift to waterway. This gives us our Indifference Curves. The vertical axis is the quantity shipped by waterway (as a function of the marginal cost of other modes), and the horizontal axis is the quantity shipped by other modes (as a function of the marginal cost of the GIWW). Points A and B lie on the same indifference curve. Point B represents the market in perfect equilibrium. Point A represents a point where there exists some inefficiencies in the waterway. The marginal cost of using the waterway is higher for a certain amount of quantities (e.g. delays), and therefore users transport by other means (rail, truck). By providing a more resilient channel, users will experience fewer delays, thereby allowing their product to be shipped cheaper. Point A would shift to Point B, and there would be a greater quantity being transported by waterway. In the longer term, with cheaper marginal cost and more efficient transport, industry would have more trust and reliability using the waterway. Industry would perhaps make some longer-term changes to their operations, and the utility curve would expand. An even greater number of goods would be transported via waterway, shifting from Point B to Point C.

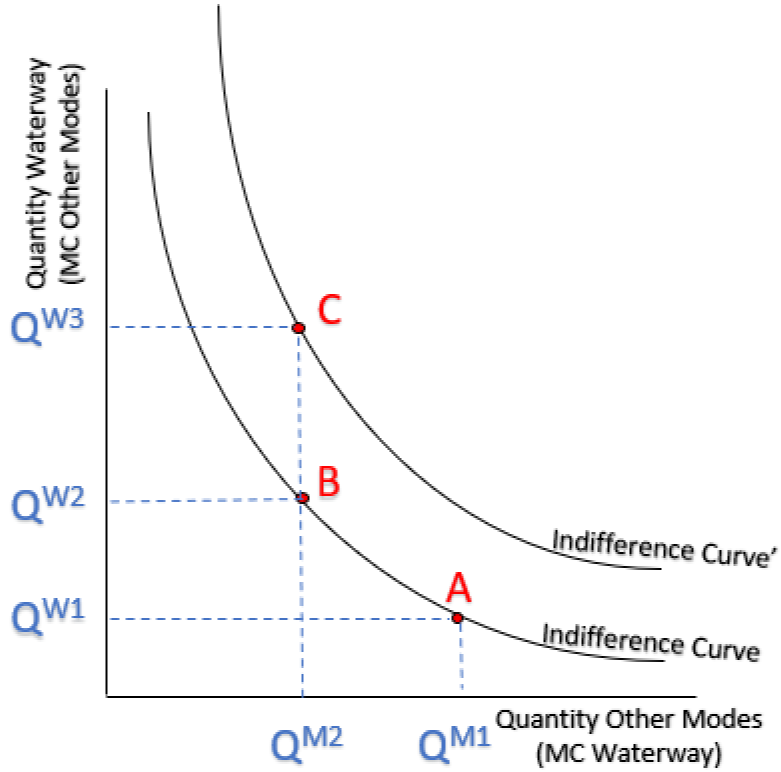

Figure 10 Indifference Curves

Another way to illustrate potential growth to the GIWW is by plotting budget lines. Every business operates under budget constraints. At a given cost of transport, a certain quantity will be transported on the GIWW. As costs increase, fewer goods will use the waterway, and similarly with other modes of transportation. If we plot all these points, we get a budget line, as illustrated in the graph below. The vertical axis is the quantity being transported on the GIWW, and the horizontal axis is the quantity being transported by other modes. Again, Point A represents inefficiencies in the GIWW, with a total of Q^{W1} using the GIWW and Q^{M1} using other modes of transport. As the channel is more resilient, and delays are reduced, Point A will shift to Point B, thereby shifting some of the commodities to the GIWW. In the longer term, with a reduction in transportation cost and as industry recognizes the more resilient channel, the unit cost will be reduced on the waterway thereby having an effect of an expanding budget line upward, assuming there is sufficient demand for the product. As the budget line expands, Point B will shift to Point C, and an even greater quantity of goods will be transported on the GIWW while having little effect on the quantity of goods being transported by other modes.

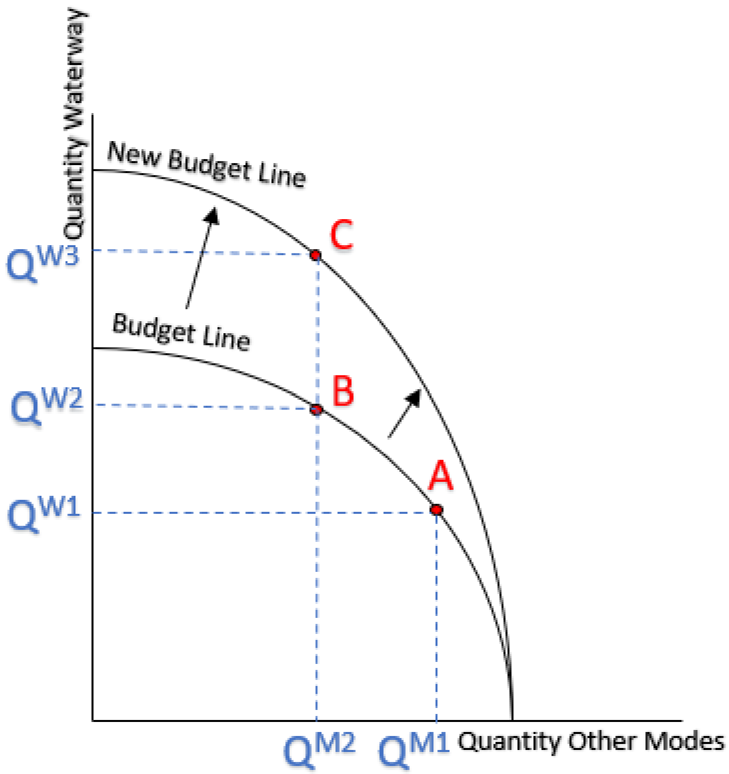

Figure 11 Budget Line

Calculating the magnitude of these quantity shifts are beyond the scope of this analysis, but the shifts are expected to occur to some degree. The importance that trust and confidence in a reliable channel play in the roles of decisions made by industry to use the GIWW cannot be overstated. These non-tangible assets to channel reliability are paramount to a thriving industry and economy. A resilient and reliable channel builds trust and dependability for its users, thereby stabilizing business operations feeding the oil and gas industry, which in turn feeds the national economy.

10.0 IS IT WORTH IT ANALYSIS

Several combinations of increments were analyzed to determine the most preferable solution that meets the study objectives of resiliency (refer to Incremental Analysis section). Descriptions of each zone and alternative are described in previous sections. Zones 12, 14, 16, and 18 only had one increment in each that was cost effective.

Increment 18.6.1 includes the most acres, so it was assessed independently. Although this option provides protection for zone 18, it leaves the remaining zones exposed and doesn't provide sufficient resilience to the channel by itself.

Similarly, 12.3.1 was the least cost option. Although cheaper, this increment by itself was also determined to be insufficient in offering a resilient channel.

Likewise, 14.6.1 provided the most O&M cost savings. The construction of increment 14.6.1 pays for itself strictly from the O&M cost savings. However, it was also determined to be insufficient to offer a resilient channel by itself.

Various combinations of the cost-effective increments were also analyzed. They were grouped together with consideration of hydrology, cost, economics, and environmental. Because of the cost of 18.6.1, the NED and the Resilience plans were considered both with and without Zone 18. The NED plan includes those increments in each zone that have positive net benefits. This includes zones 12, 14, 16, and 18. In order for the channel to have complete protection using barrier islands in the entire channel, it was determined that zone 13 also should be included even though this increment was found to not be cost effective in terms of transportation delay savings. The team recognized that the channel is only as resilient as its weakest point though, so if the rest of the channel is protected and zone 13 is exposed, it poses potential problems when adversity strikes. Therefore, 13.6.1 was added to the NED plan to consist of the resilience plan.

The Resilience plan was determined to be the optimal plan to continue the study. It includes 12.3.2, 13.6.1, 14.6.1, 16.6.1, and 18.6.1 as its components. Although the project can theoretically be constructed as separable elements, the full benefits and O&M cost savings will not be achieved until the project is completed due to the connectedness of the hydrology between zones.

11.0 RISK AND UNCERTAINTY

The following risks were considered during alternative and plan formulation.

Risk 1: Acres and linear feet may not have equal benefit toward navigation resilience in every zone and increment.

- Likelihood: Medium
- Consequence Rating: Low
- Risk Management: Consulted with GICA, Operations, hydraulic engineers to utilize best available models and data for quantifying benefits.

Risk 2: Shoaling modeling uncertainties have direct effect on benefit calculations.

- Likelihood: High
- Consequence: High
- Risk Management: Conduct scenario analysis to accommodate for uncertainty in weather, erosion rates, shoaling rates

Risk 3: Uncertainty surrounding dredging quantities and placement affect average annual costs and incremental cost analysis. Quantities and locations of placement can vary widely depending on what type of storms strike the Texas Coast, where they strike, and the frequency of storms.

- Likelihood: High
- Consequence: High
- Risk Management: Use best professional judgment on data available to date.

Risk 4: Benefit calculations allow for a reduction in delays based on vessel speeds. Without ship simulation, it is difficult to determine what speeds vessels will be able to travel in the channel in the FWOP and FWP.

- Likelihood: High
- Consequence: Medium
- Risk Management: Since this is a resilience study, the BCR is an important metric but is not the only consideration in determining the best plan. FWOP and FWP speeds were modeled based on input from the channel users when future conditions were described to them. A change in speeds could change the average annual benefits, but it would not change the plan selection.

12.0 ECONOMIC SUMMARY

The tables below displays the final array of increments for consideration and combinations thereof. Average annual benefits and average annual costs were computed using the FY22 federal discount rate of 2.25 percent and a 50-year period of analysis. Resilience metrics included acres reduced from erosion, and linear feet of channel protection.

The NED was found to include increments of 12.3.1, 14.6.1, 16.6.1, and 18.6.1. Although the NED is the most economical plan, it was determined that it was not the optimal plan when other considerations were included in the decision making.

Through the analysis and discussion, it was found that the Resilience plan would be the most preferred plan when considering costs, benefits, environmental, hydraulic factors, and overall navigation resilience for the GIWW channel. The resilience plan offers a favorable BCR, while providing protection via barrier islands the entire stretch of zones 12 to 18. The resilience plan includes the features in the NED plan, but it also includes channel modification at Caney Creek to offer some extra safety to the vessels, as well as a barrier island in zone 13. The inclusion of zone 13 would allow some flexibility in terms of placement of dredge material, as well as offer protection the entire stretch from zone 12 to 18 without any gaps. When taking all options into consideration, the resilience plan appeared to be the most logical choice to address the objective of providing a reliable channel. The tables below display the results summary.

Table 25 Economic Analysis Results

Description	Increment	Costs	Benefits			BCR
		Total Project First Costs	Average Annual O&M Costs Savings	Average Annual Cost Savings of Project (O&M Cost Savings less First Costs)*	Average Annual Net Benefits	
Most Acres	18.6.1	$ 125,078,779	$ 4,060,324	$ (132,111)	$ 628,889	1.2
O&M Savings	14.6.1	$ 15,746,397	$ 665,994	$ 138,200	$ 377,200	1.7
Cost Effective	12.3.1	$ 12,023,356	$ 261,797	$ (141,206)	$ 685,794	2.7
Least Cost Combo	12.3.1 - 14.6.1	$ 27,769,753	$ 927,791	$ (3,005)	$ 1,062,995	2.1
NED - 18	12.3.1 - 14.6.1 - 16.6.1	$ 60,107,559	$ 1,728,119	$ (286,588)	$ 1,353,412	1.7
NED	12.3.1 - 14.6.1 - 16.6.1 - 18.6.1	$ 185,186,338	$ 5,788,443	$ (418,699)	$ 1,982,301	1.3
Resilience - 18	12.3.2 - 13.6.1 - 14.6.1 - 16.6.1	$ 126,694,871	$ 1,798,998	$ (2,447,606)	$ (256,606)	0.9
Resilience	12.3.2 - 13.6.1 - 14.6.1 - 16.6.1 - 18.6.1	$ 251,773,649	$ 5,859,323	$ (2,579,717)	$ 372,283	1.0

Table 26 Tradeoff Analysis Results

Description	Increment					Tradeoffs Notes	
		Acres of Barrier Island Erosion Reduced by 2080	Annualized Cost per Acre of Erosion Reduced	Linear Feet of Channel Exposure Reduced by 2080	Annualized Cost per Linear Foot of Channel Protected	Pros	Cons
Most Acres	18.6.1	1161	$ 3,611	33115	$ 127	Least Cost per Acre, Number of acres	Highest First Cost for single zone
O&M Savings	14.6.1	114	$ 4,645	4329	$ 122	Project pays for itself in O&M cost savings	Little protection in linear feet
Cost Effective	12.3.1	16	$ 25,950	951	$ 424	Highest BCR, improves shoaling hot spot	Least protection in acreage and linear feet
Least Cost Combo	12.3.1 - 14.6.1	129	$ 7,207	5280	$ 176	Low first costs	High cost per acre and per linear foot
NED - 18	12.3.1 - 14.6.1 - 16.6.1	505	$ 3,988	12984	$ 155	Favorable BCR, addresses resilience at less cost	Not as resilient as zone 18 by itself
NED	12.3.1 - 14.6.1 - 16.6.1 - 18.6.1	1666	$ 3,726	46099	$ 135	Favorable BCR, addresses resilience in 4 of the 5 zones	Including Zone 18 significantly increases First Cost
Resilience - 18	12.3.2 - 13.6.1 - 14.6.1 - 16.6.1	943	$ 4,504	31984	$ 133	Addresses safety concerns in Zone 12, Addresses resilience in 4 of 5 zones with lower cost than NED	Higher Cost per Acre, O&M Costs increase, Missing Zone 18 which provides greatest resilience benefits
Resilience	12.3.2 - 13.6.1 - 14.6.1 - 16.6.1 - 18.6.1	2104	$ 4,011	65099	$ 130	Addresses safety concerns in Zone 12, Addresses resilience in all 5 zones	High First Cost, O&M Costs increase