ECONOMICS APPENDIX B

GULF INTRACOASTAL WATERWAY BRAZOS RIVER FLOODGATES AND COLORADO RIVER LOCKS FEASIBILITY STUDY

Prepared by:

Great Lakes and Ohio River Division
Planning Center of Expertise for Inland Navigation and Risk Informed Economics Division,
Navigation Planning Center Branch, Huntington District (CELRH-PX-NC)

With Assistance from Southwestern Division Economists, Mott MacDonald, and Martin Associates

March 2019

Contents

Tables

Figures

1) Overview

The Gulf Intracoastal Waterway (GIWW) traces the U.S. coast along the Gulf of Mexico 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. 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.

1.1 Existing and Historic Traffic

The following section details the number of vessels and types of commodities utilizing the Brazos River Floodgates and Colorado River Locks.

1.1.1 Historic Vessel Traffic

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). Table 1 displays vessel trips at both projects as reported in WCS. These include empty and loaded trips for all towboats and self-propelled commercial vessels.

Table 1 : Total Commercial Vessels through Brazos River Floodgates and Colorado River Locks

Year	WCS Commercial Vessels	
	Brazos River Floodgates	Colorado River Locks
2013	9,252	8,835
2014	10,403	10,002
2015	8,646	8,153
2016	7,102	6,631
Trip Totals Averaged Between the East/West Structures with rounding		

Source: Waterborne Commerce Statistics (WCS)

1.1.2 Historic Annual Commodity Tonnages

Table 2 and Table 3 display the annual tonnage by commodity for the Colorado River Locks and Brazos River Gates, respectively. Tonnage was averaged between the East and West Locks/Gates respectively to provide an average project tonnage. Some traffic may pass through one structure, and then turn up either the Brazos River (0.20% of tonnage average annually) or Colorado River (3.47% of tonnage average annually), according to LPMS data. Waterborne Commerce Statistics Center (WCSC) data does not show this behavior at the Brazos River Floodgates, but does support this occurring at the Colorado River Locks. Some of the discrepancy may also be related to inconsistent data capture between the project structures. WCSC and LPMS both report tonnage data. LPMS tonnage data tends to track 8-12% lower than WCSC data. The LPMS tonnage data is used in this report.

Table 2 : Colorado River Locks Annual Total Commodity Tons 1999 to 2016

Colorado River Locks (Thousands of Tons)										
Year	All Coal, Lignite, and Coal Coke	Petroleum and Petroleum Products	Chemicals and Related Products	Crude Materials, Inedible, Except Fuels	Primary Manufactured Goods	Food and Farm Products	Manufactured Equipment & Machinery	Waste Material	Unknown or Not Elsewhere Classified	Total
1999	49.41	8,872.58	7,954.63	3,662.95	337.69	162.28	101.94	-	12.12	21,153.60
2000	37.42	8,781.06	7,728.51	3,891.46	335.89	123.85	53.57	9.30	26.63	20,987.68
2001	35.66	8,607.08	6,935.78	3,174.42	344.26	199.36	57.03	10.10	15.73	19,379.42
2002	26.54	7,067.16	6,561.96	3,361.66	292.95	171.27	68.96	16.96	33.35	17,600.82
2003	59.72	7,654.61	6,705.52	4,117.32	544.72	191.85	61.56	21.68	12.83	19,369.81
2004	118.96	8,525.67	7,115.45	4,536.30	427.94	160.84	82.05	27.90	17.77	21,012.88
2005	89.12	9,022.13	6,606.18	4,002.09	385.29	166.11	70.76	16.40	16.86	20,374.95
2006	90.11	9,350.81	6,538.33	3,712.39	267.97	170.48	52.28	7.28	15.58	20,205.22
2007	74.56	9,474.10	6,284.72	3,431.27	478.61	189.66	53.36	45.26	11.28	20,042.82
2008	93.84	8,654.86	5,568.59	2,422.65	479.36	158.63	55.49	8.32	18.75	17,460.48
2009	44.78	8,549.00	5,135.09	1,966.80	186.53	186.20	35.75	6.60	5.76	16,116.50
2010	101.18	9,506.64	5,905.97	2,377.38	396.06	167.10	61.85	0.10	2.67	18,518.95
2011	160.53	9,355.70	5,964.29	2,540.73	522.64	211.43	53.02	13.38	17.80	18,839.50
2012	131.20	12,786.82	6,552.83	2,897.84	136.58	165.82	42.25	19.60	7.55	22,740.47
2013	83.95	13,976.65	6,021.15	2,734.15	71.87	115.75	39.19	13.85	6.12	23,062.69
2014	50.15	16,540.44	5,953.83	3,407.51	36.28	156.97	30.74	14.98	4.65	26,195.54
2015	48.41	13,199.07	5,692.22	2,965.75	51.25	124.43	39.53	18.51	2.80	22,141.95
2016	68.38	10,723.23	5,895.98	2,163.98	29.77	114.05	49.85	9.60	-	19,054.82

Source: Lock Performance Monitoring System (LPMS)

Table 3 : Brazos River Floodgates Annual Total Commodity Tons 1999 to 2016

Brazos River Floodgates (Thousands of Tons)										
Year	All Coal, Lignite, and Coal Coke	Petroleum and Petroleum Products	Chemicals and Related Products	Crude Materials, Inedible, Except Fuels	Primary Manufactured Goods	Food and Farm Products	Manufactured Equipment & Machinery	Waste Material	Unknown or Not Elsewhere Classified	Total
1999	43.54	8,843.85	8,054.74	3,598.33	342.54	155.99	117.29	-	2.80	21,159.08
2000	36.12	8,477.99	8,298.26	3,859.67	359.52	113.09	61.96	12.70	7.40	21,226.72
2001	31.76	8,222.64	7,500.98	3,120.97	349.87	197.16	60.50	8.70	-	19,492.57
2002	33.94	6,868.36	7,090.68	3,272.20	289.03	166.67	66.19	14.28	5.60	17,806.96
2003	59.40	7,442.08	7,248.84	4,102.90	555.77	183.89	59.38	24.14	3.70	19,680.08
2004	152.22	8,496.03	7,501.31	4,493.91	438.37	181.15	68.96	30.45	3.05	21,365.46
2005	73.23	8,888.07	7,083.89	3,974.64	369.47	171.69	56.74	15.30	9.40	20,642.42
2006	75.98	9,193.43	6,964.63	3,743.02	245.13	168.78	41.51	8.68	9.50	20,450.65
2007	60.18	9,288.17	6,760.17	3,413.85	512.14	181.11	53.17	28.29	6.07	20,303.15
2008	84.12	8,624.88	5,844.42	2,406.71	491.36	161.73	61.10	14.34	15.50	17,704.15
2009	35.13	8,321.42	5,537.05	1,936.35	169.52	184.30	42.91	7.18	4.30	16,238.14
2010	98.85	9,432.04	6,143.92	2,310.40	393.11	170.98	60.79	0.10	1.46	18,611.64
2011	146.17	9,376.36	6,168.81	2,521.07	494.04	215.25	54.21	11.76	7.70	18,995.37
2012	182.05	12,729.99	6,718.71	2,924.52	80.00	162.43	48.60	12.20	8.56	22,867.06
2013	128.50	13,636.19	6,503.26	2,615.05	44.41	116.30	50.11	6.70	3.90	23,104.42
2014	59.18	16,153.76	6,493.65	3,296.44	15.05	169.15	31.78	9.53	2.60	26,231.13
2015	59.41	13,116.18	5,959.17	2,904.22	9.30	124.37	43.78	15.80	-	22,232.23
2016	86.25	10,695.45	6,123.44	2,017.29	13.94	108.15	50.69	8.53	-	19,103.74

Source: Lock Performance Monitoring System (LPMS)

1.1.3 System Annual Tonnage by Commodity

Table 4 displays the detailed commodity tons for the combined Brazos River Floodgates and Colorado River Locks System for the years 1999 to 2016. Similar to how data is reported in Table 2 and Table 3, tonnage was averaged between project structures and then averaged between the projects themselves. Commodity tonnages are displayed for informational purposes, and serve as the foundation of the traffic forecasts.

Table 4 : Brazos River Floodgates / Colorado River Locks System Annual Total Commodity Tons 1999 to 2016

Brazos River Floodgates and Colorado River Locks System Tonnage (Thousands of Tons)										
Year	All Coal, Lignite, and Coal Coke	Petroleum and Petroleum Products	Chemicals and Related Products	Crude Materials, Inedible, Except Fuels	Primary Manufactured Goods	Food and Farm Products	Manufactured Equipment & Machinery	Waste Material	Unknown or Not Elsewhere Classified	Total
1999	46.48	8,858.22	8,004.69	3,630.64	340.12	159.14	109.62	-	7.46	21,156.34
2000	36.77	8,629.53	8,013.39	3,875.57	347.71	118.47	57.77	11.00	17.02	21,107.20
2001	33.71	8,414.86	7,218.38	3,147.70	347.07	198.26	58.77	9.40	15.73	19,436.00
2002	30.24	6,967.76	6,826.32	3,316.93	290.99	168.97	67.58	15.62	19.48	17,703.89
2003	59.56	7,548.35	6,977.18	4,110.11	550.25	187.87	60.47	22.91	8.27	19,524.95
2004	135.59	8,510.85	7,308.38	4,515.11	433.16	171.00	75.51	29.18	10.41	21,189.17
2005	81.18	8,955.10	6,845.04	3,988.37	377.38	168.90	63.75	15.85	13.13	20,508.69
2006	83.05	9,272.12	6,751.48	3,727.71	256.55	169.63	46.90	7.98	12.54	20,327.94
2007	67.37	9,381.14	6,522.45	3,422.56	495.38	185.39	53.27	36.78	8.68	20,172.99
2008	88.98	8,639.87	5,706.51	2,414.68	485.36	160.18	58.30	11.33	17.13	17,582.32
2009	39.96	8,435.21	5,336.07	1,951.58	178.03	185.25	39.33	6.89	5.03	16,177.32
2010	100.02	9,469.34	6,024.95	2,343.89	394.59	169.04	61.32	0.10	2.07	18,565.30
2011	153.35	9,366.03	6,066.55	2,530.90	508.34	213.34	53.62	12.57	12.75	18,917.44
2012	156.63	12,758.41	6,635.77	2,911.18	108.29	164.13	45.43	15.90	8.06	22,803.77
2013	106.23	13,806.42	6,262.21	2,674.60	58.14	116.03	44.65	10.28	5.01	23,083.56
2014	54.67	16,347.10	6,223.74	3,351.98	25.67	163.06	31.26	12.26	3.63	26,213.34
2015	53.91	13,157.63	5,825.70	2,934.99	30.28	124.40	41.66	17.16	2.80	22,187.09
2016	77.32	10,709.34	6,009.71	2,090.64	21.86	111.10	50.27	9.07	-	19,079.28

Source: Lock Performance Monitoring System (LPMS)

1.1.4 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 65 accidents occur per year at the Brazos Floodgates (Brazos River Floodgate, Supervisory Mechanic).

Figure 1 – Brazos River Floodgates Aerial Map

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.

Figure 2 – Colorado River Locks Aerial Map

1.1.5 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. 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, less than 1% of traffic traverses one lock or gate and turns up the Brazos River, while approximately 1 million tons on average utilizes one Colorado Lock and travels up the Colorado River without crossing the other lock. Table 5 shows the average annual tonnage at Brazos and Colorado from 2010 through 2014 and displays the high level of commonality between projects.

Table 5 : Average Annual Tonnage Commonality

Project Name	Average Tonnage	Average Through All	Commonality
Brazos Floodgates	22,497,593.00	21,038,012	97%
Colorado Locks	21,607,965.00		99%

Source: Waterborne Commerce Statistics (WCS) 2010-2014

Table 6 : Traffic Commonality between Brazos and Colorado Projects and Other USACE Projects

Project	Average Tonnage	Average Through Colorado, Brazos, and Lock	Commonality
Algiers	23,029,425.00	1,750,659.00	8%
Bayou Boeuf	25,253,375.00	2,116,894.00	8%
Bayou Sorrel	18,832,450.00	1,852,975.00	10%
Calcasieu	38,127,544.00	4,568,180.00	12%
Inner Harbor	15,967,412.00	425,916.00	3%
Leland Bowman	37,984,467.00	4,473,239.00	12%
Port Allen	19,486,405.00	1,850,999.00	9%

Source: Waterborne Commerce Statistics (WCS) 2010-2014

As displayed in Table 5, the Brazos and Colorado River projects have a significantly high level of traffic commonality. This suggests any substantial change at one project has the potential to alter traffic patterns or operations at the other project. These alterations can be beneficial or detrimental. For example, while expanding a chamber at a project could be beneficial in reducing trip costs and delays, it could also mean larger tows may desire to call on other projects in the system less equipped to handle them. Table 6 shows the traffic commonality with other USACE lock projects within the geographical extent of the GIWW. The relatively low level of commonality suggests that changes to Brazos or Colorado would have little relative impacts on the operational performance of other USACE Lock projects. That is to say, actions taken at the study projects are unlikely to result in increased congestion or maintenance needs at the other projects in the geographic area.

1.1.6 Project-Specific Data Issues

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 USAC lock projects. This insures 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.[1]

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. Where applicable, this is discussed in context of the specific data discrepancy. 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.

Analysts with USACE's Planning Center of Expertise for Inland Navigation and Risk-Informed Economics Division (PCXIN-RED) were made aware of certain data discrepancies at the outset of this study, and sought to process the data into a usable format. The PCXIN-RED does not own the LPMS dataset and cannot edit the raw data, therefore data changes featured in this study and resulting may not be

[1] *Lock Performance Monitoring System User's Manual for Data Collection and Editing (85-UM-1)*

reflected in other datasets. Furthermore, the data issues highlighted in this documentation are reflective of those identified throughout the study process and are not necessarily reflective of other potential data issues that may or may not be present.

The following sections will detail data issues that arose throughout the course of this study with respect to LPMS, and what steps were undertaken to address the data discrepancies for use in this analysis.

1.1.6.1 Flotilla Data

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." The LPMS dataset is structured around the concept of flotillas and these groupings of vessels are assigned a flotilla identification (Flotilla ID) number within the LPMS system to track the characteristics of these movements. For simplicity's sake within the data, a self-powered vessel moving commercial tonnage is also assigned a Flotilla ID despite it being a single vessel. This allows for these self-propelled vessels to have the characteristics of their movements tracked with the same criteria as tow packages and simplifies the relational dataset structure.

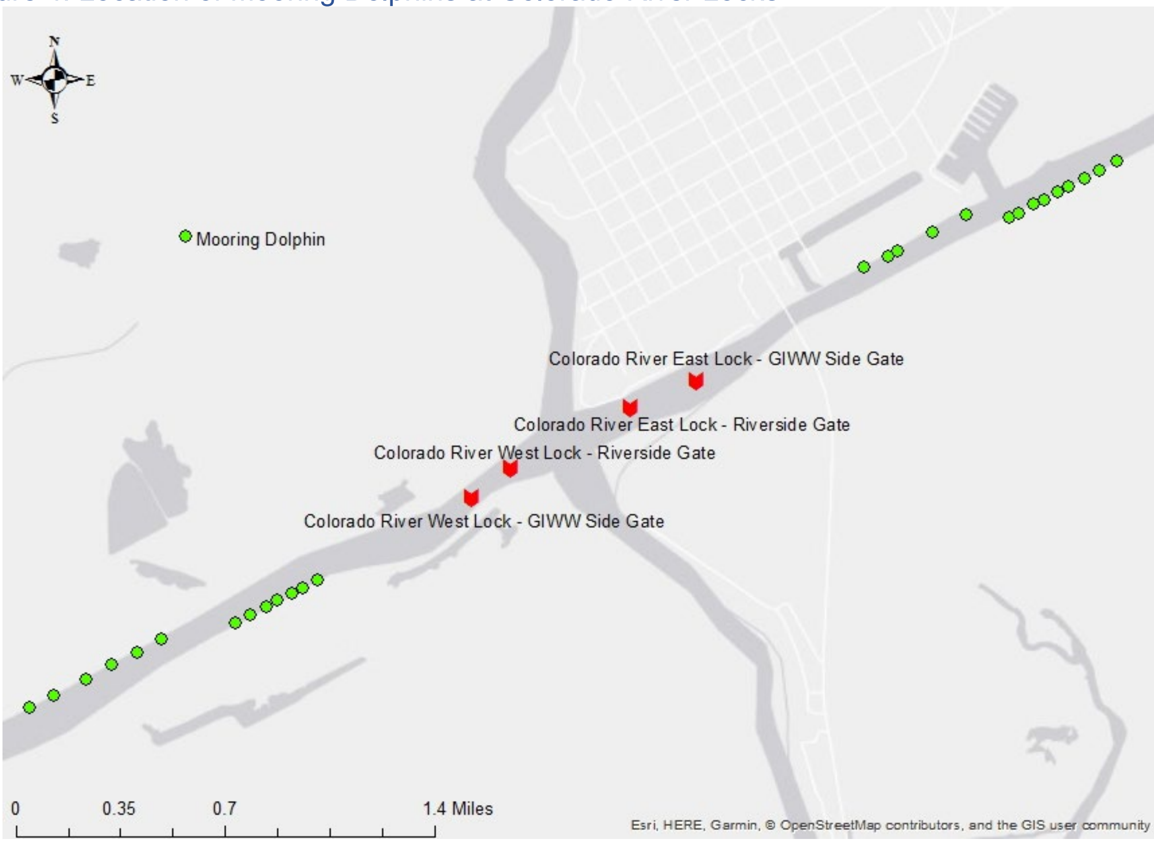
Flotilla IDs are especially important at smaller navigation projects where the practice of cutting tows is employed to allow for tow packages larger than the size of the chamber, or projects such as the Brazos River Floodgates or Colorado River Locks where tow packages may need to cut so they can safely transit the reach. A Flotilla ID allows for each cut to be related to the same common tow package, and thus analysts and modelers can track the details for each cut. For example, if a tow package requires three separate cuts to transit a project, the Flotilla ID allows for the timing and characteristics of each individual cut to be related back to the overall tow package. It also prevents cuts two and three of the example tow package from being attributed delay relating to the first cut's processing.

A typical inland waterway lock chamber is essentially a single service one-way bridge between two navigation pools at two different elevations. An oversized tow at one of these projects may make multiple cuts, but the lock chamber is typically fully involved in processing the entire tow before moving on to the next tow. The different segments of the tow are typically separated at the lock chamber and processed one at a time through the chamber, and then reassembled on the other side. This operation blocks the entire lock chamber and navigation area around the guide walls and gates, effectively preventing two-way traffic.

This is not the typical operating policy for the Brazos River Floodgates and Colorado River Locks. While a tow may require multiple cuts to transit the projects, there is nowhere to disassemble/reassemble the tow. For example, a two-cut tow traveling east to west will disassemble at a set of mooring dolphins on the east side that could be over a mile away from the gates. Next, the powered towboat will transport the first set of barges to the west side while leaving the second set at the dolphins. After securing the first set of barges at a dolphin on the west side of the project, the tow travels back through the project to retrieve the second set of barges. The towboat travels west through the project with the second set of barges and reassembles the tow at the west side dolphin. This process can take multiple hours, and other tows can utilize the projects while this operation is occurring. Figures 1 and 2 display the location of mooring dolphins in relation to the projects for the Brazos River Floodgates and Colorado River Locks respectively.

Figure 3: Location of Mooring Dolphins at Brazos River Floodgates

Figure 4: Location of Mooring Dolphins at Colorado River Locks



At the Brazos River Floodgates and the Colorado River Locks, the data was not captured at the Flotilla ID level. Instead, data for each individual cut was treated as its own independent package and is thus given a completely new Flotilla ID. An analysis of the data suggests no multi-cut tows at either project, despite this being a common practice at both facilities due to various restrictions that are discussed later in this document. While this is inconsistent with how the relational datasets are structured, and thus lead to a myriad of issues when working with the data, it is more consistent with how the projects actually operate.

To address this issue, the multiple flotilla numbers for a single tow within the LPMS data where identified and reassigned a single flotilla number. This was accomplished by pulling all the LPMS records at the E/W gates/locks at each project and ordering by the data by vessel ID number and then by the time of arrival. If a vessel was found to have gone through both gates, moving the same direction, and the End of Lockage (EOL) from the first gate was the same, or within minutes, as the Start of Lockage (SOL) for the second gate, then the 2 LPMS records were updated to show the same Flotilla ID. In addition, if the next observed arrival for the same vessel ID was going the same direction as the previous 2 records, and happened within 12 hours of the recorded arrival at the first gate of the previous 2 records, then it was assumed that those records represented the 2nd (or greater) cut and was given the same flotilla number.

1.1.6.2 Light Boat Data

In investigating the data discrepancies related to the lack of consistent Flotilla IDs, analysts noticed that Light Boat trips were not being recorded at either project location. A Light Boat is a powered towboat that is traveling by itself, without any barges. Every time a multi-cut occurs, and a vessel has to travel back to retrieve the remaining barges it left behind, a light boat trip reflecting that transit should have been recorded based on the way the data was being collected at the projects. PCXIN analysts estimate from the data that less than 5% of the light boat trips were recorded in the data being analyzed. This made the process of piecing the Flotillas back together much more difficult, as it would otherwise have been fairly straightforward to associate various cuts of the flotilla by tracking the light trips.

1.1.6.3 Stall/Stoppage Data

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 as 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 project downtime.

At the Brazos River Floodgates and Colorado River Locks, these stall/stoppage records are recorded in LPMS, at best, sporadically. Estimates for project closure 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. Table 7 displays the recorded stall/stoppage records for LPMS at both projects. Neither project's recorded stall/stoppage records reflect the level of closures cited by project staff.

Table 7 : Brazos River Floodgates and Colorado River Locks Stall/Stoppage Records

	Sum of Stall/Stoppage Duration (hours)					
Year	Colorado East	Colorado West	Colorado Locks Total	Brazos East	Brazos West	Brazos Floodgates Total
2000	3	1	4			0
2001	81	29	110	342	351	693
2002	48	34	82	193	186	379
2003	16	61	77	274	195	469
2004	49	61	110	475	407	882
2005	57	60	117	778	695	1,473
2006	34	33	67	396	374	770
2007	2	14	16	536	477	1,013
2008	40	9	49	831	802	1,633
2009	124	52	176	638	593	1,231
2010	136	22	158	588	501	1,089
2011	32	18	50	460	729	1,189
2012	230	253	483	479	807	1,286
2013	233	306	539	640	155	795
2014	113	82	195	177	381	558
2015	20		20	190	238	428

Source: Lock Performance Monitoring System (LPMS)

The lack of reliable stall/stoppage records in LPMS posed a difficulty for the analysis, given that these closures were identified as the largest impediment to the safe and efficient movement of commodities along this stretch of the GIWW. As a result, the stall/stop records from LPMS were blended with other information sources, such as notices to navigation issued by SWG and accident reports, to create a more reliable sample of data from which to analyze. This is described in greater detail in Section 2.4.2.3.1.

2) Evaluation Procedure

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. Further benefits can accrue from induced (new output / production) traffic that is transported only because of the lower transportation cost deriving from an improved project, and from creating or enhancing the potential for other productive uses of the waterway, such as the generation of hydropower. National defense benefits can also be realized from regional and national growth, and from diversity in transportation modes. In many situations, lower emissions can be achieved by transporting goods on the waterway. 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 which also accounts for any difference in transportation costs arising from loading, unloading, trans-loading, demurrage, and other activities involved in the ultimate point to point transportation of goods. For this analysis, for reasons discussed in detail later in this appendix, the benefit of barge transportation (rate savings) is not addressed, as the benefit for an alternative is calculated as the cost savings between waterway transportation costs for than alternative and waterway transportation costs for the baseline condition. In both cases, the benefit for federal investment in commercially-navigable waterways (benefits with a plan as opposed to benefits without a plan) ends up as a transportation cost reduction.

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 P&G provides general guidance for doing the benefit assessment, but leaves open opportunities to improve the analytical tools used as new data and computational capabilities are developed.

2.1 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 (e.g. flood gate) 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.

2.1.1 Analysis Framework

To understand the GIWW and inland navigation analysis framework, it is best to first understand the investment issues involved with inland navigation projects. The inland waterway transportation system is a mature transportation system and as a result, the investment options are focused on operational measures. The investment decisions are not whether to build a waterway transportation system, but whether and how to maintain and / or enhance the existing system (e.g. extended or new locks, channel improvements, replacement of key components, alternative maintenance policies, etc.). The objective is not to determine the value of the waterway transportation system, but to determine the value to changes in the waterway transportation system.

Navigation performance issues can arise as traffic levels increase (congestion) and / or the infrastructure degrades and becomes less reliable. At locks and gates too small to efficiently handle higher traffic volumes (and / or changing fleet configurations) congestion leads to a degradation in service reflected in increased delays and higher transit times. Aging projects and heavy usage can also cause serious reliability issues necessitating disruptive maintenance outages and causing disruptive service failures (e.g. closures). Increased lock and gate transit times, whether caused by traffic growth congestion or a lock or gate outage, increases transportation costs for shipments transiting the lock or gate, increasing trip cycles and ultimately requiring more equipment to move the same annual volume of traffic.

In response to shifting demands and increased traffic levels in some areas of the system, along with consideration of the aging infrastructure and increasing reliability concerns, the Corps desires identification of investments to maintain and / or enhance service where economically justified. In addition, in a budget constrained world, quantification and prioritization of investment options with consideration of risk becomes important in managing the system. These issues and concerns help frame the needed analysis framework as discussed below.

2.1.2 Sectoral, Spatial, and Temporal Detail

Economic models vary in terms of sectoral, spatial, and temporal detail. At one extreme are spatially-detailed computable general equilibrium (CGE) models. A general equilibrium analysis (despite the abstraction from the real economy) attempts to explain the behavior of supply, demand, and prices in a whole economy with an equilibration of all prices. CGE models are appropriate for issues expected to have economy-wide effects or whose economic effects follow complex but tractable pathways. If economy-wide effects are not realistically associated with the project being considered, modelers must make informed tradeoffs among the three dimensions.

As noted, from a transportation perspective the needed investment decisions are on relatively small improvements; whether and how to maintain or enhance the existing system. For this analysis the need does not exist to estimate the total benefits the nation would lose if a waterway system no longer existed.

2.1.3 Principles and Guidelines

As previously noted, the primary guidance for this framework is described in P&G (the latest regulatory successor to the Green Book). Inland navigation investments are to be analyzed through a NED analysis following an incremental and iterative planning process that "*… relies on the marginal analysis of benefits and costs for the formulation, evaluation, and selection of alternative plans that provide incremental changes in the net value of desired goods and services.*" 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. Further benefits accrue from traffic that is transported only because of the lower transportation cost deriving from an improved project, and from creating or enhancing the potential for other productive uses of the waterway, such as the generation of hydropower. National defense benefits can also be argued from the regional and national growth, and from diversity in transportation modes that the improvement provides. In some situations lower emissions can be achieved by transportation of goods on the waterway. Regardless, the conceptual basis for the "*… basic economic benefit of a navigation project is the reduction in the value of resources required to transport commodities.*" These reductions in transportation costs can be classified as:

- Cost-reduction benefits for commodity movements having the same origin, destination and waterway routing that realize cost reductions because of a navigation improvement. This reduction represents an NED gain because resources will be released for productive use elsewhere in the economy. Examples for the GIWW and inland navigation are reductions in costs incurred from trip delays (e.g. reduction in lock congestion), reduction in costs associated with the use of larger or longer tows, and reduction in costs due to more efficient use of barges. Examples for deep draft navigation are reductions in costs associated with the use of larger vessels, with more efficient use of existing vessels, with more efficient use of larger vessels, with reductions in transit time, with lower cargo handling and tug assistance costs, and with reduced interest and storage costs.

- Shift-of-mode benefits for commodity movements having the same origin and destination that realize a cost savings by shifting from their current mode/routing to the improved waterway. In this case, benefits are the difference in costs of transport between the without-project condition (when rails, trucks or different waterways or ports are used) and the with-project condition (improved locks, gates, waterways or channels). The economic benefit to the national economy is the savings in resources from not having to use a more costly mode or point of transport.

- Shift-in-origin and / or destination benefits that would provide benefits by either reducing the cost of transport if a new origin is used or by increasing net revenue of the producer, if a change in destination is realized. This benefit cannot exceed the reduction in transportation costs achieved by the project.

- New movement benefits are claimed when there are additional movements in a commodity or there are new commodities transported due to decreased transportation costs as a result of a navigation improvement. The new movement benefit is defined as the increase in producer and consumer surplus, thus the estimate is limited to increases in production and consumption due to lower transportation costs. Increases in shipments resulting from a shift in origin or destination are not included in the new movement benefits. This benefit cannot exceed the reduction in transportation costs achieved by the project.

- Induced movement benefits are the value of a delivered commodity less production and transportation costs when a commodity or additional quantities of a commodity are produced and consumed due to lower transportation costs. The benefit, in this case, is measured as the difference between the cost of transportation with the project and the maximum cost the shipper would be willing to pay.

Basically, the economic analysis of waterway investments focuses on the evaluation and comparison of the costs and benefits 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).

In the BRFG and CRL WPCs the modifications to the gates leads to increased reliability and lower transportation costs through the gates primarily by reducing the number of accidents, thereby reducing the delays caused by congestion.

2.2 Modeling Framework

Since the inland navigation investments analyzed have long lives (and regulation requires a CBA assuming a 50-year investment life), costs and benefits must be estimated through time. These estimated life-cycle WOPC and WPC benefit and cost cash flows then serve as the basis for the CBA. The process of identifying these future cost and benefit streams is discussed in this section.

2.2.1 Life-Cycle Analysis

A CBA is sensitive to the life-cycle period being considered and to the handling and comparison of the life-cycle cash flows. This is especially true for inland navigation investments which are costly and have long payback periods. Before proceeding further, the planning period and cash flow analysis will be discussed.

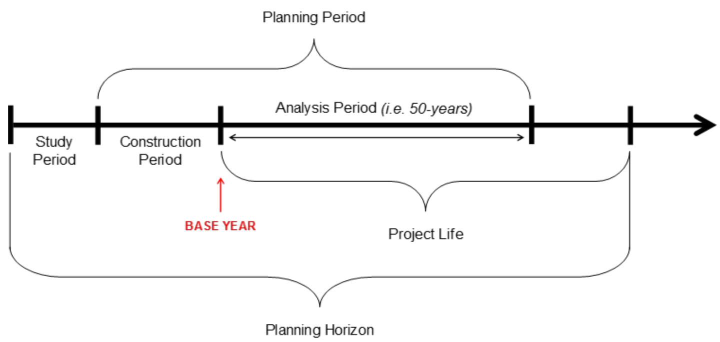
2.2.1.1 The Planning Period

Corps guidance requires that the period of analysis should be the same for each alternative plan, and include the time required for plan implementation plus the time period over which any alternative would have significant beneficial or adverse effects. In studies for which alternative plans have different implementation periods, Corps guidance says that a common "*base year*" should be established for calculating total NED benefits and costs, reflecting the year when the project is expected to be "*operational*".

Guidance also specifies that for inland navigation projects, the time period over which WPC alternatives have significant beneficial or adverse effects is 50-years. This is not to say that the project or alternative will only last 50-years (the actual life is often much longer), but that only 50-years' worth of benefits can be considered to off-set the investment cost. The 50-year period is often referred to as the analysis period or assumed economic project life.

The plan implementation period, however, must also be considered in the analysis. This does not mean the entire time leading up to the alternative completion including both the study and construction periods, but instead the period when costs are incurred that are to be compared against the project benefits (i.e. the construction period). Figure 3 displays the terminology that will be used in the remainder of this document.

Figure 5: Planning Horizon



For the BRFG-CRL analysis, the implementation (or construction period) is approximately 2.3 years (2 years and 3 months for the TSP action at Colorado, 2 years and 2 months at Brazos). As a result, the planning period extended over 52-years. The first year of the construction period was set as 2023, resulting in a base year of 2025 and a final analysis period year of 2074.

2.2.1.2 Compounding, Discounting, and Amortization

The life-cycle cash flows (whether costs or benefits) often fluctuate through time over the planning period. Project costs are incurred primarily at the time of construction while benefits accrue in varying amounts over the project life. Costs spent on construction today cannot be directly compared to the dollars in benefits that will be realized years from now. Even when inflation is not a concern, a rational person prefers one dollar now (a given level of consumption today) more highly than one dollar in the future (the same amount of consumption at some future point in time). Comparison of life-cycle benefits and costs is impossible without temporal aggregation of the cash flows; specifically compounding, discounting and amortization.

Compounding and discounting is the process of equating monetary values over time; measuring the "*time value*" of cash flows (costs and benefits) that occur in different time periods. Compounding defines past sums of money into a single equivalent value. Discounting defines future sums of money into a single equivalent value. This equivalent value is also known as a present value or present worth. Compounding and discounting requires the use of an interest rate which represents society's opportunity cost of current consumption. The same rate is used for both compounding and discounting.

The estimated benefit and cost cash flows expected to occur in time periods following the base year are to be discounted back to the base year using the prescribed interest rate. Since the implementation period for some plan may begin prior to the base year, any estimated NED costs and benefits for that plan expected to be realized before the base year are to be "*compounded*" forward to the base year. That is, for plan benefits or often known as "*benefits during construction*" and costs expected to be realized before the base year, the discounting procedure is applied in reverse, so that the interest rate serves to compound rather than discount those effects to the base year. The same prescribed interest rate is to be used for both compounding benefit and cost streams that occur prior to the base year, and for discounting benefit and costs streams that occur after the base year. The present values of all cash flows are then amortized over 50-years for comparison.

2.2.2 Cost-Benefit Analysis

Itemizing the various cost and benefits over the life-cycle for both the WOPC and WPC allows for generation of the CBA results. Essentially the WPC and WOPC costs foregone (benefits) can be compared against the WPC investment cost. The net benefits are calculated by subtracting total economic costs from total economic benefits. Corps planning policy dictates selection of the NED plan as the plan that maximizes net NED benefits. The BCR is calculated by dividing total economic benefits by total economic costs.

2.2.3 Risk and Uncertainty

Corps of Engineers guidelines as presented in the P&G have long recognized that risk and uncertainty is inherent in all phases of the analysis of waterway investments. Here, risk is defined as inputs or potential results that can be described probabilistically, while uncertainty is defined as inputs or potential results that cannot be defined with a probability. Inputs that can be defined probabilistically are modeled stochastically and the modeling results are displayed as expected values (often with minimum and maximum results displayed). Uncertain inputs are often modeled through sensitivity testing.

2.3 Stages of Analysis

Throughout the analysis, several different analytical approaches were used to screen alternatives, identify the Tentatively Selected Plan, and to refine the analysis after the TSP and ADM milestones. Over the course of the study, 3 separate analytical approaches were used, included two simplified screening level analyses performed in Microsoft Excel workbooks, and a separate model developed specifically for this study. Two rounds of alternative screening were performed, using increasingly complex evaluations of expected alternative benefits. These two rounds of alternative screening were performed on individual, project-level alternatives (i.e. alternatives at either project in the system separately). Following the identification of the final array of project-level alternatives, resulting from the second round of screening, the Waterway Limited Cost Estimator for Navigation (WLCEN) model was developed to analyze this final array in depth as system level alternatives (i.e. permutations of project-level alternative combinations), and to identify the TSP. Following the TSP milestone another set of WLCEN model runs were performed to further refine the evaluation of the TSP, and again after the ADM milestone a third set of WLCEN runs were performed to produce the final cost-benefit analysis. The sections below will detail the various stages of the analysis, including the methods employed, assumptions made, the results of each analytical approach, and how these were used in the evaluation of alternatives.

2.4 Alternative Screening

After the initial screening of measures and subsequent combination of measures into alternatives, two separate screening efforts were undertaken to remove alternatives from consideration which were identified as very unlikely to be competitive in cost-benefit analysis. The first round of screening relied heavily on existing data to roughly approximate ranges of potential benefits for alternatives. At this level of screening, individual alternatives were not analyzed, but rather potential benefit ranges were evaluated by benefit category. In a team elicitation, each alternative was qualitatively analyzed and assigned probable annual benefits by category as a point within these ranges.

2.4.1 Overview

The intent of the first round of screening was to provide rough, semi-quantitative estimates of economic benefits associated with identified alternatives, in particular structural alternatives such as new lock construction.

To accomplish this, anticipated benefits were subdivided into four categories; reduction in or avoidance of delays to shippers resulting from allisions and associated repairs (Brazos), costs to repair damages to the floodgate structures (Brazos), reduction in delays to shippers due to necessity of tripping (both projects), and other delay cost reductions (both projects). These four categories were analyzed without the extensive modeling that would be necessary to achieve a reliable estimate of benefits, and were based instead on readily available data and a number of simplifying assumptions. As such there is a significant degree of uncertainty associated with the results provided. To account for this the general approach taken was to make conservative estimates wherever possible (these are documented in subsections below).

2.4.2 Benefit Categories

2.4.2.1 Allision Induced Delay Cost Avoidance

For alternatives which reduce the risk of allisions at the Brazos River Floodgates, delays to shippers as damages to the gate structures are repaired would likewise be reduced. Multiple estimates of the costs of these impacts to shippers exist. The cost to shippers of these delays was estimated in TXDOT's Work Authorization at $10M annually. In the Gulf Intracoastal Waterway Master Plan[2], TTI estimates the value of these delays as $5M annually.

For this analysis, the Shipper Carrier Cost Model (SCC) was used to estimate these delays, for comparison with the above estimates. The SCC model estimates lost transportation savings at projects for unscheduled outages for periods of between 1 day and 365 days. Brazos River Floodgate personnel estimated on average the gates are undergoing repairs for roughly 6 months out of the year. These 6 months of repairs are not a small number of long duration closures (an estimated average of 40 accidents occur per year) as is modeled in SCC. Repairs are performed Monday through Friday, 8 hours on / 16 hours off.

To estimate the impacts of these repair closures using SCC, a 3rd of the SCC model estimates for a one day closure (to account for the 16 hours a day during repairs in which traffic is able to transit unimpeded) were multiplied by 183 (6 months of repairs). The resulting total delay cost is $8,784,000.

2.4.2.1.1 Simplifying Assumptions/Risks

To err on the side of conservatism, the $10M figure referenced in TXDOT's Work Authorization was used to represent the annual estimate of delay costs avoided. A further (and likely more significant) conservatism in this estimate is the fact that using this $10M estimate as the annual delay cost avoided

[2] *Texas A&M Transportation Institute. 2014. Texas Gulf Intracoastal Waterway Master Plan: Technical Report*

assumes 100% of delays attributable to allisions and associated repairs to the floodgates are avoided in a given alternative.

2.4.2.1.2 Results

For all alternatives which would reduce the probability of accidents at either the East or West Floodgate at the Brazos River, benefits of up to $10M annually could potentially be realized in avoidance of accident related delays. Allision induced delay cost avoidance at Colorado Locks is estimated as 1/5th that of Brazos because of similar traffic and 1/5th the allisions at Colorado Locks, as shown in the table below.

Table 8 – Allision Delay Cost Avoidance

Allision Induced Delay Cost Avoidance	
$10,000,000	Brazos Gates
$2,000,000	Colorado Locks

2.4.2.2 Allision Repair Cost Avoidance

In addition to avoiding delays to shipper caused by accidents at Brazos, alternatives which reduce the risk of these accidents would also have the benefit of reducing costs to repair the structures following these incidents. To estimate this potential benefit, accident logs were obtained from Brazos for the period between January 2002 and May 2016. The average for each full year between 2002 and 2015 of total cited repair cost estimates is $749,827. The yearly totals are shown below.

Table 9 – Annual Repair Cost Estimates, Brazos River Floodgates

Year	Total Repair Cost
2002	$350,300
2003	$683,625
2004	$566,000
2005	$1,107,600
2006	$287,500
2007	$783,585
2008	$482,860
2009	$773,720
2010	$803,850
2011	$720,250
2012	$1,046,600
2013	$605,600
2014	$1,268,000
2015	$1,018,100

The TXDOT Work Authorization references a $799K estimate of these annual repair costs, and the GIWW Master Plan estimated $800K. As repair estimates seem to be roughly trending upwards, the five year average between 2011 and 2015 of $932K was used to represent annual repair costs avoided for alternatives which address the likelihood of allisions.

2.4.2.2.1 Simplifying Assumptions/Risks

This estimate again assumes that 100% of accidents are avoided with the implementation of a given alternative, whereas some residual accident risk is likely to exist regardless of alternative.

2.4.2.2.2 Results

Alternatives which would reduce the probability of accidents at either the East or West Floodgate at the Brazos River could prevent up to an average of $932K. Allision repair cost avoidance at Colorado Locks is estimated as 1/5th that of Brazos because of similar traffic and 1/5th the allisions at Colorado Locks as shown in the table below.

Table 10 – Allision Repair Cost Avoidance

Allision Repair Cost Avoidance	
$932,000	Brazos Gates
$186,000	Colorado Locks

2.4.2.3 Tripping Time Cost Reduction

This benefit category accounts for the reduction in delay costs to shippers for alternatives in which tows would have to break up or trip fewer times to transit the gates or locks. These benefits could be realized either by a structural modification which would enable multi barge tows to transit in a single trip (i.e. side by side tank barges at 54ft across each which would need to break up to transit the 75 wide Brazos gates but would not given a 125ft wide chamber or given gate removal), or by an alternative which alleviates the need for tows to trip for safety reasons due to river conditions. More likely these benefits would be attributable to a combination of both, at least at Brazos, as there is a significant degree of overlap between the two. Regardless of chamber or gate width, during flood events or high river flow conditions many tows would need to transit in smaller, often single barge cuts for safety reasons. Likewise if the impact of these river conditions were alleviated without modification or removal of the structure, the structure itself (width of gate or size of lock chamber) would become the bottleneck.

To estimate these benefits without time-consuming capacity and traffic equilibrium modeling, existing data on traffic patterns for both Colorado and Brazos were extracted from the Lock Performance Monitoring System database (LPMS). These data were used to identify the size of arriving tows, the number of cuts, or trips necessary to transit, the average transit times, and other information which was then used to estimate delay reduction, and thus cost savings. This information was then used to quantify the potential cost savings to shippers, as described in the sections below.

2.4.2.3.1 LPMS Data Processing

LPMS data for both projects however have historically been input inconsistently relative to other projects in the database in a number of ways. Particularly relevant for this analysis is the fact that each cut, or trip through for example the Brazos East Gate was given a unique entry in the “FlotillaID” field, rather than the single identifier of the arriving flotilla. This field is intended to be used to identify and group information relating to a particular arriving tow, or flotilla. If every trip made by this arriving flotilla were given that flotillas identifier in the “FlotillaID” field, identifying the total number of barges it arrived with, their respective sizes and cargo, tonnage, the number of trips necessary to transit, total transit time, etc. would be very straightforward.

Without this identifier however, assumptions were necessary to back into this information. To do this, FlotillaIDs were aggregated together based on the towboats identifier in the "Vesselno" field. As light boats are not recorded at these two projects (another inconsistency relative to other projects), each recorded Vesselno is entered as it transits either the East or West gate and Brazos or the East or West lock at Colorado only if it is pushing a barge or set of barges through. If a given vessel transits in a given direction (upbound or downbound) multiple times consecutively[3] within a 24 hour period of the previous entry, it can then be assumed to belong to the same arriving flotilla.

In other words if Vesselno 0584092 is recorded at the Brazos West Gate, later at the East Gate, again at the West, and then again at the East, all travelling upbound and within 24 hours of each other, we can assume this vessel arrived in a tow that took 2 trips to transit the two gates, and that consisted of the number and type types of barges associated with the two East or West Gate entries (which would be identical), and whose total transit time is the difference between the earliest recorded Start of Lockage at the West Gate, and the latest recorded End of Lockage recorded at the East gate.

With this information estimated, summary statistics of arriving tows and transit times can be computed. In all calculation described here, both at Colorado and at Brazos, the East and West structures were aggregated and together treated as one large lock chamber. Thus processing time at Brazos would be, as described in the paragraph above, the difference between first Start of Lockage at the arriving gate, and the last End of Lockage at the opposite gate.

The following Tables show the number and percentage of tows by arriving number of barges for Brazos and Colorado.

Table 11 – Number of Tows by Size (barges), Brazos

Year	1	2	3	4	5	6	7+
2010	3,076	3,586	387	363	493	383	188
2011	3,520	3,382	394	493	637	540	265
2012	4,427	4,335	510	477	477	380	146
2013	4,212	4,783	407	342	375	315	113
2014	4,153	5,300	519	327	562	451	150
2015	4,101	4,417	482	322	350	246	59
2016	1,073	997	112	83	85	46	7

[3] *Consecutively here refers to recurring instances of the same vessel travelling the same direction, but not necessarily as contiguous entries in the database. It appears somewhat common at Brazos for tripping flotillas to be interrupted by other flotillas or cuts.*

Table 12 – Percent Tow Size Distribution, Brazos

Year	1	2	3	4	5	6	7+
2010	36%	42%	5%	4%	6%	5%	2%
2011	38%	37%	4%	5%	7%	6%	3%
2012	41%	40%	5%	4%	4%	4%	1%
2013	40%	45%	4%	3%	4%	3%	1%
2014	36%	46%	5%	3%	5%	4%	1%
2015	41%	44%	5%	3%	4%	2%	1%
2016	45%	41%	5%	3%	4%	2%	0%

Table 13 – Number of Tows by Size (barges), Colorado

Year	1	2	3	4	5	6	7+
2010	2,481	3,198	272	504	677	612	339
2011	2,462	3,085	213	510	859	771	385
2012	2,732	4,130	313	572	765	622	284
2013	2,508	4,793	293	459	614	450	206
2014	2,451	5,371	342	447	814	657	256
2015	2,320	4,689	347	389	593	482	174
2016	496	1,151	90	121	137	96	26

Table 14 – Percent Tow Size Distribution, Colorado

Year	1	2	3	4	5	6	7+
2010	31%	40%	3%	6%	8%	8%	4%
2011	30%	37%	3%	6%	10%	9%	5%
2012	29%	44%	3%	6%	8%	7%	3%
2013	27%	51%	3%	5%	7%	5%	2%
2014	24%	52%	3%	4%	8%	6%	2%
2015	26%	52%	4%	4%	7%	5%	2%
2016	23%	54%	4%	6%	6%	5%	1%

As can be seen in these tables, the majority of tows at both projects are one to two barge tows, with between 75% and 86% of all tows at Brazos arriving with one or two barges, and between 67% and 78% at Colorado. This would suggest that a sizeable percentage of all tows at both project are able to transit without tripping in the existing condition. The number of trips necessary can also be estimated using these processed LPMS data. Below the counts and percentages of arriving tows are broken down by the number of required trips to transit Brazos (Table 15 and

Table 16) and Colorado (Table 17 and

Table 18).

Table 15 – Number of Tows by Trips/Cuts, Brazos

Year	1	2	3	4	5	6	7+
2010	4,723	2,702	344	47	6	6	0
2011	5,344	2,709	282	37	5	3	0
2012	6,209	3,497	327	61	16	27	0
2013	6,169	3,513	245	42	22	38	0
2014	6,594	3,648	335	62	28	41	0
2015	5,622	3,402	388	103	17	18	1
2016	1,429	771	96	25	4	3	0

Table 16 – Percent Trips/Cuts Distribution, Brazos

Year	1	2	3	4	5	6	7+
2010	60%	35%	4%	1%	0%	0%	0%
2011	64%	32%	3%	0%	0%	0%	0%
2012	61%	34%	3%	1%	0%	0%	0%
2013	62%	35%	2%	0%	0%	0%	0%
2014	62%	34%	3%	1%	0%	0%	0%
2015	59%	36%	4%	1%	0%	0%	0%
2016	61%	33%	4%	1%	0%	0%	0%

Table 17 – Number of Tows by Trips/Cuts, Colorado

Year	1	2	3	4	5	6	7+
2010	4,266	2,236	363	47	8	1	0
2011	4,086	2,482	353	69	9	3	1
2012	4,663	3,258	383	64	9	3	0
2013	4,975	3,210	315	60	10	0	0
2014	5,738	3,136	359	65	3	0	0
2015	5,253	2,640	297	44	8	1	0
2016	1,225	669	68	13	1	0	0

Table 18 – Percent Trips/Cuts Distribution, Colorado

Year	1	2	3	4	5	6	7+
2010	62%	32%	5%	1%	0%	0%	0%
2011	58%	35%	5%	1%	0%	0%	0%
2012	56%	39%	5%	1%	0%	0%	0%
2013	58%	37%	4%	1%	0%	0%	0%
2014	62%	34%	4%	1%	0%	0%	0%
2015	64%	32%	4%	1%	0%	0%	0%
2016	62%	34%	3%	1%	0%	0%	0%

As seen in these tables, the majority of traffic is able to transit both projects in 1 or two cuts, with 5% or fewer tows at Brazos requiring 3 or more trips, and 6% or fewer at Colorado. The bulk then of savings attributable to tripping reductions achieved through either a modification to existing structures or construction of a new structure, to mitigating the adverse impacts of river conditions, or a combination of the two would be to tows required in the existing condition to trip twice.

For the GIWW Master Plan, TTI did a similar analysis for Brazos, looking at a 3 months of data (April, July, and October of 2013) and extrapolating to an annual estimate. Table 19 below is copied from that report for comparison to the 6-year LPMS estimate provided above. In the period analyzed by TTI 61% of tows transited in a single trip, or pass, and 32% transited in two. Only 3% required more than 2 trips or passes to transit the project.

Table 19 – Brazos River Floodgates Tow Distribution (3-Month Sample), GIWW Master Plan

Tow Type	Normal			Affected by Closure			3-Month Total
	April	July	October	April	July	October	
Single Pass	497	520	437	49	14	81	1,598
2 Passes	223	300	209	28	11	75	846
3 Passes	9	15	14	3		9	50
4 Passes	1	2	1			2	6
5 Passes	1	2	1			1	5
6 Passes	1	4	1				6
Cross Month	1	1	1				3
Single Gate	16	10	24				50
Others	10	14	19			1	44
Total	759	868	707	80	25	169	2,608

TTI's analysis for the GIWW Master Plan also included a quantitative estimate of delay costs due to tripping at Brazos, which will be presented in the following section for comparison with the results of this analysis.

2.4.2.3.2 Benefit Computation

To identify the tripping time reductions of a given alternative and to assign a dollar value in terms of transportation savings, of the subset of tows that are tripping in the without project condition, those that would not need to trip or would be able to transit in fewer trips in a with-project condition need to be identified. From these, the difference in transit time can be estimated, and a dollar value assigned to that time.

The first step is to identify which tows would be required to trip less in the with-project condition. To do this, a 1,200 x 125 ft chamber was assumed for all with project conditions. Barge sizes and counts for all arriving tows during the six year period between 2010 and 2015 were extracted from LPMS. From this each arriving tow was assessed to determine the number of trips necessary to transit this 1,200 x 125 ft chamber. This calculation did not take arriving tow configuration into account, but rather estimated based on arriving barge sizes the maximum number of barges per cut in any configuration that would fit in the chamber. The towboat itself was not factored into these calculations, however given the average tow size and the size of the chamber analyzed, were it including it would likely have minimal impact on results.

Using the above calculation, the number of trips required in the with-project condition is determined. To compute delay avoidance, the median transit time for the reduced, with project condition required number of cuts is identified, and subtracted from the reported transit time (given without project condition number of required trips). The sum difference for all tripping reductions over the period between 2010 and 2015 is averaged over the 6 years, and multiplied by average operation costs per hour ($454) to reach the total value of savings.

For the Brazos River Floodgates the total estimated annual value of tripping delays avoided is $4.2M. For Colorado, the total estimated annual savings is $1.2M.

As discussed previously, TTI performed a similar analysis for the Brazos River Floodgates as part of the GIWW Master Plan, using 3 months of data (April, July, and October 2013), and operating costs of $490.08 for towboats, and $30.41 for barges. This analysis estimated a total value of $6.3M is annual delay costs due to tripping. This is shown in the Table below.

Table 20 – Estimated Cost of Breaking Tows (Brazos), GIWW Master Plan

	Number	Weighted Avg. Time per Tow (hrs.)	Extra Time per Tow (hrs.)	Total Extra Time (hrs.)	Extra Towboat Cost*	Weighted Average Barges/Tow	Extra Barge Cost*	Total Extra Cost
Single Pass	5,816	1.72	N/A	N/A	N/A	N/A	N/A	N/A
2 Passes	2,928	5.10	3.38	9,896.64	$4,850,145	2.1	$632,009.33	$5,482,154
3 Passes	152	6.88	5.16	784.32	$384,380	3	$71,554	$455,934
4 Passes	16	8.90	7.18	114.88	$56,300	4	$13,974	$70,274
5 Passes	16	10.05	8.33	133.28	$65,318	5.3	$21,481	$86,799
6 Passes	24	11.92	10.20	244.8	$119,972	6	$44,666	$164,638
TOTALS	8,952			**11,173.92**	**$5,476,115**		**$783,684**	**$6,259,799**

The TTI analysis was not an attempt to evaluate a given with project condition, but rather to identify the total value of delay costs associated with tripping at the project. As such the $6.2M figure effectively represents savings were *every tow* transiting the project able to pass in a single trip.

2.4.2.3.3 Simplifying Assumptions/Risks

The first simplifying assumption made in the above analysis of potential tripping cost reductions is the aggregation of trip entries in LPMS into arriving flotillas, and the resulting calculation of transit times, number of trips, and other associated data points. Though the assumptions made are seen as reasonable, an explicit distinction between actual recorded data and derived data should be made. In this case data on total numbers of trips, tonnage, number of barges, etc. on the *trip level* are recorded data taken without modification from the dataset, while the flotilla level aggregation was derived from assumptions as described in the section above. These assumptions could impact the total benefit estimate if and where incorrect, as fewer, larger arriving tows would result in greater opportunity for delay cost savings, while more, smaller tows would likewise result in less savings. In general the computed results track fairly well with TTI's estimates (Table 19) and with general traffic patterns observed at other projects on the GIWW.

The second assumption is that in a given with project condition, all tows capable of tripping less than in the without project condition due to an increase in chamber size will do so, with no accounting for river conditions. This is done as no simple means was available to estimate the percentage of tripping tows that are doing so due to company policy, river conditions, US Coast Guard regulations, or other reasons other than the size/width restriction of the existing lock or gate structure, either in the without project condition, or how these would change in a given with project condition. As a conservatism, the total benefits were assumed for with project conditions/alternatives. In most cases this will likely overstate benefits.

2.4.2.3.4 Results

For all alternatives that would reduce tripping, through allowing larger tows to transit during more adverse river conditions or the structural alternatives, the following benefit estimates can be applied. It is important to note however that a degree of overlap between the two likely exists, and some alternatives will likely capture a much larger percentage of these benefits than others. The tables below recreate the distribution of tows by number of cuts at both Brazos and Colorado, in a representative with project condition.

Table 21 – WPC Number of Tows by Trips/Cuts, Brazos

Year	1	2	3	4	5	6	7+
2010	7,891	13	1	0	0	0	0
2011	8,405	19	2	0	0	0	0
2012	10,217	7	2	0	0	0	0
2013	10,112	6	0	1	0	0	0
2014	10,853	8	0	0	0	0	0
2015	9,670	2	0	0	0	0	0
2016	2,349	1	0	0	0	0	0

Table 22 – WPC Percent Trips/Cuts Distribution, Brazos

Year	1	2	3	4	5	6	7+
2010	100%	0%	0%	0%	0%	0%	0%
2011	100%	0%	0%	0%	0%	0%	0%
2012	100%	0%	0%	0%	0%	0%	0%
2013	100%	0%	0%	0%	0%	0%	0%
2014	100%	0%	0%	0%	0%	0%	0%
2015	100%	0%	0%	0%	0%	0%	0%
2016	100%	0%	0%	0%	0%	0%	0%

Table 23 – WPC Number of Tows by Trips/Cuts, Colorado

Year	1	2	3	4	5	6	7+
2010	7,083	35	7	2	1	3	1
2011	7,076	40	5	3	1	2	2
2012	8,482	28	0	1	0	0	1
2013	8,652	9	3	3	0	0	0
2014	9,402	19	1	1	0	1	1
2015	8,331	3	3	1	0	0	0
2016	1,993	2	0	0	0	0	0

Table 24 – WPC Percent Trips/Cuts Distribution, Colorado

Year	1	2	3	4	5	6	7+
2010	99%	0%	0%	0%	0%	0%	0%
2011	99%	1%	0%	0%	0%	0%	0%
2012	100%	0%	0%	0%	0%	0%	0%
2013	100%	0%	0%	0%	0%	0%	0%
2014	100%	0%	0%	0%	0%	0%	0%
2015	100%	0%	0%	0%	0%	0%	0%
2016	100%	0%	0%	0%	0%	0%	0%

Table 25 – Tripping Cost Reduction

Project	Tows with Tripping Reductions	Total Time Reduction (hrs.)	Total Tripping Cost Reduction
Brazos River Floodgates	3,487	9,259	$4,203,731
Colorado Locks	2,032	2,574	$1,168,768

2.4.2.4 Other Delay Cost Reduction

The final benefit category is other delay costs avoided, in particular the reduction in trip induced queuing delays as tows are required to break up less often and transit the projects quicker. These benefits cannot easily be quantified, but for this screening exercise, are estimated by looking at only the flotillas that are delayed by a proceeding flotilla (i.e. arrival is less than the end of lockage of the preceding flotilla) and the preceding flotilla was multi-cut. Delay times were summed and multiplied by the average hourly vessel operating cost to get an average annual cost over 2010-2015. This figure is lacking because of the operating policy where the tows can use the lock between the cuts of another tow, and thus arrival times are often inaccurate. However the short coming, this benefit estimate should prove useful in the preliminary screening of alternatives at Brazos Lock Gates and Colorado Locks on the GIWW. The table below lists the potential trip induced delay reduction benefits at Brazos Lock Gates and Colorado Locks.

Table 26 – Tripping Delay Cost Avoidance

Trip Induced Delay Cost Avoidance	
Brazos Gates	$4,625,000
Colorado Locks	$1,150,000

2.4.3 Screening Level Cost-Benefit Analysis

For this screening, annualized benefits in the four categories described above were compared against annualized screening level cost estimates. The potential annualized project benefits were compared to screening level project costs to provide a sense of project affordability. The table below summarizes and displays the potential annual benefits achievable at the Brazos Gates and Colorado Locks projects. This preliminary screening assessment of potential project benefits indicates the potential for approximately $20m per year at Brazos Gates and $5m per year at Colorado Locks.

Annual Benefit Potential in ('000$)

	Allision		Trip		
	Delay	Repair	Process	Delay	
Project	Avoidance		Reduction		Total
Brazos Gates	$ 10,000	$ 932	$ 4,204	$ 4,625	$ 19,761
Colorado Locks	$ 2,000	$ 186	$ 1,169	$ 1,150	$ 4,505

Potential average annual project benefit estimates can be used to give a fairly good estimate of project construction affordability[4] which varies with interest rate and interest during construction. As a rule of thumb, at 7 percent interest rate, multiplying the average annual benefits by 10 and at current interest rate (3.125 percent) multiplying by 15 gives the analyst a range of potentially affordable (i.e. economically justified) project first costs. The table below displays a range of potentially affordable construction projects[5] at Brazos Gates and Colorado Locks given the preliminary screening level potential annual benefits described in this paper.

Project Affordability in ('000$)

	Potential Avg. Annual	Construction Affordability	
Project	Benefit	7.000%	3.125%
Brazos Gates	$ 19,761	$ 197,610	$ 296,415
Colorado Locks	$ 4,501	$ 45,010	$ 67,515

To the extent these potential benefits are achievable at Brazos Gates and Colorado Locks, this project affordability analysis suggests project affordability at Brazos Gates in the range of $200-$300 million and at Colorado Locks in the range of $45-$70 million.

[4] *Project affordability defined as economically justified with positive net benefits.*

[5] *This preliminary affordability rule of thumb analysis varies with interest rate and interest during construction and is only intended to assist the preliminary screening of alternatives.*

2.5 Alternative Rescreening

A second round of screening was undertaken to further pare down the array of project-level alternatives before the combination of project-level alternatives into system-level alternative plans. The array of alternatives resulting from the first round of screening (7 alternatives at the Brazos River Floodgates and 4 alternatives at the Colorado River Locks) yielded 28 system-level alternative permutations, which was deemed untenable for modeling within WAM/NIM, as was the plan at this point in the study.

2.5.1 Overview

A screening tool was developed to utilize available data to quantify alternative benefits for the purposes of ranking and screening alternatives across the two projects. The period in which this available data consistently overlaps is approximately two and a half years between 2014 and 2016. This analysis was performed using this period of data, with results converted into annual impacts.

2.5.2 Modeling Approach

The general modeling approach began with sub-dividing identified problems/opportunities in the existing condition at both project into individual impact categories. These categories are shown below, further sub-divided into tripping impacts, outage impacts, and miscellaneous.

- Tripping Delays
  - Channel width
  - River velocity
  - Head differential
  - Other
- Outage Delays
  - Accidents and related repairs
  - River velocity
  - Head differential
- Miscellaneous
  - Repair costs
  - Maintenance costs
  - Dredging costs

Tripping delays are incurred by traffic transiting one or both projects when multi-barge tows must break up to transit in more than one cut or trip. The sub-categories represent various reasons why multi-barge tows would be required to trip; either because the arriving tow as configured could not pass through the project due to width restrictions, because of adverse river conditions, or for other reasons which will be described in greater detail in later sections.

Outage delays are incurred by traffic during closures of a project to navigation. These closures can occur because of allisions and related repairs, as well as adverse river conditions.

The final category of impacts includes project repair costs resulting from allisions, as well as annual maintenance and dredging costs.

The next step is to define the impacts within each category as a function of a series of parameters. For the existing condition these parameters were drawn from existing data; namely time series hydraulic data at both river crossings, Lock Performance Monitoring System (LPMS) data on tow arrivals, tripping, and processing times, LPMS data on recording project closures from the Stall/Stoppage dataset, and notices to navigation for traffic disruptions. The following section will describe how existing impacts are associated with data from these various sources.

2.5.2.1 Existing Condition Tripping

The existing condition tripping impacts were evaluated primarily using tow arrival, processing time, and tripping data from LPMS. This data include date and time of arrival, start of lockage (SOL), and end of lockage (EOL) for each arriving tow, along with number of barges and number of trips required. The data/time fields allow this LPMS data to be paired with river conditions on tow arrival and SOL for each tow, which in turn can be used to identify which multi-barge tows were required to trip single barges due to river conditions. If river conditions exceeded thresholds established in lock regulations (33 CFR 207.187) for head differential or velocity, a multi-barge tow which tripped single barges can be said to have done so because of river conditions.

Tripping due to channel width was evaluated using a simple formula which compares the maximum possible single-trip length and width of a tow to the estimated length and width of each tow recorded in LPMS.

All existing condition tripping recorded in LPMS which cannot be identified as having been caused by channel/project width restrictions or adverse river conditions are included in the 'other' category. This other category can include arriving tows not being optimally configured for transiting a project in a single trip or shipper risk-averse policy. For example, some users trip single barges regardless of conditions as a risk avoidance measure.

Tripping costs for all tripping tows regardless of cause were estimated by multiplying the change processing time required by hourly average vessel operating costs.

2.5.2.2 Existing Condition Outages

Existing condition outages impacts were evaluated using LPMS data, both on tow arrivals and lockages and recorded lock closures, hydraulic river condition data, and issued notices to navigation. In general two of these data sources, the LPMS Stall/Stoppage dataset and notices to navigation give an estimate of the number of times and when the project was closed to traffic during the period of analysis. Other input data was used to assign causes (river conditions or accidents) to these closures and to verify the closure durations.

To relate project closures to causes, the data sources were merged. For each hour in which no LPMS lockages were recorded (no traffic), if a navigation notice was issued for a period overlapping that date/time (weekends and 17:00 – 06:00 weekdays excluded) OR a closure was recorded in the Stall/Stoppage dataset, that hour was assumed to be a closure for repairs resulting from an allision. For each hour in which no LPMS lockages were recorded and river conditions exceeded thresholds for lock closure specified in lock regulations, that hour was assumed to be a closure due to adverse river conditions.

To estimate the delay impacts of these closures, the average number of lockages per hour given normal operation were assumed every hour of a given closure duration. Each hour's assumed arriving tows were assumed delayed for the duration between their arrival and the end of the closure. The total vessel hours delayed were again multiplied by average hourly vessel operating costs.

2.5.3 Input Values

Having defined existing condition impacts by category, the next step in evaluating alternatives is to define these impacts in terms of changes relative to the existing condition. Given the way these impacts are related to datasets representing existing conditions, this can be accomplished by quantifying changes to this data, for example revised river condition tripping thresholds or a wider channel/project. To estimate what these parameters would look like in a with-alternative condition, a team elicitation was held in which each parameter was elicited for each alternative. These parameters are shown below with descriptions.

Table 27 – Input Parameters Elicited

Parameter	Description
Change in Base Transit Time	Change in average base time for a single cut to transit the project (both structures). 100% represents no change, values above 100% represent an increase in base time, and values below represent a decrease. 80% for example would represent a 20% decrease in transit time.
"Chamber" Length	Length of the "chamber" in feet.
"Chamber" Width	Width of the "chamber" or channel given alternative. Channel width related tripping reduction is calculated based on number of cuts necessary for optimally configured tow to transit the project.
Lock?	Whether or not the project would be a lock. Used to compute head differential related benefits. If a lock is created but does not exist in the WOPC, head differential related tripping and closures are removed. If a lock exists in the WOPC and is removed, head differential related tripping and outage occur.
Reduction in other tripping	This is a catch-all to account for all tripping occurring in the WOPC which cannot be directly attributed to river conditions or to channel width. Many operators trip single barges as policy. Additionally as not all arriving tows are optimally configured, their tripping reductions would also be captured here.
Velocity Threshold (mph)	Existing threshold in nav regulations beyond which single barge tripping is required.
Head Differential Threshold (ft)	Existing threshold in nav regulations beyond which single barge tripping is required.
Accident % Reduction	Percentage reduction in annual occurrence of accidents. Used to reduce annual rate savings at the project as a proportion of the years total rate savings given the number of non-contiguous days the project is closed for repairs. Is a composite of hours in a year in which the project is closed (07:00 - 10:00 Monday - Friday closures are converted into total days).
% Reduction in Velocity Related Closures	Percentage reduction in annual closure days due to river velocity exceeding thresholds in nav regulations
% Reduction in Head Diff Related Closures	Percentage reduction in annual closure days due to head differential exceeding thresholds in nav regulations
Changing Dredging Cost	Increase or decrease in annual dredging cost.
WOPC Maint/Rehab Costs	Costs in the WOPC for maintenance and rehab of project components. This is an annualized value, so for example costs of every other year maintenance actions would be divided by two to roughly approximate the annual cost.
WPC Maint/Rehab Costs	Costs in the WPC for maintenance and rehab, see above.
Total Cost ($000)	Total NED cost to implement alternative, including all cost categories.

Once these parameters were elicited for each alternative, each alternative was separately evaluated in the tool and benefits estimated.

Table 28 – Elicited Input Parameters, BRFG

Brazos River Floodgates	Rehab existing + guide walls (2a)	Rebuild New floodgates (3a)	Open Channel (9a)	New Alignment - Gates (9b)	New Alignment - Gates + Control (9c)	New Alignment - Locks (9d)
Change in Base Transit Time	100%	80%	50%	80%	80%	110%
"Chamber" Length	1000	1000	1000	1000	1000	1000
"Chamber" Width	75	125	125	125	125	125
Lock?	No	No	No	No	No	Yes
Reduction in other tripping	10%	60%	100%	80%	80%	90%
Velocity Threshold (mph)	2	3	5	5	5	5
Head Differential Threshold (ft)	0.7	1.2	1.8	1.8	1.8	1.8
Accident % Reduction	50%	80%	100%	90%	90%	90%
% Reduction in Velocity Related Closures	0%	50%	75%	50%	75%	75%
% Reduction in Head Diff Related Closures	0%	50%	95%	50%	100%	100%
Changing Dredging Cost	0	0	+2M	0	0	0
WOPC Maint/Rehab Costs	2.6M	2.6M	2.6M	2.6M	2.6M	2.6M
WPC Maint/Rehab Costs	2.6M	2M	0	2M	2M	2.3M
Total Cost ($000)	$42,000	$130,000	$95,000	$190,000	$190,000	$326,000

Table 29 – Elicited Input Parameters, CRL

Colorado River Locks	Rehab existing (2b)	Open Channel (3b)	Convert locks to floodgates (4b)	Rebuild New locks (6)
Change in Base Transit Time	100%	50%	80%	100%
"Chamber" Length	1000	1000	1000	1000
"Chamber" Width	75	125	125	125
Lock?	Yes	No	No	Yes
Reduction in other tripping	0%	100%	80%	80%
Velocity Threshold (mph)	2	5	3	3
Head Differential Threshold (ft)	0.7	1.8	1.2	1.2
Accident % Reduction	0%	100%	50%	50%
% Reduction in Velocity Related Closures	0%	75%	50%	50%
% Reduction in Head Diff Related Closures	0%	95%	50%	100%
Changing Dredging Cost	0	+2M	0	0
WOPC Maint/Rehab Costs	3.3M	3.3M	3.3M	3.3M
WPC Maint/Rehab Costs	2.8M	0	3.3M	2.3M
Total Cost ($000)	$45,000	$35,000	$130,000	$266,000

2.5.4 Rescreening Cost-Benefit Analysis

The results of the screening analysis are shown below as Table 30 and Table 31 below.

Table 30 – Screening Results, BRFG

Brazos River Floodgates	Rehab existing + guide walls (2a)	Rebuild New floodgates (3a)	Open Channel (9a)	New Alignment - Gates (9b)	New Alignment - Gates + Control (9c)	New Alignment - Locks (9d)
Annual Benefit ($000)	$2,253	$6,858	$11,443	$8,082	$8,177	$8,188
Annual Cost ($000)	$1,836	$5,684	$6,154	$8,308	$8,308	$14,255
BCR	1.23	1.21	1.86	0.97	0.98	0.57
Net Annual Benefit ($000)	$416	$1,174	$5,289	-$226	-$131	-$6,067

Table 31 – Screening Results, CRL

Colorado River Locks	Rehab existing (2b)	Open Channel (3b)	Convert locks to floodgates (4b)	Rebuild New locks (6)
Annual Benefit ($000)	$629	$7,396	$2,835	$3,619
Annual Cost ($000)	$1,968	$3,530	$5,684	$11,631
BCR	0.32	2.09	0.50	0.31
Net Annual Benefit ($000)	-$1,338	$3,866	-$2,849	-$8,012

Multiple alternatives appear likely to be feasible at the Brazos River Floodgates, however due to significantly less benefits to be captured at Colorado, similar cost alternatives there are not likely justified. It should be noted that these benefits are additive, project-specific benefits and not system level benefits. In other words costs and benefits of an alternative at Brazos could be added to those for an alternative at Colorado to estimate that alternative combination's benefit/cost ratio. This does not account for possible benefits to be realized from changes to the fleet or shift of mode benefits given a system wide (both projects in this case) improvement. These benefits were not quantified for this analysis due to lack of available data, but as they would likely be realized for any combination in which the minimum channel width between both projects were increased, any alternative at Colorado (where only one alternative is likely justified) which accomplishes this increase in channel width would capture these benefits.

Also noteworthy is that open channel alternatives 9a and 3b were evaluated assuming a $2M annual increase in dredging cost, however the value of dredging impacts is highly uncertain. If future analyses reveal open channel alternatives to be unfeasible due to dredging or other considerations, it is recommended that the next least cost alternative at Colorado, though shown unfeasible here, should be re-considered as a means to capture these currently unquantified non-additive system benefits.

2.6 WLCEN Model

Since the 1970s, the Corps has been performing inland waterway cost-benefit analysis with a system level evaluation. Through the Navigation Planning Center Branch (CELRH-PX-NC)[6] of the Huntington District's Planning Center of Expertise for Inland Navigation and Risk Informed Economics Division (PCXIN-RED), the Corps has adopted and maintains a set of computerized analytical models for estimating the NED benefits of proposed improvements to the inland navigation system.

The initial decentralized nature of Corps program execution resulted in the early development of several system models. The first model was developed by the North Central Division for the Illinois Waterway in the 1960s. In the early 1970s, with more complex studies on the horizon, a centralized research and development program was initiated within the Office of the Chief of Engineers called the Inland Navigation Systems Analysis (INSA) Coordination Group. In the mid-1970s the Waterway Analysis Model (WAM) and the Flotilla Model were developed. The Flotilla Model evolved into what is now called the

[6] The PCXIN-RED traces its evolution back to a regional center established in 1981 by the former Ohio River Division (ORD). The U.S. Army Corps of Engineers Director of Civil Works then designated LRD's Navigation Planning Center as the National Planning Center of Expertise for Inland Navigation in August, 2003, which was renamed to PCXIN-RED in 2012.

Navigation Investment Model (NIM). These two models, WAM and NIM, have been used in a countless number of inland navigation feasibility studies.

These models together are designed to evaluate equilibrium transportation costs in systems in which traffic shifts between alternate modes in response to changes in transportation costs resulting from increases or decreases in waterway efficiency, unscheduled service disruptions, and other causes. For reasons which will be described in detail below, this equilibrium modeling approach was determined by the study team to be an imperfect fit for modeling performance of the Brazos River Floodgates and Colorado River Locks in the existing and proposed alternative condition. In place of this standard suite of models, the Waterway Limited Cost Estimator for Navigation (WLCEN) was developed to specifically address the unique characteristics of the studied projects.

2.6.1 Unique Study Characteristics

The BRFG-CRL system on the GIWW between Freeport, TX and Matagorda, TX is unique within the inland waterways system. Instead of a single project providing pool control and lockages between lower and higher elevations, the projects act as sedimentation structures that also allow for the normalization of head differentials between the GIWW and the intersecting Brazos and Colorado Rivers. Early in the study process, several specific unique characteristics of the projects analyzed were identified which necessitated a non-standard modeling approach. These characteristics are as follows:

2.6.1.1 Nature of Significant Problems and Opportunities

The primary identified existing condition issue impacting traffic on this stretch of the GIWW is the frequency of allisions (vessels colliding with gate or lock structures) and the resultant closures of these projects to affect repairs. In particular at the Brazos River Floodgates, a significant number of accidents occur yearly, and result in periodic closures for repairs. Table 32 below illustrates the frequency of accidents requiring repairs that result in traffic disruption for the 8-year period between 2008 and 2015 at the Brazos River Floodgates.

Table 32 : Accidents 2002-2015, Brazos River Floodgates

Year	Accidents	Vessel Transits	Accident Rate
2008	38	9,071	0.42%
2009	49	9,107	0.54%
2010	46	11,067	0.42%
2011	41	11,037	0.37%
2012	65	14,527	0.45%
2013	47	14,474	0.32%
2014	61	15,640	0.39%
2015	65	14,589	0.45%

These closures cause direct delays, as well as indirect delays resulting from queuing following the service disruption event. These service disruption events are scheduled closures, occurring Monday through Friday, 7:00 to 17:00, for the duration of the repair. As such these closures do not result in significant, long duration outages, but rather frequent short duration closures which significantly slow the processing of traffic.

2.6.1.2 Lack of Alternative Overland Modes

Interviews conducted by Martin and Associates (by contract with TXDOT) with shippers using the analyzed stretch of the GIWW (Texas Lehigh Cement, Formosa, Philips 66, Oil Tanking, Dow Seadrift, Citgo Refinery, Nustar Energy, and Valero Refinery) have indicated that existing condition delays do not generally result in the use of overland routes, as they do not have the ability to use truck or rail as a substitute mode given waterway service disruptions. Although the shippers interviewed do not have the ability to use truck or rail, existing infrastructure exist to allow shifts in mode from the waterway to either truck or rail.

Historically the cycle of closures at the study projects have not led to extended duration outages. These structures are somewhat unique from other navigation structures in the inland system. Most inland navigation lock projects assist vessel transits between points of the river with significant elevation changes, with the result being that vessels cannot transit during closures. These projects, however, are designed to mitigate against sedimentation in the GIWW not to directly assist with navigation. That is to say that if all structures were removed, navigation could still continue, unlike other inland navigation projects. The result of this dynamic allows for the historic pattern of 10 hours closed/14 hours open on a daily basis during repair work, which is the predominant cause of project closure at the study sites. This pattern of closure relates to both regular maintenance cycle work, major maintenance efforts, and accident related closures, which is the predominant closure reason at these projects.

This pattern of traffic closures has not historically led to shippers (those who receive shipments of waterborne goods) who utilize the Brazos River Floodgates or Colorado River Locks to explore receiving their products from another mode of transportation, such as truck or rail. This determination was based on interviews conducted with shipper's utilizing these projects by Martin Associates, the contractor for study partner, TXDOT. "This is due to the fact that the waterborne movements are essentially a part of the production process of chemicals and petroleum products, and the shippers do not have the ability to use truck or rail as a substitute due to capacity limitations of the surface modes regarding the volume of product that would be required to substitute for the barge volumes. Currently, the customers are notified when the barge shipment is within 4 hours of delivery, and at that time, the process of berth availability at the shipper's facility is planned. Only in very isolated instances, such as a week or more delay, would inventory stocks be jeopardized, and since the average delay time is less than 6 hours per tow, the impact on the logistics supply chain of delays is negligible. (Martin Associates)"

The overriding assumption being made is that there is limited pressure on commodities currently utilizing the GIWW to shift to an overland mode. However, a more detailed analysis of comparative cost of overland vs waterborne routes based on traffic and delays on through the Brazos River Floodgates and Colorado locks may identify points where modal shifts would likely occur. Based on Department of Energy data on movements by rail, truck, barge and pipeline, any movements by rail and truck would consist of a small percentage of overall movements. The potential benefits of modal shifts will be examined during the economic update to be conducted during PED.

Under both the without-project condition and all of the with-project condition alternatives analyzed for the TSP, this operating policy for closures is not expected to change. Historically the only long-duration, sustained closures which do not allow for this pattern are those related to extreme weather events, such as Hurricane Harvey. None of the alternatives evaluated for the TSP were identified as either mitigating or exacerbating the impacts of events such as these, and thus there was no incremental difference between the without-project condition and the alternatives being evaluated for the potential with-project condition.

This assessment is based on the assessment of engineering and H&H team members who conducted various flow, velocity, and sedimentation analyses. Under the various alternatives, the results of these analyses did not indicate an increased likelihood or increased duration of significant outage associated with these extreme events. Given this lack of incremental difference between the with- and without-project conditions, the ability of the economic analysis to evaluate the impact of modal shifts for the shippers utilizing these projects is limited. It should be noted, however, that any uncertainty regarding the engineering and H&H analysis of the alternatives for these events directly impacts this economic assumption.

2.6.1.3 System Traffic Commonality

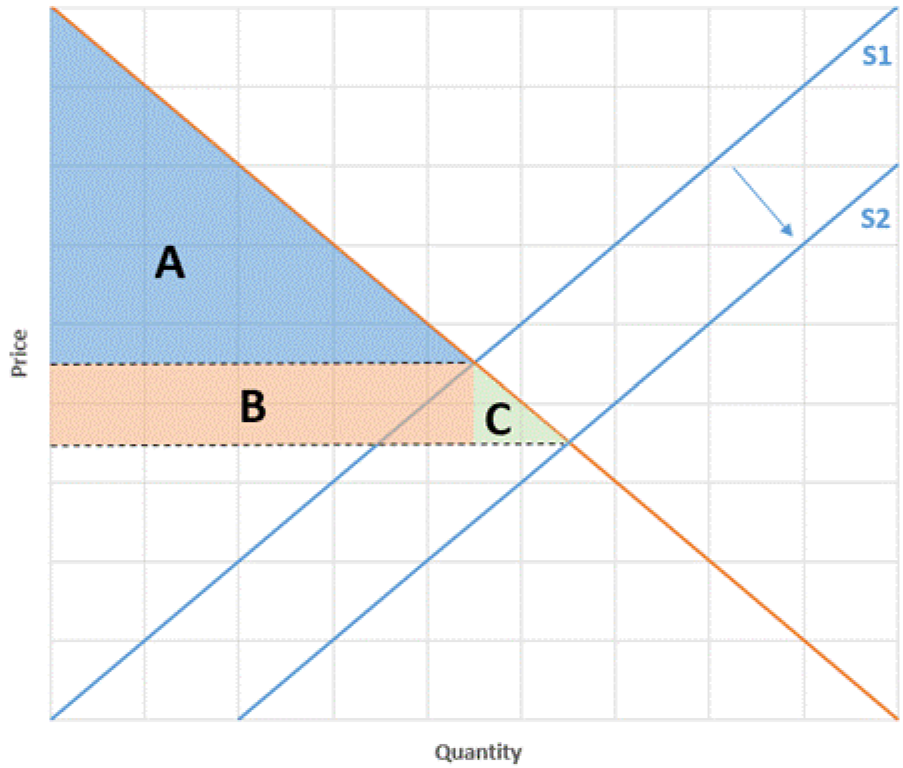
As displayed in Table 5 and Table 6, the Brazos and Colorado River projects have a significantly high level of traffic commonality between the two projects, but limited traffic commonality with other USACE inland waterway projects. This suggests any substantial change at one project has the potential to alter traffic patterns or operations at the other project, but that this influence is limited to only these two projects. Given that the majority of traffic between these projects never transits another outside the system, it stands to reason that traffic would be particularly sensitive to any changes at the Brazos River Floodgates or Colorado River Locks. This is not always the case in a navigation study, as the restrictions and navigation needs of projects far away can limit the benefits derived from changes at individual projects.

2.6.2 General Modeling Theory

The general theory underlying this model is that, given an environment in which modal shifts do not commonly occur in response to changes in transportation costs and thus system equilibrium traffic given a defined condition should generally mirror observed or forecasting traffic under the existing condition (traffic moving or forecasted to move on the waterway rather than traffic *demand*), the vast majority of existing condition traffic delay or disruption impacts and thus the degree to which an alternative can reduce these impacts (benefits) can be closely approximated by computing the total cost of vessel delays in the existing and alternative conditions, and taking the difference.

An equilibrium analysis broadly speaking would quantify the consumer surplus, or willingness-to-pay for barge transportation in the existing condition and equilibrium traffic levels, and again in each analyzed alternative condition, and subtract the latter from the former to estimate benefits in terms of rate savings. This is depicted in Figure 4 below.

Figure 6 – Willingness-to-Pay Visualization



A system improvement shifts the supply curve from S1 to S2, reflecting a reduced price to provide any given quantity of barge transportation. At the new equilibrium the area A + B+ C represents the with-project willingness-to-pay, and the difference, B + C, represents the benefit. The area B represents the increase in consumer surplus for traffic already using the waterway, while the area C represents the added consumer surplus for traffic which shifts from other transportation modes onto the waterway in response to the system improvement.

Assuming a sharply inelastic demand curve, that would represent the unavailability or high relative cost of alternate overland modes, the relative size of the area C will shrink to a very small contribution to the total benefit of any alternative. However, if overland modes are available at comparable costs creating a more elastic demand curve the contribution of benefits associated with area C could be significant.

Extending from this premise, if the total equilibrium cost of waterway transportation for a given movement involves all transportation rates between origin and destination, so long as demand is very inelastic and under analyzed alternatives these origin-destination movements remain essentially unchanged, knowing or quantifying this total line haul cost is not necessary to evaluate alternative benefits (the area B in the figure above) as all components of this line haul cost other than delay costs will be the same in both the existing condition and alternative condition. As such the benefits of a given alternative can be defined as the reduction in total vessel delay in hours multiplied by the hourly operating cost. The model is designed to estimate this total vessel delay.

2.6.3 Model Description

In general terms the model estimates total annual vessel delay by project over a specified analysis period, for a set number of iterations. The model uses Monte Carlo random sampling for these iterations to select variable inputs from uncertainty distributions. This calculation is performed for a system which is comprised of nodes, which in turn are either projects or river linkages between projects. Because the two projects analyzed have such a high degree of commonality of traffic and with low commonality with other projects on the GIWW, the system is defined in the model as the Brazos River Floodgates, the Colorado River Locks, and the stretch of the GIWW between them. These nodes are linked together, such that downbound traffic departing the Brazos River Floodgates would move from the BRFG node to the GIWW node, and later from there to the CRL node before exiting the system.

The central calculation of the model loops continuously through these nodes for each minute of the user-specified analysis period. The other significant component piece of the model are flotillas, which represent individual tows transiting the system. Flotillas are added into the system on either end (downbound arrival at BRFG and upbound arrival at CRL), and processed through the system based on general logic for tasks like breaking and reassembling tows, mooring, queuing, etc., and defined characteristics of the node where the flotilla is currently located.

At every given simulation minute each node will contain lists of flotillas currently transiting that node, and each of these flotillas will increment by one minute the duration they have spent in their current transit activity, such as queuing for example. When a flotilla completes transiting a node, before it is transferred to the next linked node in the system or removed from the system entirely, the total time spent in various transit time categories or tasks is written to an output data class which stores this information at the project level until the simulation completes, when it is written to an output file. In this way the total number of minutes all tows spent queuing at a project for example can be evaluated.

Both projects and flotillas are defined by a series of parameters, including static information – characteristics which define the project or flotilla but which do not change over the course of the simulation; statistical distribution parameters – including shape, scale, and other parameters for the parametric input distributions; transient information - data on the current status or condition of a project or flotilla which will change over the course of the simulation; and finally for flotillas, output metrics – data which will be written to the output file at the conclusion of the simulation.

Table 33 below shows the parameters used to define a project node. The modeling of tow processing at a project is in part based upon these parameters. The chamber width for example will dictate whether or not tows of varying sizes will need to break and reassemble (or "trip”) to transit the project. In this way, an alternative can be analyzed by directly capturing changes to the structure within the model. If an alternative changes a projects chamber width for example, this information can be adjusted in the projects definition and the model rerun.

Table 33 : Project Level Parameters

Static Information:
Name
Chamber length
Chamber width
Project or river linkage
Number of mooring cells per side
Upbound project
Downbound project
Upbound percent empty tows
Downbound percent empty tows
Average tons per tow
Velocity Threshold for Restriction
Velocity Threshold for Day Hours Only
Velocity Threshold for Closure
Head Diff Threshold for Restriction
Head Diff Threshold for Closure
River Condition Update Interval

Statistical Distribution Parameters:
Transit time
Arrival intervals
Accident probabilities
Repair duration
Risk aversion chance
Mooring times
Tripping times
Tow size distribution
Barge size distribution

Transient Information:
Current queue (list of Flotillas)
Flotillas mooring
Flotillas tripping
Closed Y/N
Traffic restricted Y/N
Repair information
Currently processing flotilla
Last flotilla arrival time

Table 34 below lists the parameters which define a flotilla. The majority of these track the current status of the flotilla within the system or represent output metrics.

Table 34 : Flotilla Level Parameters

Static Information:
Number of barges
Barge size

Transient Information:
Current project (where it is in the system)
Arrival time at project
SOL at project
EOL at project
Risk aversion (will trip even if not required)
Number of trips required at project
Time per cut at project
Time to moor at project
Time per side to trip at project
Current activity (mooring, tripping, processing)
Pushing a barge Y/N

Output Metrics:
Time spent queuing at project
Time spent processing at project
Time spent mooring at project
Time spent tripping at project
Time delayed due to closures of project
Time delayed waiting on mooring cell

In somewhat more specific terms, the vessel delays estimated by the model are the product of multiple different, interrelated causes, which themselves can be broken down into a series of impact categories. These categories are tripping due to channel width, river velocity, head differential, and operator policy; and outages due to accidents and related repairs, river velocity, and head differential.

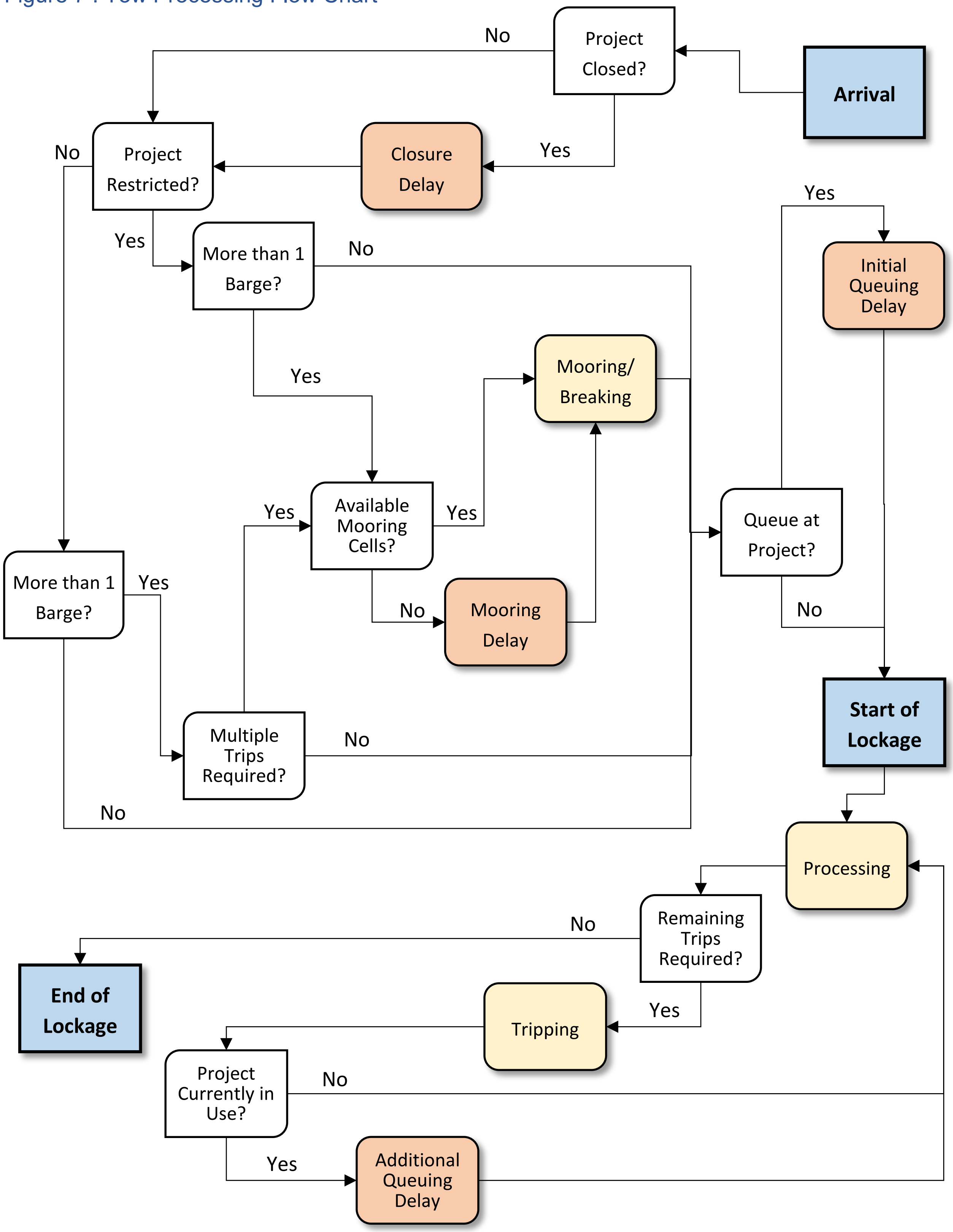
Tripping impacts are delays incurred by traffic transiting one or both projects as they must break up multi-barge tows to transit a project in more than one cut or trip. The sub-categories are various reasons why multi-barge tows would be required to trip; either because the arriving tow as configured could not pass through the project due to width restrictions, because of adverse river conditions, or because the operators policy is to trip regardless of river condition. Outage impacts are delays incurred by traffic during closures of a project to navigation. These closures can occur because of allisions and related repairs as well as adverse river conditions. While both tripping and outages have discrete delay impacts, there is also some degree of overlap as any event leading to slowed traffic or a closure to traffic will result in additional queuing.

For each minute of the simulation, for each project, flotillas currently within the system will incrementally step through the process of transiting the project or river linkage where they are currently located.

This process is described using the flow chart in Figure 5 below. In the figure, blue shaded boxes represent significant components or bookends of a transit. These use LPMS terminology, however the definitions do not match entirely. The tan colored boxes represent normal, non-delay times necessary to transit a project under certain circumstances. These non-delay times are generally based on project node level inputs rather than dynamically calculated, as they are not dependent on delay causes such as closures, restrictions, or the size of the queue at the project. The orange shaded boxes represent explicit delay categories, and are dynamically calculated based on the current status of the project and the amount of current traffic at it.

The white boxes represent the conditional logic used to describe how a flotilla transits a project, based on both the flotilla and projects characteristics, both static and transient. Progressing from arrival through the flowchart below, this conditional logic and how it is implemented in the model will be described.

Figure 7 : Tow Processing Flow Chart



Project closure is evaluated as a boolean condition, which is evaluated based on two closure causes; river condition and accident repairs. River condition related closures are evaluated based on current simulated river conditions, the projects defined closure thresholds due to velocity and head differential, and the current date/time of the simulation. Accident related closures are evaluated based on the current date/time of the simulation and the schedule of accident repairs. If a scheduled repair is currently underway, and the date and time for the current simulation minute falls within the repair closure times (Monday through Friday, 07:00 – 17:00), the project is set as closed due to accidents. During closures, all tows in queue at the project do not transit and accrue closure delay times. Any tows currently mooring/breaking will continue to do so until they are ready to begin processing, at which point they too will begin to accrue closure delay time.

Project restriction is similarly a boolean condition, and is evaluated based solely on river conditions. As with river related closures, if the current simulated river conditions exceed defined project restriction thresholds, the project is set as restricted. During restriction, the number of required trips for all tows is set to that tows number of barges.

The number of barges is determined when the flotilla is instantiated, and this logic simply uses that information to categorize flotillas. Flotillas with only one barge will bypass all tripping related logic.

For tows with more than one barge, the necessity to trip must also be evaluated. This logic returns an integer value representing the minimum number of trips the tow can transit the project in. This number is determined by a function of the number of barges in the tow, the size of the tow, and the size of the project chamber. The equation used is given below.

$$Trips = \left\lceil \frac{T_B}{\left\lfloor \frac{C_L}{T_L} \right\rfloor \cdot \left\lfloor \frac{C_W}{T_W} \right\rfloor} \right\rceil$$

Where
$Trips$ = number of trips required
T_B = number of barges in tow
C_L = length of project chamber
C_W = width of project chamber
T_L = length of tow
T_W = width of tow

If the number of trips required exceeds one, the tripping logic will then be evaluated, using the number of required trips as an input, otherwise the tripping logic is bypassed.

For tows in which tripping is required, the first step is to determine whether or not mooring buoys are available to begin the tripping process. This is a simple calculation, which compares the total number of project mooring buoys on a side, to the number of currently claimed mooring buoys. If the number of claimed buoys equals the total number at the project, the evaluated tow will incur mooring delay time until a buoy becomes available.

The next step is to determine if a queue currently exists at the project. This is not explicitly evaluated within the model, rather as tows arrive they are added to a list of flotillas at the project, which represents the queue, with each tows index within this list representing its place in the queue. If currently evaluated tow at given simulation minute is at position 0 in the list, it commences start of lockage and is set as the currently processing tow, while tows at all other queue positions incur 1 minute of initial queuing delay time. If a tow arrives at a project with no queue, it is added at position 0 and immediately begins processing.

After the initial processing, tows are evaluated to determine if remaining trips are required to complete the transit. This is done by comparing the total computed number of required trips, with the number of currently completed trips. If all required trips have not been completed, the towboat will process back through the project to its origin side and retrieve an additional barge or set of barges. The final piece of logic shown in the figure above is the determination of whether or not, given the necessity of this return trip, the project is currently in use. When the currently active tow completes processing and begins to tie off barges on a mooring buoy it temporarily foregoes its place in the queue, and other tows may begin processing in the meantime. If the project is currently in use when the tow in position 0 of the queue completes tying off a barge or barges at a mooring buoy, that tow will accrue additional queuing delay until the project becomes available.

2.6.3.1 Model Inputs

As previously described, the primary model inputs are those parameters which define the nodes (projects and river linkages) which comprise the system, and the flotillas. These inputs can be sub-divided into two categories; constants and distributional parameters. Table 35 below identifies these input parameters.

Table 35 : Input Parameters

Parameter	Distribution Type
Chamber Length	*Constant*
Chamber Width	*Constant*
UB/DB project	*Constant*
Tow arrival direction (UB/DB)	*Constant*
Number of Mooring Cells	*Constant*
UB/DB percent empty	*Constant*
Average tons per tow	*Constant*
Risk Aversion/Operator Policy	*Constant*
Velocity Threshold for Restriction	*Constant*
Velocity Threshold for Day Hours Only	*Constant*
Velocity Threshold for Closure	*Constant*
Head Diff Threshold for Restriction	*Constant*
Head Diff Threshold for Closure	*Constant*
River Condition Update Interval	*Constant*
Arrival Interval	Exponential
Barges per Tow	Discrete
Barge sizes	Empirical
Processing Time	Exponential
Tow Break Time	Triangular
Tow Reassemble Time	Triangular
Travel Time Between Projects	Gamma
Accident Probability	Triangular
Accident Repair Duration	Weibull
River Velocity	Markov Chain
Head Differential	Markov Chain
Traffic Forecasts	Annual Tonnage; Base, High, Low

Constant input parameters generally define fixed characteristics of a node, in particular a project. These parameters influence how traffic transits the node, but are fixed values which do not vary within a simulation/iteration or between iterations. The distributional parameters represent variable or uncertain values, and these are set or changed during the simulation based on the distributions defined by these input parameters. All parameters above are used to define nodes in the system.

2.6.3.1.1 Chamber Size

Chamber size (length and width) together are used in the calculation the number of trips an arriving flotilla will need to make to transit a project. Chamber is a term used somewhat loosely as the BRFG are gate structures only and do not have a lock chamber. For the baseline condition, chamber sizes of 1,000’ x 75’ were used at both projects. Given the configurations of tows on this stretch of the GIWW, only the width parameter at either project significantly impacts transit times. For alternative conditions, the width parameter was changed to reflect the expected minimum width of the implemented alternative. For alternatives with gates, a width of 125’ was used. For alternatives without gates (open channel), a width of 200’ was used.

2.6.3.1.2 Project Location within System

The projects location in the system is defined relative to other project or linkages in the system, and is used to determine how traffic arrives at the project and where departing traffic goes. The input parameters which describe a projects location are the upbound and downbound projects, and the direction of arriving tows if the project is an end node in the system (i.e. is not linked to other projects on both directions).

2.6.3.1.3 Mooring Locations

The number of mooring locations is used to determine whether or not arriving flotillas which require multiple trips can begin tripping immediately or need to wait on an available mooring buoy. This parameter represents the number of mooring locations per side (both banks) of a project, with project referring to both gates/locks at either river crossing. This parameter was not changed between baseline and alternative conditions as no alternative included a change in number of mooring locations. For the baseline and all alternative conditions, per discussions with site operations personnel, 18 mooring locations were assumed per side at the Brazos River, and 15 were assumed per side at the Colorado River.

2.6.3.1.4 UB/DB Percent Empty Tows

The percentage of empty tows, both upbound and downbound, is used to inform how multi-barge tows are configured. From discussions with industry it was discovered that two barge tows pushing empty barges typically are configured with the empty barges side-by-side, which depending on the size of barges can result in multiple trips necessary to transit a 75 foot wide project.

2.6.3.1.5 Average Tons per Tow

The average tons per tow was used to apply traffic forecasts to system traffic levels modeling in future simulation years. Average tons per tow is used to convert forecasted future traffic levels into estimated number of tows necessary to move this forecasted tonnage, which is then converted into a revised arrival interval distribution. It is important to note that this approach implicitly assumes that future traffic will adhere to the same general configurations in terms of barge sizes and tow sizes as under the existing condition.

2.6.3.1.6 Operator Tripping Policy

The operator policy parameter is a flat percentage value used to capture the fact that some operators transit these projects in single barge trips regardless of river conditions or other factors as a matter of company policy. To estimate the prevalence of this, LPMS records were matched with historic river condition data, and in each case in which the recorded flotilla transited in multiple trips a cause assigned; either river conditions (head differential or velocity) at the start of lockage, the size of the tow relative to the projects chamber size, and barring these causes, operator policy. The percentage of tows tripping without other identifiable cause is then input by project as this risk aversion/operator policy parameter. Within the model every tow with multiple barges upon arrival at a project will, using these values, randomly sample whether or not it will transit in single barge trips regardless of other variables.

For the existing condition, per the LPMS based calculation described above, an estimated 30.1% of multi-barge tows tripped single barges in absence of river related restriction. This estimate was computed from Brazos River traffic over a 2 year period only, as data gaps in river condition data and LPMS data quality issues prevented synchronization of these two datasets for a longer period at Brazos, and for even a single full year at Colorado. It was assumed that this operator policy would be comparable at both projects, however this parameter represents a significant uncertainty. Additionally, Martin and Associates stated that communications with operators indicated a much higher percentage being adopted, as high as 85%. This value was not used as in does not agree with the synchronized LPMS and river condition data, and results in total evaluated tripping statistics which also calibrate poorly with LPMS. However, given the previously identified issues with LPMS data and the short period of record from which the 30.1% figure was computed, this discrepancy serves to heighten uncertainty around this parameter. To quantitatively assess this uncertainty, a sensitivity analysis was performed using the 85% adoption of this policy.

From the elicitation conducted with industry representatives on 05 October 2017, the percentage of operators adopting this policy given all evaluated alternative conditions was assumed to be zero. All industry representatives in attendance indicated that given each of the alternatives presented, they would be able to abandon this policy and trip only when river conditions necessitated it.

2.6.3.1.7 Project Operation

The next five parameters in Table 35 above are used to define operating policy at the project. For the existing condition these parameters were taken from 33 CFR 207.187 and the Gulf Intracoastal Waterway Navigation System High Water Operations Policy. These operating policies represent a series of river condition thresholds, for both river velocity and head differential at gate structures, at which project operations change. These thresholds are summarized in below, with the operational change enacted at each.

Table 36 : Existing Condition Operating Policies

River Velocity	Head Differential	Other	Operation
0 - 2 mph	0 - 0.7’	-	Normal
2 - 5 mph	0.7 - 1.8’[7]	-	Single barge tripping
5 - 7 mph	-	-	Single barge tripping during daylight, closure at night
> 7 mph	> 1.8’[4]	-	Closure
		Post Closure	Queue clearing, 1 barge tows prioritized

These operational thresholds were not changed for any alternative condition, with the exception of the riverside gate removal at Colorado (4b.1). While the river conditions modeled for each alternative varied, the operation of projects given these river conditions were assumed to remain constant. For alternative 4b.1, time constraints did not permit an analysis of head differentials given the absence of the riverside gates at Colorado. In place of a head differential analysis, the thresholds were altered to reflect an increased probability of head differential related closures. An analysis of the existing data found a head differential of 1.8 feet, roughly equate to 4.5 ft/s velocity. To capture closures given this head differential which are not possible in the existing condition, the threshold for velocity related closures was changed to 4.5 ft/s.

[7] *For Brazos River Floodgates only*

Finally the river condition update interval parameter is a static input which determines the number of minutes between updates of river conditions at the project, and is set equal to the smallest time step for which river condition data can be hind cast. This is discussed in greater detail in the river condition input parameters section below. This parameter was not changed for any alternative from the baseline condition.

2.6.3.1.8 Traffic Characteristics

Traffic characteristic parameters are used within the program to define distributions which can be sampled from during the simulation to capture the uncertainty or variability inherent in the values they represent. These distributions were fit to historical or forecasted data.

The arrival interval represents the time in minutes between arrivals from outside of the modeled system (downbound at the BRFG, upbound at the CRL). An exponential distribution was fit to historical arrivals at these projects in LPMS over the three year period 2013-2015. The arrival interval parameter is used to add flotillas to the system, and is sampled after a flotilla is added. The resulting sampled value is the number of minutes until the next flotilla arrival at a project.

Figure 8 : Arrival Interval Distribution, Brazos River Floodgates

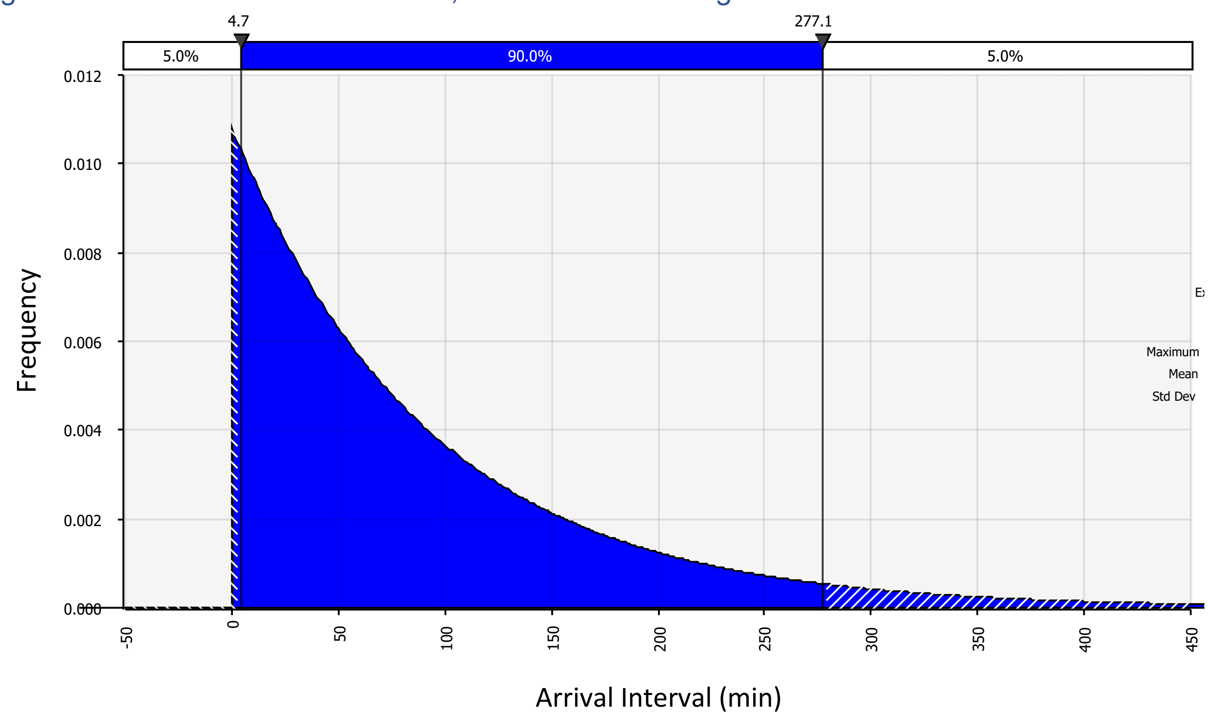
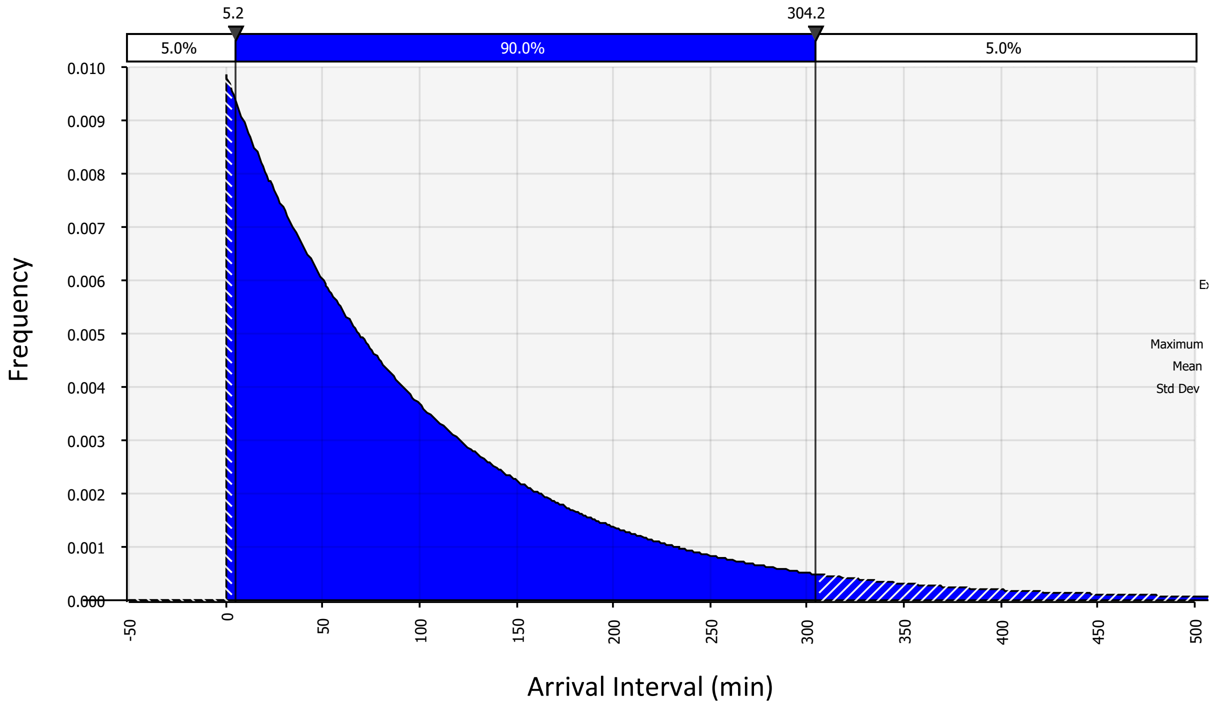


Figure 9 : Arrival Interval Distribution, Colorado River Locks



For this stage in the analysis, due to the flat nature of the most likely condition traffic forecast developed by Martin and Associates, only a single, flat traffic forecast scenario was evaluated. At later stages in the analysis however, sensitivity analysis for varying traffic forecast scenarios will be performed. To incorporate traffic decline or growth scenarios in the WLCEN model, these arrival interval distributions will be adjusted as they are the input parameter which directly affects the annual traffic modeled through each project.

Tow size, or the number of barges per tow, was also fit to historical LPMS data and is defined as a discrete distribution, with the frequency of tow sizes between 1 and 6 barges. This tow size parameter is used whenever a flotilla is instantiated. As these distributions are sampled only on the creation of a flotilla when that flotilla enters the modeled system, they were based on LPMS data on tow size for arriving either from the east downbound at Brazos, or from the west upbound at Colorado. These are shown in the tables below.

Table 37 : Barge Size Distribution - Downbound at Brazos River Floodgates

Barges	Frequency
1	43%
2	47%
3	5%
4	2%
5	0.4%
6	1%

Source: Lock Performance Monitoring System (LPMS)

Table 38 : Barge Size Distribution - Upbound at Colorado River Locks

Barges	Frequency
1	35%
2	54%
3	6%
4	3%
5	0.2%
6	2%

Source: Lock Performance Monitoring System (LPMS)

As indicated by these tables, the overwhelming majority of tows transiting this system are single or two barge tows. From discussions with industry representatives, this general composition of traffic is not anticipated to change in any alternative conditions. According to discussions with industry, the infrastructure at the shipping and receiving docks has been developed around the existing traffic patterns, with limited berthing for extra barges. It is not expected that shippers would invest in the expansion of this infrastructure in the with-project condition.

An exponential distribution was also fit to processing time based on historic LPMS processing times. Historic processing times recorded in LPMS which were greater than the 99^{th} percentile or less than the 1^{st} percentile were assumed to result from input error and discarded as outliers. A projects processing time distribution is sampled for each flotilla upon arrival at the project to determine how much time each trip of that flotilla will require to process through the project.

For this stage of the analysis processing times were assumed to match these distributions in both the baseline condition and all alternative conditions. As each project analyzed represents two separate structures (tracked separately in LPMS); the east and west gates at the Brazos River, and the east and west locks at the Colorado River, the processing time for the combined project essentially represents the time a trip takes to navigate the river crossing. At the CRL, this distribution also reflects the project operating as locks under certain circumstances. When this occurs, processing times increase due to the additional time required to operate gates, fill, and empty. This time could change under alternative conditions however, in particular at the CRL, where alternatives include removal of either one set or all gates and would preclude the operation of the project as locks. The post-TSP analysis stage will address these issues in greater detail.

Figure 10 : Processing Time Distribution, Brazos River Floodgates

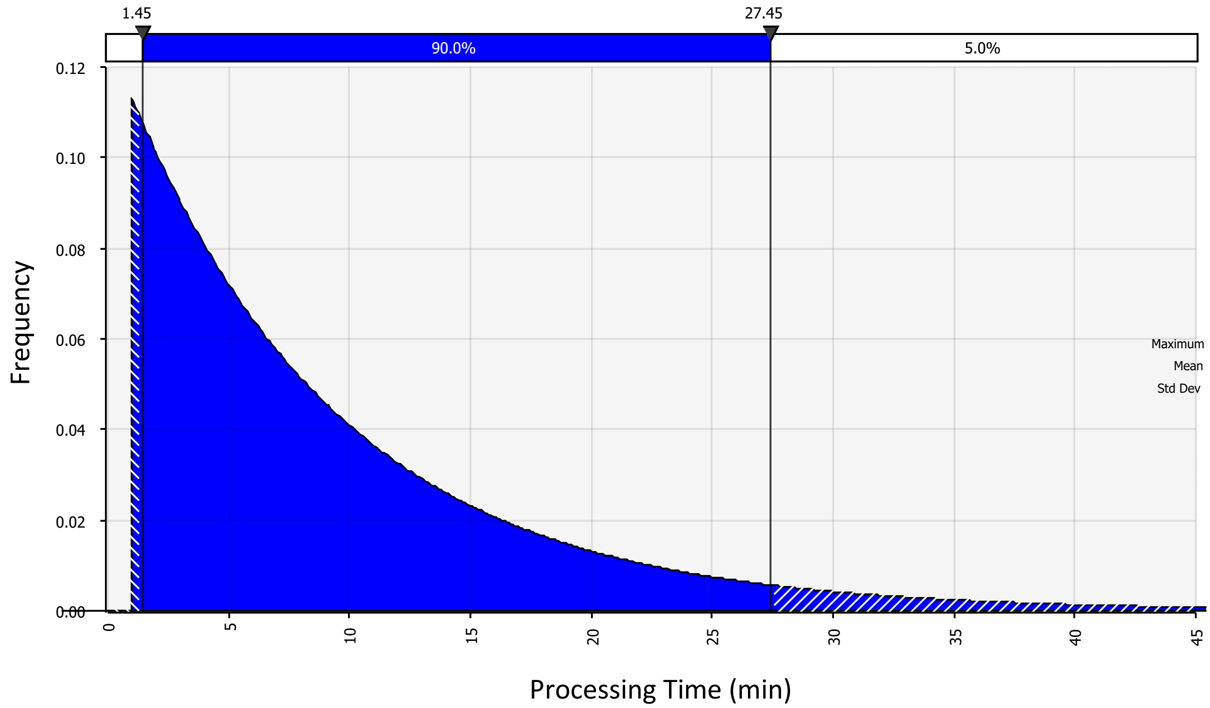
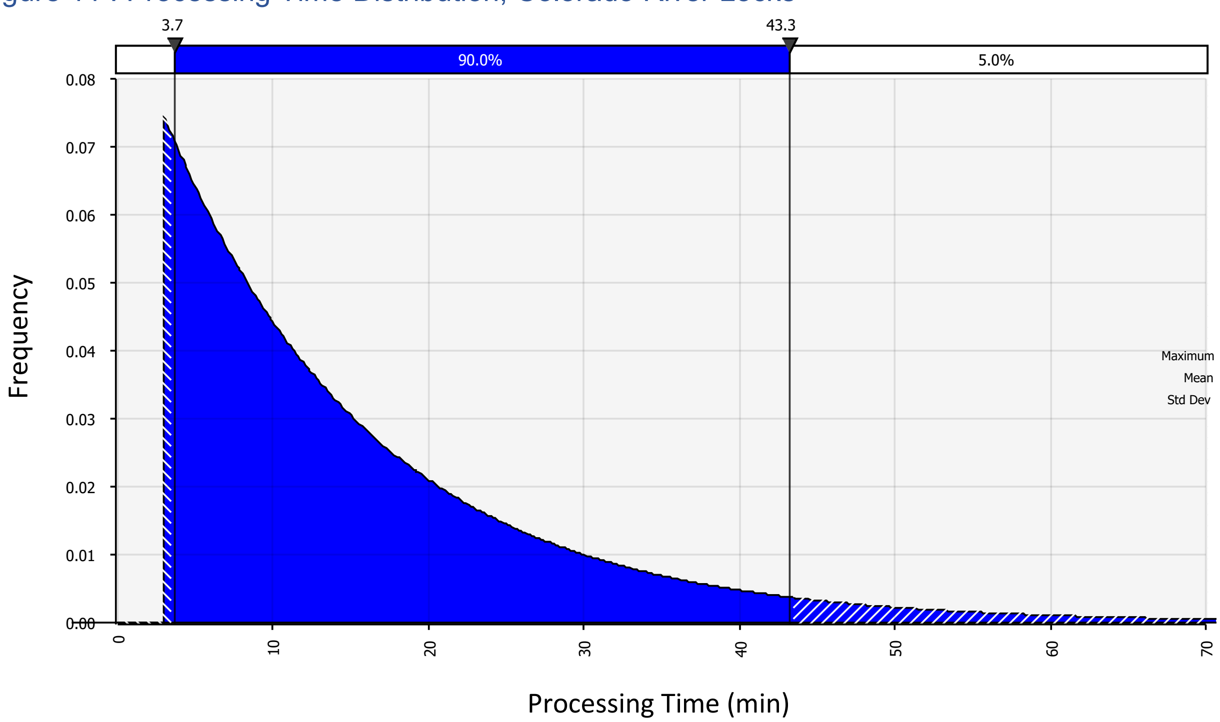


Figure 11 : Processing Time Distribution, Colorado River Locks



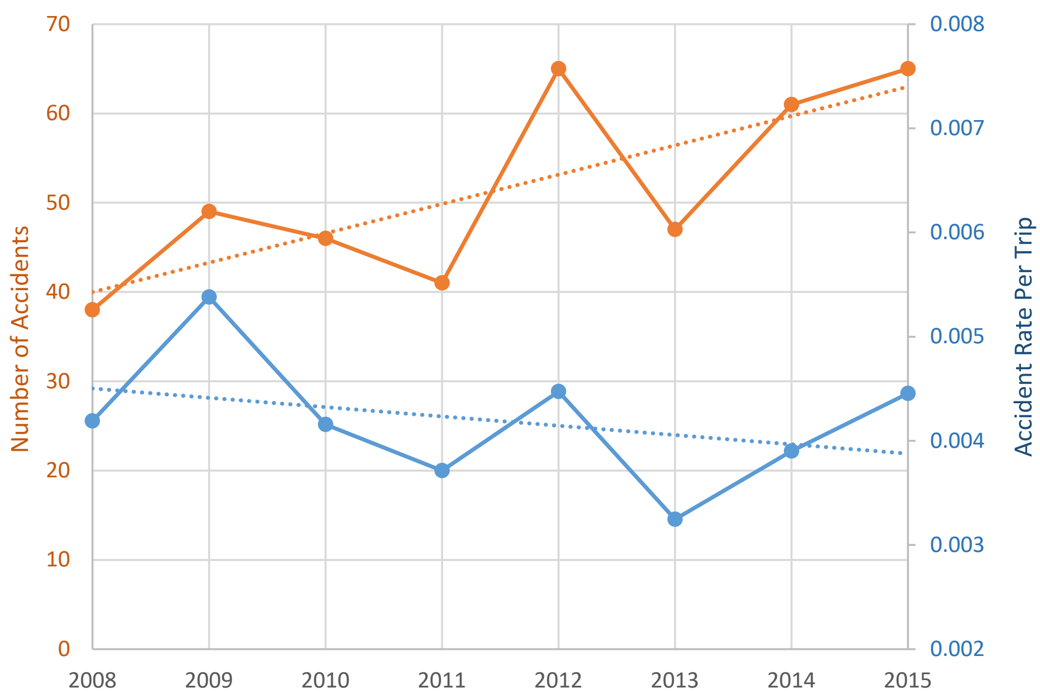
The following two parameters, tow break time and tow reassemble time, represent the average time it takes for barges with multiple tows to moor and break a tow or tie off a barge, and to reassemble. These parameters were based on discussions with the lockmaster and barge operators, and include the average time to travel from mooring cells to the project or from the project to mooring cells. To capture uncertainty a triangular distribution was used.

The travel time between projects parameter reflects the average time tows take to transit the stretch of the GIWW between projects. A gamma distribution was fit to historic travel times estimated from LPMS. To estimate these travel times, the difference between recorded end of lockage for downbound flotillas at the Brazos River Floodgates and upbound flotillas at the Colorado River Locks and arrival times at the other project was calculated. Again, to eliminate extreme outliers, computed travel times greater than the 99th percentile or lower than the 1st percentile were excluded.

2.6.3.1.9 Accident Risk

The next two parameters represent the accident risk for a given project. The first, the accident probability, is the probability of an accident for each vessel transit. To estimate this, both numbers of accidents and total vessel transits were identified for each year from 2008 through 2015. The rates of accident over this period – the number of accidents divided by the total number of transits – were used to generate a triangular distribution, defined by the mean, minimum, and maximum of these rates. The number of accidents per year as well as yearly rate of accidents per trip at the Brazos River Floodgates are shown in Figure 10 below.

Figure 12 : Accidents at Brazos River Floodgates, 2008-2015



The distributions of baseline accident risk computed from accident data for both projects are summarized in Table 39 below.

Table 39 : Baseline Condition Accident Risk Distribution

	Brazos River Floodgates	Colorado River Locks
	Existing Condition	Existing Condition
Min	0.32%	0.04%
Mean	0.42%	0.15%
Max	0.54%	0.08%

For each alternative condition, a reduction in these baseline accident risks was assumed. Given the significance of this input parameter for evaluating alternative benefits, ideally analysis of each alternative using ShipSim would be performed to quantitatively address this accident risk reduction, however due to available study schedule this was not possible. In place of this quantitative analysis, a qualitative assessment of accident risk reduction was generated via elicitation with industry representatives. This elicitation was performed in Galveston TX on 05 October 2017. In this elicitation, for each alternative, participants were asked to estimate a minimum, maximum, and most likely percentage reduction in accident risk relative to the existing/baseline condition, based on discussion and visual representation of the alternative. These elicited reductions and computed alternative risk distributions are shown in the tables below.

Historically, accidents which have resulted in downtime at both project sites have been those resulting in allisions with the project structures, which result in damage to the facilities such that they then need to be repaired. No other type of accident resulting in downtime was presented to the team as an area of concern. As referenced above, on 05 October 2017, the PDT met with operators/carrier's utilizing the Brazos River Floodgates and Colorado River Locks to discuss, among other things, the impact that proposed measures and alternatives would have on their ability to transit the projects. All carriers present stated that the removal of the structures would logically be expected to reduce the likelihood of allisions to 0, as there is no longer a structure to impact. Additionally, carrier's utilizing these project have tended to operate under more restrictive policies than specified by USACE out of an abundance of caution. Examples of this include the employment of self-help policies under adverse river conditions, where a light towboat has positioned itself within the channel to "catch" any vessels that have trouble making the turn, and by tripping in smaller tow packages than specified by USACE policy. The latter of which is identified as a potential benefit category in this analysis as some of the proposed alternatives were identified by the carrier's present as having the capability to render this extra cost unnecessary in the with-project condition.

Without any historic precedent for other types of accidents that could result in project closures, the team would not be able to evaluate any potential impacts without a source of data to derive both a probability of occurrence and an associated consequence. Since the only accidents assessed in this analysis were related to allisions, and the only benefits claimed in the accident category are related to allisions, the likelihood of significantly overstating project benefits in this category such that it impacts plan selection is small.

Table 40 : Alternative Accident Risk Distributions, Brazos River Floodgates

		9a	3a	9c	3a.1
Alternative Probability per Trip	Min	0%	0.06%	0.03%	0.05%
	Mean	0%	0.10%	0.08%	0.08%
	Max	0%	0.27%	0.16%	0.15%
Elicited Percent Reduction per Trip	Min	100%	50%	70%	72%
	Mean	100%	75%	80%	81%
	Max	100%	80%	90%	85%

Table 41 : Alternative Accident Risk Distributions, Colorado River Locks

		3b	4b.1
Existing Condition Probability per Trip	Min	0%	0%
	Mean	0%	0%
	Max	0%	0%
Elicited Percent Reduction per Trip	Min	100%	100%
	Mean	100%	100%
	Max	100%	100%

Open channel alternatives, as well as the riverside gate removal (4b.1) at Colorado were assumed to reduce accidents by 100% because no structure would remain for vessels to impact. Other accidents such as vessel groundings would remain a possibility, but the type of accident (allision with structures) which result in scheduled river closures for repairs would be reduced by 100%. For 4b.1 at Colorado, industry representatives indicated during the elicitation that removal of the riverside gates would fully address accident risk at Colorado, both by adding to available forebay, and by removing the gates were the vast majority of existing condition allisions occur.

The second category of accident related parameters, accident repair duration, represents the average period after an accident during which the affected project must be closed to traffic for repairs. To estimate the distribution of repair durations, multiple data sources needed to be merged together, including issued navigation notices, stall stoppage records, and LPMS lockage data. As reliable estimates of closure durations, which would typically be recorded in the stall/stoppage dataset, did not exist for the project, these closure times had to be approximated using this merged dataset to narrow down all periods in which traffic did not occur to those likely to result from closures. For only two years of the available data was this merging possible given data gaps in the various databases. To estimate the number of hours of accident related closure, all hours within this two year period which fell within an issued navigation notice and in which no lockages were reported in LPMS, or which fell within a period recorded as a closure in the stall/stoppage dataset in which likewise no lockages were recorded in LPMS, provided they fell within 07:00 and 17:00 on a weekday, were identified as hours of repair related closure.

This dataset was used to determine the mean repair duration. The shape of the distribution was based on the distribution of repair costs for accidents in the period 2002-2015, based on discussions with the lockmaster at the BRFG, using the assumption that repair durations generally scale with recorded repair costs. A Weibull distribution was fit to these repair costs, using the mean of historic repair durations.

Over this 2 year period, an average of 13.9 accidents occurred per issued navigation notice, suggesting that a notice and subsequent closure does not follow each accident, but rather than closure periods are scheduled to repair accumulated damages. It was assumed that ten accidents would be allowed to accumulate before a repair closure is scheduled to the model.

2.6.3.1.10 River Conditions

The final two parameters represent the river conditions. To capture these, hydraulic models were used to hindcast river velocities and head differentials for the past 50+ years based on historic recorded discharge. These hindcast values were produced hourly for the BRFG and daily for the CRL. Unlike other input parameters, river conditions exhibit wave-like patterns, in that conditions at each time step are correlated to previous time-steps. This pattern can be modeled with a Markov chain, in which each time step n's distribution of possible values is informed by the previous time step, n-1. To do this, the hindcast river condition values were first divided into six bins. These bins were then used to create a 2-dimensional matrix, in which the vertical axis depicts the river condition bin at time step n-1, and the horizontal axis the river condition bin at time step n. This is illustrated in Table 43 below.

Table 42 : Velocity Transition Matrix - Totals, Brazos River Floodgates

	1	2	3	5	7	10
1	302,130	2,460	0	0	0	0
2	2,460	47,818	654	0	0	0
3	0	654	17,098	328	0	0
5	0	0	328	15,747	135	0
7	0	0	0	135	4,895	45
10	0	0	0	0	45	732

These are then converted into percentage values, which in rows essentially represent the probabilities of river condition values on the horizontal axis at time step n, given the river condition value on the vertical axis at time step n-1.

Table 43 : Velocity Transition Matrix - Percentage, Brazos River Floodgates

	1	2	3	5	7	10
1	99.19%	0.81%	0%	0%	0%	0%
2	4.83%	93.89%	1.28%	0%	0%	0%
3	0%	3.62%	94.57%	1.81%	0%	0%
5	0%	0%	2.02%	97.14%	0.83%	0%
7	0%	0%	0%	2.66%	96.45%	0.89%
10	0%	0%	0%	0%	5.79%	94.21%

In this way an entire year of river velocities for example can be simulated with periods of rising and falling velocity which mirror in both shape, frequency, and duration those found in the hindcast period of record.

2.6.3.1.11 Traffic Forecast

Traffic forecasts are loaded into the model via a separate input file, which provides forecasted system tonnage levels for each future year in the analysis period. A separate traffic forecast file is prepared for each forecast scenario (in this case the base forecast, a low traffic scenario, a high traffic scenario, a no traffic growth scenario, and a no growth after 20 years scenario). When the simulation is run, as the date and time tracker progresses through the defined simulation period, the arrival interval distribution is redefined every calendar year based on forecasted tonnage in this input file and the project level average tons per tow. As additional traffic is forecasted on the system, the number of tows needed to move the forecasted tonnage are estimated, and the arrival patterns adjusted to accommodate these additional tows. It should be noted that no optimization is performed on tow size distributions, and that this approach implicitly assumes an unlimited supply of towboats and that additional towboats will be purchased by waterway users to move the additional barges.

2.6.3.2 Model Outputs

The WLCEN model outputs total annual hours of vessel delay and transit time by category for each model iteration. The four time categories are processing time, queuing time, closure delay time, and tripping time. Outputs can alternatively be broken down into time sub-categories such as various tripping activities, and total annual values can be expanded into tow level timing data throughout a simulated year for calibration or validation. However the primary outputs used in the benefit cost analysis are the default aggregated annual timing by category. These annual level results are output for each simulation iteration, resulting in a distribution of possible model outputs based on the uncertainty and variability of input parameters. The mean outputs from this distribution represent the expected value of total annual vessel transit times, while other descriptive statistics such as standard deviation, minimum, maximum, and percentiles can be used to describe the shape of output uncertainty.

Model outputs for each of the above mentioned time categories are in total tow transit hours; meaning the sum of every hour each tow that transited the system in a simulated year spent in each of these four time categories. During a closure for example in which 5 tows spent 10 hours waiting to transit the project, 50 hours of closure delay time would be incremented towards the total in that year. To convert these annual transit hours into transit costs, hourly vessel operating costs were multiplied by annual hours for each category. Two tow operating cost categories were used; idling and maneuvering. Delay activities (closure delay and queuing) were monetized using the idling costs, while regular processing time categories (processing and tripping) were monetized using the maneuver costs. Average operating costs for all tows on the system were used in place of vessel/barge/size specific costs. These costs are based on confidential surveys conducted amongst vessel operators and vessel builders on a regular basis by the USACE Institute for Water Resources (IWR).

Table 44 : Vessel Operating Costs

	Vessel Idle Cost	Vessel Maneuver Cost	Weighted Avg. Barge Cost
Brazos River Floodgates (East)	$ 221.26	$ 283.27	$ 98.22
Brazos River Floodgates (West)	$ 220.73	$ 282.35	$ 97.70
Colorado River Locks (East)	$ 219.07	$ 279.41	$ 124.19
Colorado River Locks (West)	$ 221.44	$ 283.58	$ 129.30

Evaluation of alternative transportation cost reductions was performed by running the model for the baseline as well as each alternative, and computing the net change in transit cost between each alternative and the baseline. Detailed model outputs for these conditions are provided in the sections below.

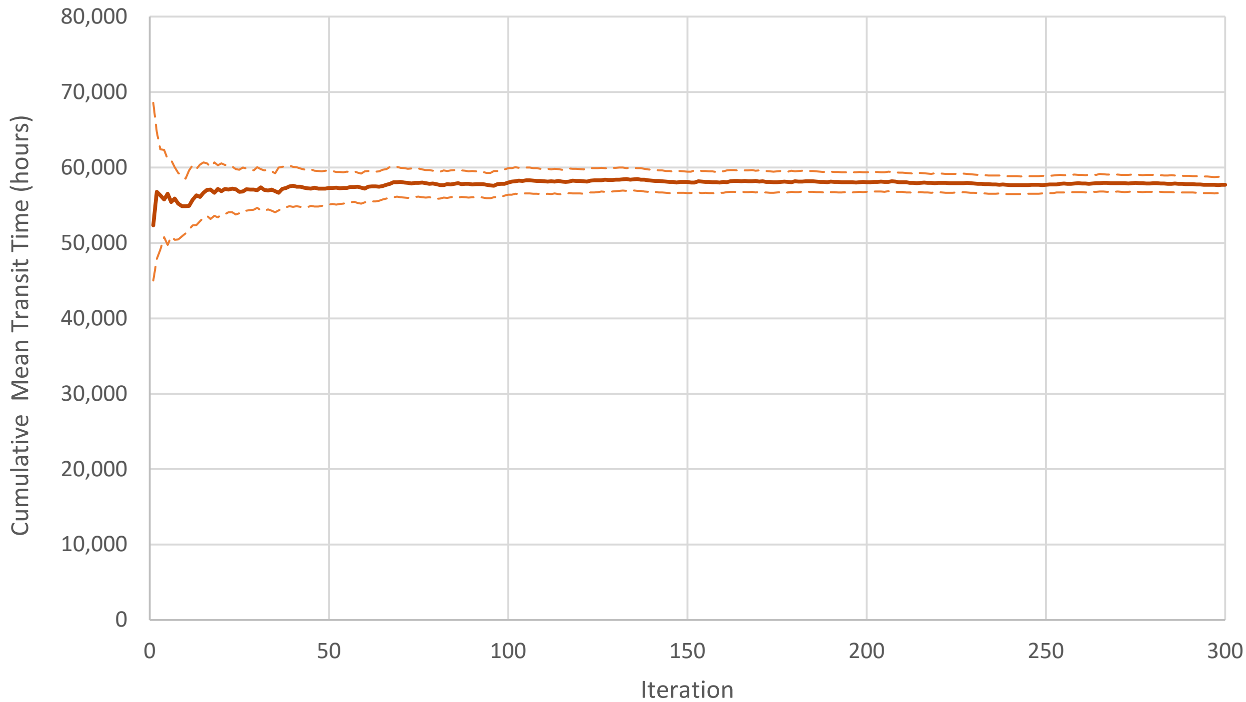
As previously discussed, the model performs a Monte Carlo analysis. This analysis seeks to define the distribution of possible outcomes by repeated random sampling from distributions of uncertain inputs. These uncertainties result from a combination of parameterized uncertainty (for example ranges of accident risk) and probabilistic inputs (river conditions).

As more model iterations are performed, the correspondingly increasing sample of results will more closely mirror the true distribution of all possible outcomes. Convergence testing is performed to test the degree to which the cumulative sample of outputs for a given number of performed iterations represents the true distribution of possible outcomes. Convergence is reached when the cumulative mean model output on which convergence is tested remains consistent across subsequent iterations, within specified tolerances.

Typically convergence testing is performed during simulations after each iteration is complete, and the simulation is ended when the computed error of the cumulative mean output falls within the specified tolerances and convergence is reached. For this analysis to reduce model run times and ensure that a consistent number of model iterations were performed across all analyzed scenarios, convergence testing was performed on a completed 1,000 iteration simulation, and an appropriate number of iterations for the full array of final model runs determined to achieve desired confidence levels.

The model output upon which convergence was tested was the total transit hours at both the Brazos River Floodgates and Colorado River Locks. Figure 11 below illustrates the cumulative mean total transit hours for the baseline condition by model iteration. The orange lines indicate the range of approximated error. As more iterations are performed the cumulative mean stabilizes or "converges". For this analysis, convergence was assumed when 99% confidence was reached of the cumulative mean value falling with 1% (convergence tolerance) of the true mean of all possible outcomes. This is reached after 291 iterations using the baseline condition results depicted below.

Figure 13 : Convergence Testing



Based on this convergence testing analysis, 300 iterations were performed for the baseline condition and each alternative condition.

2.6.4 Iterative Analysis

Over the course of the study, several iterations of the analysis within the WLCEN model were performed. The three primary iterations documented in this appendix are the modeling performed for the TSP milestone, the modeling performed for the ADM milestone, and again post-ADM milestone. For each iteration model assumptions were revised, and for the post-ADM milestone these revised assumptions were the primary impetus for the additional analysis.

2.6.4.1 Comparison of Modeling Assumptions

For each of the three iterations of WLCEN modeling, different sets of input parameters and assumptions were used. These are summarized in Table 45 below.

Table 45 : Modeling Assumptions Comparison

	Traffic Forecast	Empty 2-Barge Tow Configuration	FWOP CRL River Closure Proxy	Dredge Disposal Site Expansion Cost	Barge Size Distribution
TSP Milestone	None	System optimal	None	Fixed investment	Fixed bins
ADM Milestone	National forecast	Side-by-side	Colorado river velocity	Fixed investment	Empirical
Post-ADM	Regional forecast	Side-by-side	GIWW channel velocity	Unit cost	Empirical

The sections below go into detail on each iteration of the modeling, and under the section detailing each iteration these assumptions are described in greater detail. In summary, for the ADM milestone traffic forecasts were introduced (these were omitted during the TSP milestone analysis as a simplifying assumption as discussed previously), the configuration of 2 barge empty tows were adjusted to side-by-side from optimal configuration, a river closure proxy was utilized at Colorado to capture river related project closures at that project, and the barge size distribution in the modeling was refined to better match observed data.

For the post-ADM milestone a second set of regional traffic forecasts were adopted per comments received from SWD, the river closure proxy was revised per discussions with industry, and dredge disposal costs were revised downwards from previous estimates.

2.6.5 TSP Milestone Analysis

2.6.5.1 Baseline Condition

2.6.5.1.1 Transit Cost

Total annual transit times are output from the WLCEN model. From these, annual transit costs can be estimated. These costs, as estimated for the baseline condition, essentially represent the existing condition transportation costs possible to be reduced via alternatives. This reduction is estimated as the difference between these baseline condition outputs and alternative condition outputs. As the system analyzed includes both the Brazos River Floodgates and the Colorado River Locks, transit times and costs are evaluated at both projects, with system level transit costs being simply the sum of both project level estimates.

The box-and-whisker plots shown below as Figure 12 and Figure 13 illustrate the distribution of possible baseline condition transit costs for both projects. The left-most box-and-whisker is the distribution of total transit costs, while the remaining four break this total cost down into the 4 evaluated transit time categories; processing time, queuing time, tripping time, and closure time. In both of these figures, the box represents the mean (middle line) and 25th and 75th percentiles, while the whiskers represent the 5th and 95th percentiles. The mean is shown as the central line in each box rather than the more common median, or 50th percentile, as the mean value from output distributions is used as the expected value for this analysis, and thus is the basis of all benefit cost analysis.

Figure 14 : Transit Cost Uncertainty Distribution, Existing Condition, Brazos River Floodgates

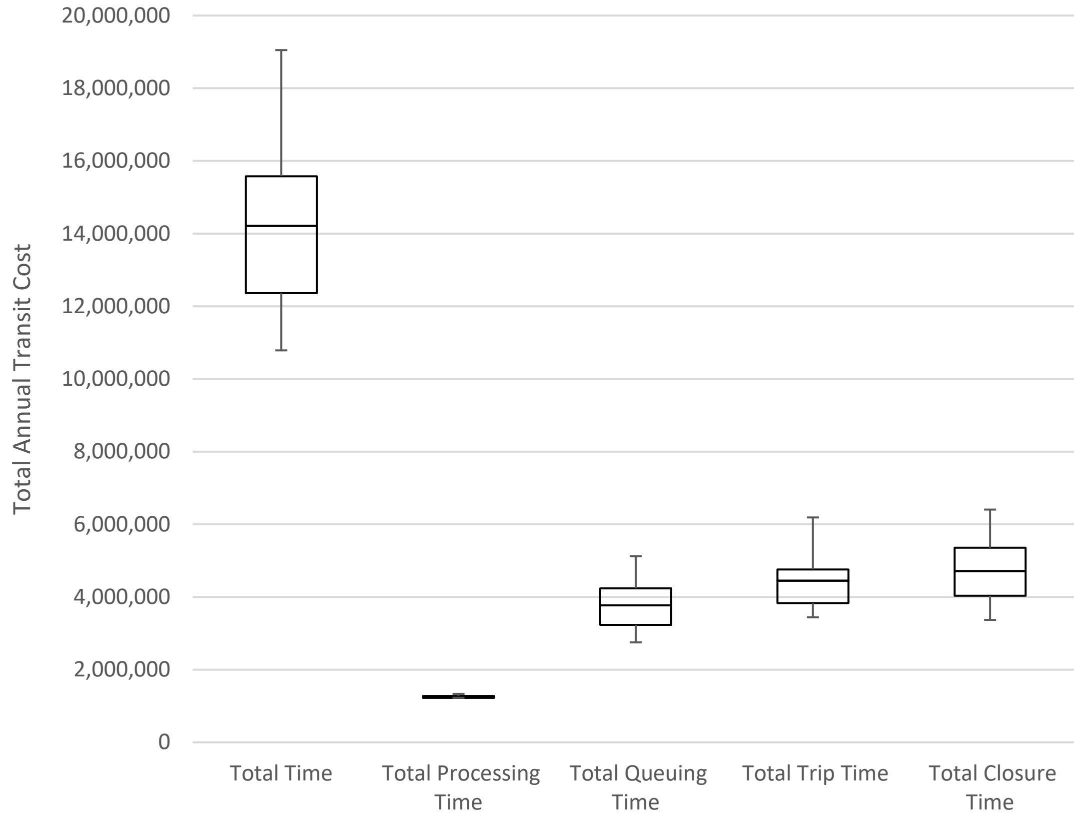
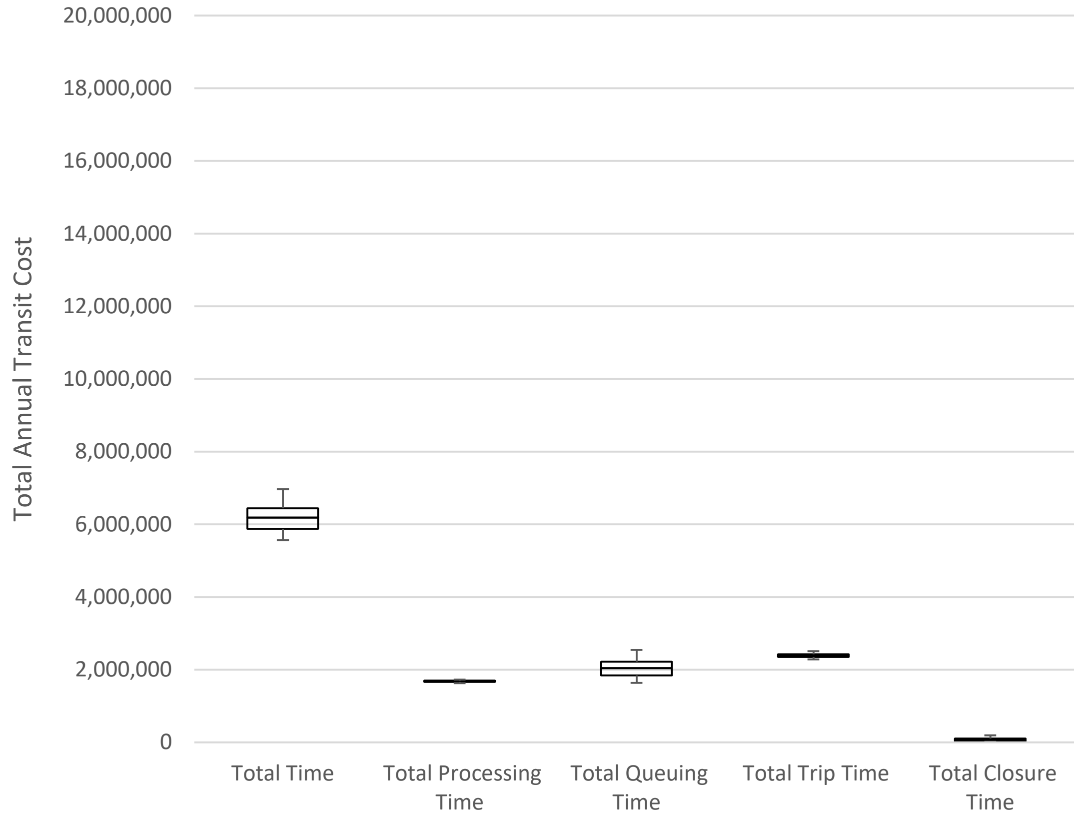


Figure 15 : Transit Cost Uncertainty Distribution, Existing Condition, Colorado River Locks



The mean values for each of these categories are shown for both projects and for the combined system in below.

Table 46 : Existing Condition Mean Transit Costs

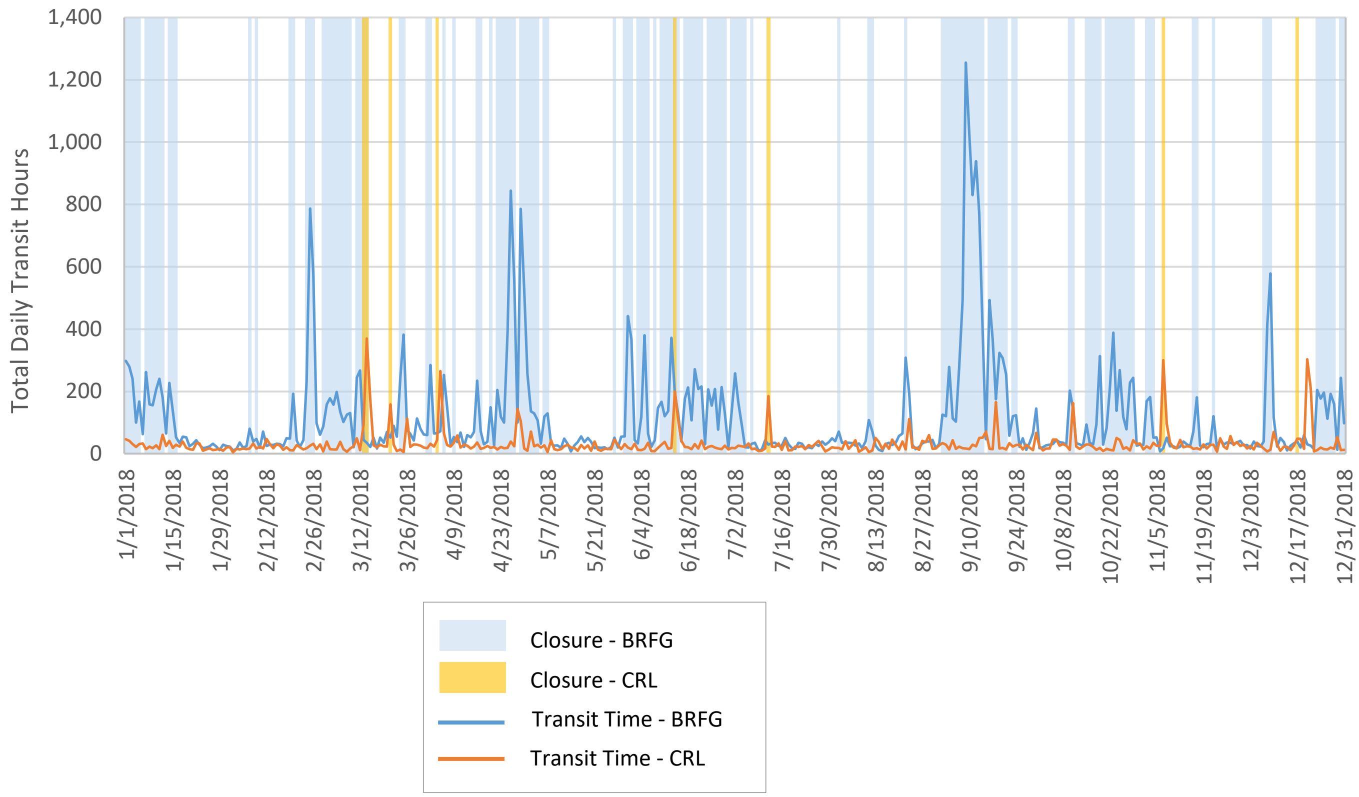
	Brazos River Floodgates	Colorado River Locks	System
Processing Time	$1,279,965	$1,679,180	$2,959,145
Queuing Time	$3,768,769	$2,039,660	$5,808,429
Tripping Time	$4,449,567	$2,390,826	$6,840,393
Closure Delay Time	$4,712,640	$75,074	$4,787,714
Total	$14,210,940	$6,184,740	$20,395,680

Transit costs are significantly higher at the BRFG than at the CRL, driven in large part by risk of accidents and related repair closures. Significant variability exists in these estimates, driven by the number of accidents sampled to occur in a given simulation year; the frequency, duration, and severity of hydraulic events resulting in high river velocities and/or head differentials at gates; as well as the interactions between these and other input parameters such as tow arrival patterns. The existing condition accident risk at BRFG is high and relatively stable. Given an average of 12,000 trips annually, the range of accidents given the historic rates per trip is between 40 and 67 accidents. For this reason, while accident risk does substantially contribute to the total annual transit costs, it does not contribute as significantly to variability in transit costs as other parameters such as river conditions, or as the interactions between variable inputs.

The effects of queuing, and compounding effects of queuing on tripping times contribute a significant amount of variability to model outputs, as the size of the queue when a given service disruption event occurs will to a large extent dictate the transit cost impact of that event. These effects are not isolated to the variability of the queuing time transit time category in the figures above, because of how these variables interact. If a queue of 10 tows exists at the time of a closure for example, all 10 of these tows will accrue closure delay hours until the project reopens. Likewise, after the project reopens, each of these 10 tows, as well as any that arrived during the closure, will accrue additional queuing delay above and beyond what they would have experienced without the closure.

How these various parameters and transit time categories interact is illustrated in an example simulation year in Figure 14 below. In the figure the blue line represents the total daily transit hours at the BRFG, while the orange line represents the total daily transit ours at the CRL. The blue shaded bars represent periods (days) during which the BRFG are closed, while the orange shaded bars represent periods during which the CRL are closed. In this example simulation year, both accident related repair closures and river related closures occur. For each iteration of the model, this sequence of closures and transit times will vary significantly.

Figure 16 : Closures and Transit Times, Sample Simulation Year, Existing Condition



Transit times and associated costs also vary significantly based on the number of trips required to transit a project. The number of required trips primarily affects the tripping time and processing time, but other time categories are affected as well. Queuing times scale to some degree with the number of required trips as following completion of a trip, a tripping tow can accrue additional queuing time waiting to process if the project is currently in use by another tow. Queuing and closure delay times also are affected by the number of required trips, as after a project reopens in enters a queue clearing mode in which single barge tows are prioritized. Multiple barge tows then disproportionately bear the cost of closure delays. Transit times by category and project are shown in the following tables.

Table 47 : Average Time by Category, by # Trips Required, Brazos River Floodgates

Trips	Average Time (hours)			
	Processing Time	Queuing Time	Tripping Time	Closure Time
1	0.16	0.75	0.00	0.93
2	0.49	1.70	2.70	1.98
3	0.83	2.04	4.11	2.52
4	1.16	2.21	5.51	2.61
5	1.48	2.31	6.61	2.70
6	1.85	2.58	8.05	3.82

Table 48 : Average Total Transit Time by # Trips Required, Brazos River Floodgates

Trips	Average Time (hours)		
	Arrival - SOL	SOL - EOL	Total
1	1.68	0.16	1.85
2	4.28	2.59	6.87
3	4.47	5.02	9.50
4	4.49	7.02	11.51
5	3.57	9.53	13.10
6	4.42	11.88	16.31

Table 49 : Average Time by Category, by # Trips Required, Colorado River Locks

Trips	Average Time (hours)			
	Processing Time	Queuing Time	Tripping Time	Closure Time
1	0.27	0.34	0.00	0.01
2	0.81	0.84	2.00	0.08
3	1.32	1.40	3.35	0.22
4	1.87	1.40	4.65	0.17
5	2.57	1.68	6.05	0.10
6	2.88	1.98	7.31	0.17

Table 50 : Average Total Transit Time by # Trips Required, Colorado River Locks

Trips	Average Time (hours)		
	Arrival - SOL	SOL - EOL	Total
1	0.36	0.27	0.63
2	1.26	2.48	3.74
3	1.59	4.71	6.30
4	1.36	6.74	8.11
5	1.38	9.03	10.42
6	1.42	10.92	12.34

2.6.5.1.2 Accident Repair Cost

In addition to costs incurred by shippers during periods in which projects are closed for repairs, the cost of these repairs also represents a cost to the nation's economy. These costs are not directly computed in the WLCEN model, but rather were based on historic repair costs over the period between 2002 and 2015. The total repair cost and number of accidents at both projects for this period are shown in below. From this dataset, an average repair cost per accident was calculated, which as with the hourly vessel operating costs is then multiplied by WLCEN outputs, in this case the number of accidents, to estimate the total incurred repair cost. These costs only include direct repairs to the projects themselves, and do not include costs to repair damages to barges or towboats. These costs also represent a cost to the nation's economy, however insufficient data was available to evaluate them.

Table 51 : Repair Cost History

Year	Brazos River Floodgates		Colorado River Locks	
	Repair Cost	Accidents	Repair Cost	Accidents
2002	$ 350,300	22	$ 35,860	3
2003	$ 683,625	33	$ 108,540	4
2004	$ 566,000	33	$ 106,560	7
2005	$ 1,107,600	37	$ 209,844	9
2006	$ 287,500	25	$ 39,000	4
2007	$ 783,585	39	$ 198,400	11
2008	$ 482,860	38	$ 78,000	3
2009	$ 773,720	49	$ 363,000	6
2010	$ 803,850	46	$ 502,000	11
2011	$ 720,250	41	$ 103,000	4
2012	$ 1,019,900	67	$ 246,000	7
2013	$ 632,300	47	$ 300,000	5
2014	$ 1,268,000	61	$ 685,000	11
2015	$ 1,018,100	65	$ 917,500	18

From these estimates, the baseline condition annual accident repair cost is $984,417 at the Brazos River Floodgates, and $316,832 at the Colorado River Locks.

2.6.5.1.3 OMRR&R

Operations, maintenance, repair, replacement, and rehabilitation (OMRR&R) costs in the existing condition represent the annual costs to operate and maintain both projects as well as the analyzed reach of the GIWW. These costs include for general subcategories; normal O&M, which includes general facility operation and maintenance costs incurred every year; major maintenance, which includes periodic investments to perform repairs and other work necessary to keep the project operational; maintenance dredging costs, which include the dredging and disposal costs necessary to maintain a navigable channel; and finally maintenance closure impact costs, which include any transit costs resulting from service disruptions due to maintenance dredging or periodic major maintenance. These costs will be discussed individually in the sections below.

2.6.5.1.3.1 Normal O&M

Normal O&M costs used in the economic analysis were fixed values provided by district operations. For both projects, an assumed annual normal O&M cost of $1,750,000 was assumed.

2.6.5.1.3.2 Maintenance Dredging

Maintenance dredging costs are a significant component of this analysis, both because dredging needs (and thus costs) in the existing condition are significant, but also because many of the analyzed alternatives induce significant changes to the deposition of sediment and the expected required dredging to mitigate these changes. Dredging costs were evaluated as a function of unit cost, mobilization and demobilization cost, and periodic cost related to disposal, including levee raises at disposal areas and EPA testing of dredge material for offshore disposal.

Four reaches were evaluated for dredging cost related to the BRFG, and three reaches for the CRL. For each reach, currently available disposal areas were identified, including the cost per cubic-yard (CY) for disposal in each, its capacity in terms of total CY, and what alternate disposal options exist when that capacity is reached. Additionally, periodic costs necessary to extend the use of each disposal area were provided by district operations, and the thresholds in terms of disposed CY of material at which these costs would be incurred were identified.

For each reach, an annual frequency of dredging was estimated. Annual sediment quantities in each analyzed reach were estimated using ADH modeling, and both these annual quantities and cumulative total quantities were tallied. As the thresholds discussed above were met or exceeded, costs were incurred or alternate (offshore) dredging options used. Mobilization and demobilization costs were incurred at estimated annual dredge frequency.

This analysis results in a stream of dredging costs, including unit costs, mobilization and demobilization, and periodic investments, which can be converted to a present worth and amortized into an annual average dredging cost. In the year at which capacity of existing disposal areas is exceeded, and offshore disposal of all dredge material at a higher unit cost becomes necessary, investments in levee raises cease, and EPA testing costs every 5 years are incurred.

2.6.5.1.3.3 Periodic Major Maintenance

Like normal O&M cost, periodic major maintenance costs used in the analysis were fixed annual estimates provided by district operations. These costs were assumed at $1,200,000 at the BRFG and $2,400,000 at the CRL.

2.6.5.1.3.4 Maintenance Closure Impact Costs

Maintenance closure impact costs represent the cost in terms of traffic disruption due to maintenance activities, in particular dredging costs. As these are a function of transit costs, these were estimated using the WLCEN model, however no traffic disruptions were assumed in the baseline condition. The evaluation of these costs will be discussed in greater detail in later sections.

2.6.5.1.4 Total Baseline Condition Cost

The total baseline condition costs for the analyzed system include costs of all above categories at both the BRFG and the CRL. The tables below itemize the total annualized costs for each category, for both projects separately (Table 52 and Table 53) and for the system as a whole (Table 54).

Table 52 : Total Baseline Condition Costs, Brazos River Floodgates

	2.75%	7%
Transit Time		
Processing Time	$1,279,965	$1,279,965
Queuing Time	$3,768,769	$3,768,769
Tripping Time	$4,449,567	$4,449,567
Closure Delay Time	$4,712,640	$4,712,640
Total	**$14,210,940**	**$14,210,940**
Accidents		
Accident Repair Cost	**$984,417**	**$984,417**
O&M		
Normal O&M	$1,750,000	$1,750,000
Maintenance Dredging	$17,904,989	$4,469,647
Periodic Major Maintenance	$1,200,000	$1,200,000
Maintenance Closure Impact Costs	$0	$0
Total	**$20,854,989**	**$20,854,989**
Total Annual Benefit	**$36,050,346**	**$36,050,346**

Note: 2.75% - 2018 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

Table 53 : Total Baseline Condition Costs, Colorado River Locks

	2.75%	7%
Transit Time		
Processing Time	$1,679,180	$1,679,180
Queuing Time	$2,039,660	$2,039,660
Tripping Time	$2,390,826	$2,390,826
Closure Delay Time	$75,074	$75,074
Total	**$6,184,740**	**$6,184,740**
Accidents		
Accident Repair Cost	**$316,832**	**$316,832**
O&M		
Normal O&M	$1,750,000	$1,750,000
Maintenance Dredging	$4,424,376	$4,150,000
Periodic Major Maintenance	$2,400,000	$2,400,000
Maintenance Closure Impact Costs	$0	$0
Total	**$8,574,376**	**$8,574,376**
Total Annual Benefit	**$15,075,948**	**$15,075,948**

Note: 2.75% - 2018 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

Table 54 : Total Baseline Condition Costs, System Total

	2.75%	7%
Transit Time		
Processing Time	$2,959,145	$2,959,145
Queuing Time	$5,808,429	$5,808,429
Tripping Time	$6,840,393	$6,840,393
Closure Delay Time	$4,787,714	$4,787,714
Total	**$20,395,680**	**$20,395,680**
Accidents		
Accident Repair Cost	**$1,301,249**	**$1,301,249**
O&M		
Normal O&M	$3,500,000	$3,500,000
Maintenance Dredging	$22,329,365	$22,329,365
Periodic Major Maintenance	$3,600,000	$3,600,000
Maintenance Closure Impact Costs	$0	$0
Total	**$29,429,365**	**$29,429,365**
Total Annual Benefit	**$51,126,294**	**$51,126,294**

Note: 2.75% - 2018 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

2.6.5.2 Evaluation of Alternatives

For the TSP Milestone analysis, previously analyzed project-level alternatives were combined into system-level alternatives, one for each possible combination of project-level alternatives determined by the second round of screening to be feasible. Annual cost, benefit, net benefit, and benefit-cost ratios for each of these alternatives are provided in Table 55 : Alternative Analysis - 2.75% Federal Discount Rate

Alt ID	Brazos River Floodgates	Colorado River Locks	Total Annual Cost	Total Annual Benefit	Net Benefit	Benefit-Cost Ratio
EC-EC	Existing	Existing	-	-	-	-
EC-3b	Existing	Open Channel	**5,956,000**	**7,737,000**	**1,781,000**	**1.3**
EC-4b.1	Existing	Inner Gate Removal	**1,412,000**	**8,219,000**	**6,807,000**	**5.8**
9a-EC	Open Channel	Existing	**11,467,000**	**18,569,000**	**7,102,000**	**1.6**
9a-3b	Open Channel	Open Channel	**17,423,000**	**24,390,000**	**6,967,000**	**1.4**
9a-4b.1	Open Channel	Inner Gate Removal	**10,860,000**	**22,321,000**	**11,461,000**	**2.1**
3a-EC	125' Gates Existing Align	Existing	**10,505,000**	**11,432,000**	**927,000**	**1.1**
3a-3b	125' Gates Existing Align	Open Channel	**16,358,000**	**17,421,000**	**1,063,000**	**1.1**
3a-4b.1	125' Gates Existing Align	Inner Gate Removal	**11,918,000**	**17,289,000**	**5,371,000**	**1.5**
9c-EC	125' Gates Align C	Existing	20,470,000	9,715,000	(10,756,000)	0.5
9c-3b	125' Gates Align C	Open Channel	26,426,000	15,205,000	(11,221,000)	0.6
9c-4b.1	125' Gates Align C	Inner Gate Removal	19,863,000	13,194,000	(6,669,000)	0.7
3a.1-EC	125' Gate East/Open West	Existing	**7,782,000**	**14,600,000**	**6,817,000**	**1.9**
3a.1-3b	125' Gate East/Open West	Open Channel	**13,738,000**	**20,376,000**	**6,638,000**	**1.5**
3a.1-4b.1	125' Gate East/Open West	Inner Gate Removal	**7,175,000**	**18,252,000**	**11,077,000**	**2.5**

Note: 2.75% - 2018 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

below. The Alternative name in the first column represents the alternative at Brazos first, followed by the alternative at Colorado, with "EC" denoting the existing condition.

Table 55 : Alternative Analysis - 2.75% Federal Discount Rate

Alt ID	Brazos River Floodgates	Colorado River Locks	Total Annual Cost	Total Annual Benefit	Net Benefit	Benefit-Cost Ratio
EC-EC	Existing	Existing	-	-	-	-
EC-3b	Existing	Open Channel	**5,956,000**	**7,737,000**	**1,781,000**	**1.3**
EC-4b.1	Existing	Inner Gate Removal	**1,412,000**	**8,219,000**	**6,807,000**	**5.8**
9a-EC	Open Channel	Existing	**11,467,000**	**18,569,000**	**7,102,000**	**1.6**
9a-3b	Open Channel	Open Channel	**17,423,000**	**24,390,000**	**6,967,000**	**1.4**
9a-4b.1	Open Channel	Inner Gate Removal	**10,860,000**	**22,321,000**	**11,461,000**	**2.1**
3a-EC	125' Gates Existing Align	Existing	**10,505,000**	**11,432,000**	**927,000**	**1.1**
3a-3b	125' Gates Existing Align	Open Channel	**16,358,000**	**17,421,000**	**1,063,000**	**1.1**
3a-4b.1	125' Gates Existing Align	Inner Gate Removal	**11,918,000**	**17,289,000**	**5,371,000**	**1.5**
9c-EC	125' Gates Align C	Existing	20,470,000	9,715,000	(10,756,000)	0.5
9c-3b	125' Gates Align C	Open Channel	26,426,000	15,205,000	(11,221,000)	0.6
9c-4b.1	125' Gates Align C	Inner Gate Removal	19,863,000	13,194,000	(6,669,000)	0.7
3a.1-EC	125' Gate East/Open West	Existing	**7,782,000**	**14,600,000**	**6,817,000**	**1.9**
3a.1-3b	125' Gate East/Open West	Open Channel	**13,738,000**	**20,376,000**	**6,638,000**	**1.5**
3a.1-4b.1	125' Gate East/Open West	Inner Gate Removal	**7,175,000**	**18,252,000**	**11,077,000**	**2.5**

Note: 2.75% - 2018 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

As detailed in Table 55, Alternative 9a (open channel) at the Brazos River and 4b.1 (river side gate removal) for Colorado yield the highest net benefits at $11,461,000 with a BCR of 2.1. There is significant uncertainty however with regards to the rate of sedimentation in an open system and how it would impact future navigation functionality and what environmental impacts may be associated with increased sediment loads into areas that are currently important habitats for fishery/aquatic resources.

Additional uncertainty exists as to the logistics of executing the dredging activities included in the cost/benefit analysis, in particular if sedimentation volumes exceed those modeled. How frequently dredging would need to occur, whether or not multiple mobilization and demobilization costs for dredge contracts within one year could be incurred, whether or not the capability exists to dredge as necessary to maintain a navigable channel without impacts to traffic are uncertainties that have not been sufficiently captured in the analysis to date.

Finally industry representatives of the Port of Freeport have indicated that during periods in which the existing east gate at Brazos River is open increased cross currents are observed in Freeport Channel, and that they expect that given an open channel condition these increased velocities could impede traffic in and out of the channel. These effects have not been modeled to date, and therefore potentially represent an additional impact category of indeterminate magnitude.

Given the similarity in net NED benefits between the above alternative and Alternative 3a.1 (125’ gate on the east side, open channel on the west, both along existing alignment) for Brazos and 4b.1 (river side gate removal) for Colorado, this latter alternative is assumed to reasonably maximize net benefits, as it minimizes the risk posed by these uncertainties. The presence of the gate on the east side of the Brazos River eliminates the vast majority of expected increase in sedimentation as well as likely minimizes potential velocity impacts to traffic in the Freeport Channel.

The sections below will focus on the calculation of cost (and benefits as reductions from baseline condition costs) for each of the 14 alternatives.

2.6.5.2.1 Transit Cost

As with the baseline condition, transit costs for each alternative condition were evaluated using the WLCEN model. Transit costs across the four time categories; processing, tripping, queuing, and closure delay, were estimated for each alternative condition by altering the input parameters which define the system to reflect the prevailing condition under these alternatives. These parameters, which are described in detail above in section 2.6.3.1, include the gate width at projects, accident risk per trip, river condition markov chain matrices, and shipper and project operating policies. The total vessel hours and transit costs for each alternative are shown in Table 56 below. Applied vessel operating costs were assumed the same between the baseline and all alternative conditions.

Table 56 : Transit Cost, Alternative Conditions

Alt ID	Brazos River Floodgates	Colorado River Locks	Processing Time	Queuing Time	Tripping Time	Closure Delay Time
EC-EC	Existing	Existing	2,959,145	5,808,429	6,840,393	4,787,714
EC-3b	Existing	Open Channel	2,576,424	4,899,452	4,784,324	4,865,593
EC-4b.1	Existing	Inner Gate Removal	2,112,351	3,997,974	4,942,215	4,660,164
9a-EC	Open Channel	Existing	2,321,421	1,619,681	1,728,284	91,731
9a-3b	Open Channel	Open Channel	2,083,523	1,265,506	933,193	125,200
9a-4b.1	Open Channel	Inner Gate Removal	1,614,864	580,675	1,241,149	89,346
3a-EC	125' Gates Existing Align	Existing	2,508,439	2,765,067	3,003,973	1,404,145
3a-3b	125' Gates Existing Align	Open Channel	2,259,109	2,309,267	2,107,793	1,380,272
3a-4b.1	125' Gates Existing Align	Inner Gate Removal	1,800,030	1,630,032	2,544,461	1,386,660
9c-EC	125' Gates Align C	Existing	2,494,836	3,348,760	3,409,143	2,142,098
9c-3b	125' Gates Align C	Open Channel	2,253,197	3,054,737	2,818,804	2,244,098
9c-4b.1	125' Gates Align C	Inner Gate Removal	1,792,075	2,313,499	3,096,326	2,230,358
3a.1-EC	125' Gate East/Open West	Existing	2,411,786	1,963,306	2,331,562	489,246
3a.1-3b	125' Gate East/Open West	Open Channel	2,172,913	1,615,742	1,572,772	525,199
3a.1-4b.1	125' Gate East/Open West	Inner Gate Removal	1,705,726	932,811	1,907,136	514,329

2.6.5.2.2 Accident Repair Cost

Accident repair cost was calculated in the same manner as in the baseline condition. Accident frequencies from the WLCEN model runs were multiplied by the average cost per accident from the accident history.

2.6.5.2.3 OMRR&R

Operation and maintenance costs were evaluated for each alternative condition in the same manner as described in section 2.6.5.1.3 above. Table 57 below displays the estimated O&M costs for each project level alternative. These costs and their calculation for the alternative conditions are further discussed in the individual sections below.

Table 57 : Operation and Maintenance Cost, Alternative Conditions - 2.75% Federal Discount Rate

	Brazos River Floodgates				Colorado River Locks	
	9a	3a	9c	3a.1	3b	4b.1
Normal O&M	0	1,750,000	1,750,000	1,750,000	0	1,750,000
Maintenance Closure Impact Costs						
Periodic Major Maintenance	3,449,767	1,579,635	2,239,529	1,607,341	0	0
Maintenance Dredging	8,117,933	6,511,334	7,723,114	6,510,804	0	0
Freeport	6,323,710	3,888,224	7,372,145	3,847,911	0	0
East of Brazos to Freeport	10,102,107	5,823,080	10,102,107	8,057,127	0	0
Brazos Channel & Crossing	0	0	0	0	4,407,496	828,968
West of Brazos	0	0	0	0	1,807,687	746,768
East of CRL to GIWW	0	0	0	0	3,222,701	828,968
CRL Channel and Crossing	0	1,200,000	1,200,000	600,000	0	1,200,000
West of CRL	263,021	0	0	0	120,438	0

In cases in which annualized O&M costs increase relative to the baseline condition, this increment of increase is considered a cost of that alternative. In cases in which annualized O&M costs decrease relative to the baseline, this increment of decrease is considered a benefit of that alternative. This comparison is done at the O&M category level, such that an increase in one can be reflected on the cost side of the analysis, while a reduction in another is reflected on the benefit side.

2.6.5.2.3.1 Normal O&M

Normal O&M was estimated by district operations, as with the baseline condition. For open channel alternatives 9a at the BRFG and 3b at the CRL, normal O&M costs in the alternative condition were assumed to be zero, as with the removal of projects nothing related to costs within this category would remain to operate and maintain. For the removal of the riverside gates at Colorado, alternative 4b.1, baseline condition O&M costs of $2.4M were assumed to reduce by half to $1.2M. This reduction is predicated on the assumption that normal O&M costs generally scale with the number of project gates.

2.6.5.2.3.2 Maintenance Dredging

Maintenance dredging costs were also estimated in the same manner as in the baseline condition. The assumptions for each alternative remain the same, with the exception of modeled changes in annual sedimentation quantities. These were estimated within the ADH modeling, and applied to the disposal logic described in Section 2.6.5.1.3.2. The rates of annual sedimentation by reach for each alternative condition assumed are shown in Table 58 and Table 59 below.

Table 58 : Annual Sedimentation Quantity, Alternative Conditions, Brazos River Floodgates

	Average Annual Quantity (CY)			
Alternative	Freeport	East of Brazos to Freeport	Brazos Channel & Crossing	West of Brazos
EC	295,385	395,000	110,000	360,000
3a	316,615	400,321	135,385	320,466
9a	978,462	478,503	211,539	507,355
9c	550,154	462,948	245,385	507,355
3a.1	326,420	400,270	133,678	423,828

Table 59 : Annual Sedimentation Quantity, Alternative Conditions, Colorado River Locks

	Average Annual Quantity (CY)		
Alternative	East of CRL to GIWW	CRL Channel and Crossing	West of CRL
EC	75,000	55,000	75,000
3b	402,144	134,391	294,042
4b.1	75,000	55,000	75,000

In general, alternatives which result in a substantial increase in annual sedimentation result in more frequency periodic costs for expanding disposal area capacity through levee raises, more frequency mobilization and demobilization costs, and will exceed adjacent disposal capacity sooner than under the baseline, resulting in an earlier shift to the more costly offshore disposal.

2.6.5.2.3.3 Periodic Major Maintenance

Periodic major maintenance costs are handled identically to normal O&M costs. For many alternatives, these remain the same as under the baseline condition, however for open channel alternatives 9a at the BRFG and 3b at the CRL, periodic maintenance costs are reduced to zero. For the river side gate removal alternative at the CRL (4b.1), these costs are reduced by half, again to reflect the removal of half of the project gates.

2.6.5.2.4 Alternative Cost

The calculation of alternative cost is shown for each alternative in the tables below. As with benefits, costs associated with each alternative are comprised of the net increase in cost among all categories between the alternative condition and the without-project condition.

Table 60 : Cost Calculation, CRL - 2.75% Federal Discount Rate

	3b	4b.1
Construction Cost		
Total First Cost	**21,592,000**	**36,862,000**
Interest During Construction		
Construction Duration	1	1
Interest During Construction	**593,780**	**1,013,705**
Annualized Construction Cost		
Annualized First Cost	799,788	1,365,402
Annualized IDC	21,994	47,096
Total	**821,782**	**1,412,498**
Operation and Maintenance		
Normal O&M	-1,750,000	0
Maintenance Closure Impact Costs	120,438	0
Periodic Major Maintenance	-2,400,000	-1,200,000
Maintenance Dredging		
Freeport	0	0
East of Brazos to Freeport	0	0
Brazos Channel & Crossing	0	0
West of Brazos	0	0
East of CRL to GIWW	2,972,990	-605,538
CRL Channel and Crossing	252,323	-808,596
West of CRL	1,788,195	-605,538
Total	**983,946**	**-3,219,671**
Total Annual Cost	**1,805,728**	**-1,807,173**

Table 61 : Cost Calculation, BRFG - 2.75% Federal Discount Rate

	9a	3a	9c	3a.1
Construction Cost				
Total First Cost	29,303,000	266,819,000	272,226,000	147,818,000
Interest During Construction				
Construction Duration	0	0	0	0
Interest During Construction	0	0	0	0
Annualized Construction Cost				
Annualized First Cost	1,085,410	9,883,221	10,083,501	5,475,315
Annualized IDC	29,849	622,059	854,976	188,857
Total	**1,115,259**	**10,505,280**	**10,938,477**	**5,664,171**
Operation and Maintenance				
Normal O&M	-1,750,000	0	0	0
Maintenance Closure Impact Costs	263,021	0	0	0
Periodic Major Maintenance	-1,200,000	0	0	-600,000
Maintenance Dredging	0	0	0	0
Freeport	1,930,119	59,988	719,882	87,693
East of Brazos to Freeport	1,661,429	54,830	1,266,610	54,300
Brazos Channel & Crossing	3,104,521	669,035	4,152,956	628,722
West of Brazos	3,392,458	-886,569	3,392,458	1,347,478
East of CRL to GIWW	0	0	0	0
CRL Channel and Crossing	0	0	0	0
West of CRL	0	0	0	0
Total	**7,401,549**	**-102,716**	**9,531,906**	**1,518,193**
Total Annual Cost	**8,516,807**	**10,402,564**	**20,470,383**	**7,182,364**

2.6.5.2.5 Alternative Cost-Benefit Analysis

The system total benefit cost analysis of each of the analyzed alternatives are shown in the tables below.

Table 62 : Benefit-Cost Analysis, EC-3b, System Total - 2.75% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,959,145	$2,576,424	$382,721
Queuing Time	$5,808,429	$4,899,452	$908,977
Tripping Time	$6,840,393	$4,784,324	$2,056,068
Closure Delay Time	$4,787,714	$4,865,593	-$77,879
Total	**$20,395,680**	**$17,125,794**	**$3,269,887**
FWP O&M			
Normal O&M	$3,500,000	$1,750,000	$1,750,000
Maintenance Dredging	$22,329,365	$27,342,873	$0
Periodic Major Maintenance	$3,600,000	$1,200,000	$2,400,000
Maintenance Closure Impact Costs	$0	$120,438	$0
Total	**$29,429,365**	**$30,413,311**	**$4,150,000**
Accidents			
Accident Repair Cost	**$1,301,249**	**$984,417**	**$316,832**
Total Annual Benefit			**$7,736,719**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$821,782**	**$821,782**
FWP O&M			
Normal O&M	$3,500,000	$1,750,000	$0
Maintenance Dredging	$22,329,365	$27,342,873	$5,013,508
Periodic Major Maintenance	$3,600,000	$1,200,000	$0
Maintenance Closure Impact Costs	$0	$120,438	$120,438
Total	**$29,429,365**	**$30,413,311**	**$5,133,946**
Total Annual Cost			**$5,955,728**

NET BENEFIT			**$1,780,991**
BENEFIT-COST RATIO			**1.30**

Table 63 : Benefit-Cost Analysis, EC-4b.1, System Total - 2.75% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,959,145	$2,112,351	$846,794
Queuing Time	$5,808,429	$3,997,974	$1,810,455
Tripping Time	$6,840,393	$4,942,215	$1,898,178
Closure Delay Time	$4,787,714	$4,660,164	$127,550
Total	**$20,395,680**	**$15,712,703**	**$4,682,977**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$20,309,694	$2,019,671
Periodic Major Maintenance	$3,600,000	$2,400,000	$1,200,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$26,209,694**	**$3,219,671**
Accidents			
Accident Repair Cost	**$1,301,249**	**$984,417**	**$316,832**
Total Annual Benefit			**$8,219,480**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$1,412,498**	**$1,412,498**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$20,309,694	$0
Periodic Major Maintenance	$3,600,000	$2,400,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$26,209,694**	**$0**
Total Annual Cost			**$1,412,498**

NET BENEFIT			**$6,806,982**
BENEFIT-COST RATIO			**5.82**

Table 64 : Benefit-Cost Analysis, 9a-EC, System Total - 2.75% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,959,145	$2,321,421	$637,724
Queuing Time	$5,808,429	$1,619,681	$4,188,747
Tripping Time	$6,840,393	$1,728,284	$5,112,109
Closure Delay Time	$4,787,714	$91,731	$4,695,983
Total	**$20,395,680**	**$5,761,117**	**$14,634,563**
FWP O&M			
Normal O&M	$3,500,000	$1,750,000	$1,750,000
Maintenance Dredging	$22,329,365	$32,417,893	$0
Periodic Major Maintenance	$3,600,000	$2,400,000	$1,200,000
Maintenance Closure Impact Costs	$0	$263,021	$0
Total	**$29,429,365**	**$36,830,914**	**$2,950,000**
Accidents			
Accident Repair Cost	**$1,301,249**	**$316,832**	**$984,417**
Total Annual Benefit			**$18,568,980**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$1,115,259**	**$1,115,259**
FWP O&M			
Normal O&M	$3,500,000	$1,750,000	$0
Maintenance Dredging	$22,329,365	$32,417,893	$10,088,528
Periodic Major Maintenance	$3,600,000	$2,400,000	$0
Maintenance Closure Impact Costs	$0	$263,021	$263,021
Total	**$29,429,365**	**$36,830,914**	**$10,351,549**
Total Annual Cost			**$11,466,807**

NET BENEFIT			**$7,102,172**
BENEFIT-COST RATIO			**1.62**

Table 65 : Benefit-Cost Analysis, 9a-3b, System Total - 2.75% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,959,145	$2,083,523	$875,621
Queuing Time	$5,808,429	$1,265,506	$4,542,923
Tripping Time	$6,840,393	$933,193	$5,907,200
Closure Delay Time	$4,787,714	$125,200	$4,662,514
Total	**$20,395,680**	**$4,407,422**	**$15,988,258**
FWP O&M			
Normal O&M	$3,500,000	$0	$3,500,000
Maintenance Dredging	$22,329,365	$37,431,401	$0
Periodic Major Maintenance	$3,600,000	$0	$3,600,000
Maintenance Closure Impact Costs	$0	$383,459	$0
Total	**$29,429,365**	**$37,814,860**	**$7,100,000**
Accidents			
Accident Repair Cost	**$1,301,249**	**$0**	**$1,301,249**
Total Annual Benefit			**$24,389,508**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$1,937,041**	**$1,937,041**
FWP O&M			
Normal O&M	$3,500,000	$0	$0
Maintenance Dredging	$22,329,365	$37,431,401	$15,102,036
Periodic Major Maintenance	$3,600,000	$0	$0
Maintenance Closure Impact Costs	$0	$383,459	$383,459
Total	**$29,429,365**	**$37,814,860**	**$15,485,495**
Total Annual Cost			**$17,422,535**

NET BENEFIT			**$6,966,972**
BENEFIT-COST RATIO			**1.40**

Table 66 : Benefit-Cost Analysis, 9a-4b.1, System Total - 2.75% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,959,145	$1,614,864	$1,344,280
Queuing Time	$5,808,429	$580,675	$5,227,754
Tripping Time	$6,840,393	$1,241,149	$5,599,244
Closure Delay Time	$4,787,714	$89,346	$4,698,368
Total	**$20,395,680**	**$3,526,034**	**$16,869,646**
FWP O&M			
Normal O&M	$3,500,000	$1,750,000	$1,750,000
Maintenance Dredging	$22,329,365	$30,398,222	$0
Periodic Major Maintenance	$3,600,000	$1,200,000	$2,400,000
Maintenance Closure Impact Costs	$0	$263,021	$0
Total	**$29,429,365**	**$33,611,243**	**$4,150,000**
Accidents			
Accident Repair Cost	**$1,301,249**	**$0**	**$1,301,249**
Total Annual Benefit			**$22,320,895**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$2,527,757**	**$2,527,757**
FWP O&M			
Normal O&M	$3,500,000	$1,750,000	$0
Maintenance Dredging	$22,329,365	$30,398,222	$8,068,857
Periodic Major Maintenance	$3,600,000	$1,200,000	$0
Maintenance Closure Impact Costs	$0	$263,021	$263,021
Total	**$29,429,365**	**$33,611,243**	**$8,331,878**
Total Annual Cost			**$10,859,635**

NET BENEFIT			**$11,461,260**
BENEFIT-COST RATIO			**2.06**

Table 67 : Benefit-Cost Analysis, 3a-EC, System Total - 2.75% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,959,145	$2,508,439	$450,705
Queuing Time	$5,808,429	$2,765,067	$3,043,362
Tripping Time	$6,840,393	$3,003,973	$3,836,419
Closure Delay Time	$4,787,714	$1,404,145	$3,383,569
Total	**$20,395,680**	**$9,681,625**	**$10,714,055**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$22,226,649	$102,716
Periodic Major Maintenance	$3,600,000	$3,600,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$29,326,649**	**$102,716**
Accidents			
Accident Repair Cost	**$1,301,249**	**$685,989**	**$615,261**
Total Annual Benefit			**$11,432,032**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$10,505,280**	**$10,505,280**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$22,226,649	$0
Periodic Major Maintenance	$3,600,000	$3,600,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$29,326,649**	**$0**
Total Annual Cost			**$10,505,280**

NET BENEFIT			**$926,752**
BENEFIT-COST RATIO			**1.09**

Table 68 : Benefit-Cost Analysis, 3a-3b, System Total - 2.75% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,959,145	$2,259,109	$700,036
Queuing Time	$5,808,429	$2,309,267	$3,499,162
Tripping Time	$6,840,393	$2,107,793	$4,732,600
Closure Delay Time	$4,787,714	$1,380,272	$3,407,442
Total	**$20,395,680**	**$8,056,441**	**$12,339,239**
FWP O&M			
Normal O&M	$3,500,000	$1,750,000	$1,750,000
Maintenance Dredging	$22,329,365	$27,240,157	$0
Periodic Major Maintenance	$3,600,000	$1,200,000	$2,400,000
Maintenance Closure Impact Costs	$0	$120,438	$0
Total	**$29,429,365**	**$30,310,595**	**$4,150,000**
Accidents			
Accident Repair Cost	**$1,301,249**	**$369,156**	**$932,093**
Total Annual Benefit			**$17,421,332**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$11,327,062**	**$11,327,062**
FWP O&M			
Normal O&M	$3,500,000	$1,750,000	$0
Maintenance Dredging	$22,329,365	$27,240,157	$4,910,792
Periodic Major Maintenance	$3,600,000	$1,200,000	$0
Maintenance Closure Impact Costs	$0	$120,438	$120,438
Total	**$29,429,365**	**$30,310,595**	**$5,031,230**
Total Annual Cost			**$16,358,292**

NET BENEFIT			**$1,063,040**
BENEFIT-COST RATIO			**1.06**

Table 69 : Benefit-Cost Analysis, 3a-4b.1, System Total - 2.75% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,959,145	$1,800,030	$1,159,115
Queuing Time	$5,808,429	$1,630,032	$4,178,397
Tripping Time	$6,840,393	$2,544,461	$4,295,932
Closure Delay Time	$4,787,714	$1,386,660	$3,401,054
Total	**$20,395,680**	**$7,361,182**	**$13,034,498**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$20,206,978	$2,122,387
Periodic Major Maintenance	$3,600,000	$2,400,000	$1,200,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$26,106,978**	**$3,322,387**
Accidents			
Accident Repair Cost	**$1,301,249**	**$369,156**	**$932,093**
Total Annual Benefit			**$17,288,978**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$11,917,778**	**$11,917,778**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$20,206,978	$0
Periodic Major Maintenance	$3,600,000	$2,400,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$26,106,978**	**$0**
Total Annual Cost			**$11,917,778**

NET BENEFIT			**$5,371,199**
BENEFIT-COST RATIO			**1.45**

Table 70 : Benefit-Cost Analysis, 9c-EC, System Total - 2.75% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,959,145	$2,494,836	$464,309
Queuing Time	$5,808,429	$3,348,760	$2,459,669
Tripping Time	$6,840,393	$3,409,143	$3,431,249
Closure Delay Time	$4,787,714	$2,142,098	$2,645,616
Total	**$20,395,680**	**$11,394,837**	**$9,000,844**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$31,861,271	$0
Periodic Major Maintenance	$3,600,000	$3,600,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$38,961,271**	**$0**
Accidents			
Accident Repair Cost	**$1,301,249**	**$587,547**	**$713,702**
Total Annual Benefit			**$9,714,546**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$10,938,477**	**$10,938,477**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$31,861,271	$9,531,906
Periodic Major Maintenance	$3,600,000	$3,600,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$38,961,271**	**$9,531,906**
Total Annual Cost			**$20,470,383**
NET BENEFIT			**-$10,755,837**
BENEFIT-COST RATIO			**0.47**

Table 71 : Benefit-Cost Analysis, 9c-3b, System Total - 2.75% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,959,145	$2,253,197	$705,948
Queuing Time	$5,808,429	$3,054,737	$2,753,692
Tripping Time	$6,840,393	$2,818,804	$4,021,588
Closure Delay Time	$4,787,714	$2,244,098	$2,543,616
Total	**$20,395,680**	**$10,370,837**	**$10,024,843**
FWP O&M			
Normal O&M	$3,500,000	$1,750,000	$1,750,000
Maintenance Dredging	$22,329,365	$36,874,779	$0
Periodic Major Maintenance	$3,600,000	$1,200,000	$2,400,000
Maintenance Closure Impact Costs	$0	$120,438	$0
Total	**$29,429,365**	**$39,945,217**	**$4,150,000**
Accidents			
Accident Repair Cost	**$1,301,249**	**$270,715**	**$1,030,535**
Total Annual Benefit			**$15,205,378**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$11,760,259**	**$11,760,259**
FWP O&M			
Normal O&M	$3,500,000	$1,750,000	$0
Maintenance Dredging	$22,329,365	$36,874,779	$14,545,414
Periodic Major Maintenance	$3,600,000	$1,200,000	$0
Maintenance Closure Impact Costs	$0	$120,438	$120,438
Total	**$29,429,365**	**$39,945,217**	**$14,665,852**
Total Annual Cost			**$26,426,111**

NET BENEFIT			**-$11,220,733**
BENEFIT-COST RATIO			**0.58**

Table 72 : Benefit-Cost Analysis, 9c-4b.1, System Total - 2.75% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,959,145	$1,792,075	$1,167,070
Queuing Time	$5,808,429	$2,313,499	$3,494,930
Tripping Time	$6,840,393	$3,096,326	$3,744,066
Closure Delay Time	$4,787,714	$2,230,358	$2,557,356
Total	**$20,395,680**	**$9,432,258**	**$10,963,422**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$29,841,600	$0
Periodic Major Maintenance	$3,600,000	$2,400,000	$1,200,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$35,741,600**	**$1,200,000**
Accidents			
Accident Repair Cost	**$1,301,249**	**$270,715**	**$1,030,535**
Total Annual Benefit			**$13,193,957**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$12,350,975**	**$12,350,975**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$29,841,600	$7,512,235
Periodic Major Maintenance	$3,600,000	$2,400,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$35,741,600**	**$7,512,235**
Total Annual Cost			**$19,863,210**

NET BENEFIT			**-$6,669,254**
BENEFIT-COST RATIO			**0.66**

Table 73 : Benefit-Cost Analysis, 3a.1-EC, System Total - 2.75% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,959,145	$2,411,786	$547,359
Queuing Time	$5,808,429	$1,963,306	$3,845,123
Tripping Time	$6,840,393	$2,331,562	$4,508,830
Closure Delay Time	$4,787,714	$489,246	$4,298,467
Total	**$20,395,680**	**$7,195,900**	**$13,199,780**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$24,447,558	$0
Periodic Major Maintenance	$3,600,000	$3,000,000	$600,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$30,947,558**	**$600,000**
Accidents			
Accident Repair Cost	**$1,301,249**	**$501,410**	**$799,839**
Total Annual Benefit			**$14,599,619**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$5,664,171**	**$5,664,171**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$24,447,558	$2,118,193
Periodic Major Maintenance	$3,600,000	$3,000,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$30,947,558**	**$2,118,193**
Total Annual Cost			**$7,782,364**

NET BENEFIT			**$6,817,255**
BENEFIT-COST RATIO			**1.88**

Table 74 : Benefit-Cost Analysis, 3a.1-3b, System Total - 2.75% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,959,145	$2,172,913	$786,231
Queuing Time	$5,808,429	$1,615,742	$4,192,687
Tripping Time	$6,840,393	$1,572,772	$5,267,621
Closure Delay Time	$4,787,714	$525,199	$4,262,515
Total	**$20,395,680**	**$5,886,625**	**$14,509,055**
FWP O&M			
Normal O&M	$3,500,000	$1,750,000	$1,750,000
Maintenance Dredging	$22,329,365	$29,461,066	$0
Periodic Major Maintenance	$3,600,000	$600,000	$3,000,000
Maintenance Closure Impact Costs	$0	$120,438	$0
Total	**$29,429,365**	**$31,931,504**	**$4,750,000**
Accidents			
Accident Repair Cost	**$1,301,249**	**$184,578**	**$1,116,671**
Total Annual Benefit			**$20,375,726**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$6,485,953**	**$6,485,953**
FWP O&M			
Normal O&M	$3,500,000	$1,750,000	$0
Maintenance Dredging	$22,329,365	$29,461,066	$7,131,701
Periodic Major Maintenance	$3,600,000	$600,000	$0
Maintenance Closure Impact Costs	$0	$120,438	$120,438
Total	**$29,429,365**	**$31,931,504**	**$7,252,139**
Total Annual Cost			**$13,738,092**

NET BENEFIT			**$6,637,634**
BENEFIT-COST RATIO			**1.48**

Table 75 : Benefit-Cost Analysis, 3a.1-4b.1, System Total - 2.75% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,959,145	$1,705,726	$1,253,419
Queuing Time	$5,808,429	$932,811	$4,875,618
Tripping Time	$6,840,393	$1,907,136	$4,933,256
Closure Delay Time	$4,787,714	$514,329	$4,273,385
Total	**$20,395,680**	**$5,060,001**	**$15,335,679**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$22,427,887	$0
Periodic Major Maintenance	$3,600,000	$1,800,000	$1,800,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$27,727,887**	**$1,800,000**
Accidents			
Accident Repair Cost	**$1,301,249**	**$184,578**	**$1,116,671**
Total Annual Benefit			**$18,252,350**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$7,076,669**	**$7,076,669**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$22,427,887	$98,522
Periodic Major Maintenance	$3,600,000	$1,800,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$27,727,887**	**$98,522**
Total Annual Cost			**$7,175,192**

NET BENEFIT			**$11,077,158**
BENEFIT-COST RATIO			**2.54**

2.6.5.3 Tentatively Selected Plan

The tentatively selected plan is the removal of the west gate at the BRFG, and replacement of the east gate with a 125’ width gate (3a.1), and removal of the river side gates at the CRL (4b.1). The total comparison of annual benefits and costs for this alternative, by category for both projects and the system total, is shown in the following tables.

Table 76 : Benefit-Cost Analysis, Tentatively Selected Plan, Brazos River Floodgates - 2.75% Federal Discount Rate

Benefit – BRAZOS RIVER FLOODGATES

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$1,279,965	$870,375	$409,590
Queuing Time	$3,768,769	$648,048	$3,120,720
Tripping Time	$4,449,567	$1,256,168	$3,193,399
Closure Delay Time	$4,712,640	$453,599	$4,259,041
Total	**$14,210,940**	**$3,228,190**	**$10,982,750**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$17,904,989	$20,023,182	$0
Periodic Major Maintenance	$1,200,000	$600,000	$600,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$20,854,989**	**$22,373,182**	**$600,000**
Accidents			
Accident Repair Cost	**$984,417**	**$184,578**	**$799,839**
Total Annual Benefit			**$12,382,589**

Incremental Cost – BRAZOS RIVER FLOODGATES

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$5,664,171**	**$5,664,171**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$17,904,989	$20,023,182	$2,118,193
Periodic Major Maintenance	$1,200,000	$600,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$20,854,989**	**$22,373,182**	**$2,118,193**
Total Annual Cost			**$7,782,364**
NET BENEFIT			**$4,600,225**
BENEFIT-COST RATIO			**1.59**

Table 77 : Benefit-Cost Analysis, Tentatively Selected Plan, Colorado River Locks - 2.75% Federal Discount Rate

Benefit – COLORADO RIVER LOCKS

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$1,679,180	$835,351	$843,829
Queuing Time	$2,039,660	$284,763	$1,754,898
Tripping Time	$2,390,826	$650,968	$1,739,858
Closure Delay Time	$75,074	$60,730	$14,344
Total	**$6,184,740**	**$1,831,811**	**$4,352,929**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$4,424,376	$2,404,705	$2,019,671
Periodic Major Maintenance	$2,400,000	$1,200,000	$1,200,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$8,574,376**	**$5,354,705**	**$3,219,671**
Accidents			
Accident Repair Cost	**$316,832**	**$0**	**$316,832**
Total Annual Benefit			**$7,889,432**

Incremental Cost – COLORADO RIVER LOCKS

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$1,412,498**	**$1,412,498**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$4,424,376	$2,404,705	$0
Periodic Major Maintenance	$2,400,000	$1,200,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$8,574,376**	**$5,354,705**	**$0**
Total Annual Cost			**$1,412,498**

NET BENEFIT			**$6,476,934**
BENEFIT-COST RATIO			**5.59**

Table 78 : Benefit-Cost Analysis, Tentatively Selected Plan, System Total - 2.75% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,959,145	$1,705,726	$1,253,419
Queuing Time	$5,808,429	$932,811	$4,875,618
Tripping Time	$6,840,393	$1,907,136	$4,933,256
Closure Delay Time	$4,787,714	$514,329	$4,273,385
Total	**$20,395,680**	**$5,060,001**	**$15,335,679**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$22,427,887	$0
Periodic Major Maintenance	$3,600,000	$1,800,000	$1,800,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$27,727,887**	**$1,800,000**
Accidents			
Accident Repair Cost	**$1,301,249**	**$184,578**	**$1,116,671**
Total Annual Benefit			**$18,252,350**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$7,076,669**	**$7,076,669**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$22,427,887	$98,522
Periodic Major Maintenance	$3,600,000	$1,800,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$27,727,887**	**$98,522**
Total Annual Cost			**$7,175,192**

NET BENEFIT			**$11,077,158**
BENEFIT-COST RATIO			**2.54**

Of the costs and benefits displayed in the above tables, only the transit costs were computed within the Monte Carlo analysis in the WLCEN model. The uncertainty in computed benefits within this category is shown in the figures below for the BRFG and the CRL. These distributions do not reflect the entirety of uncertainty around projected benefits.

Figure 17 : Transit Cost Savings, Tentatively Selected Plan, BRFG

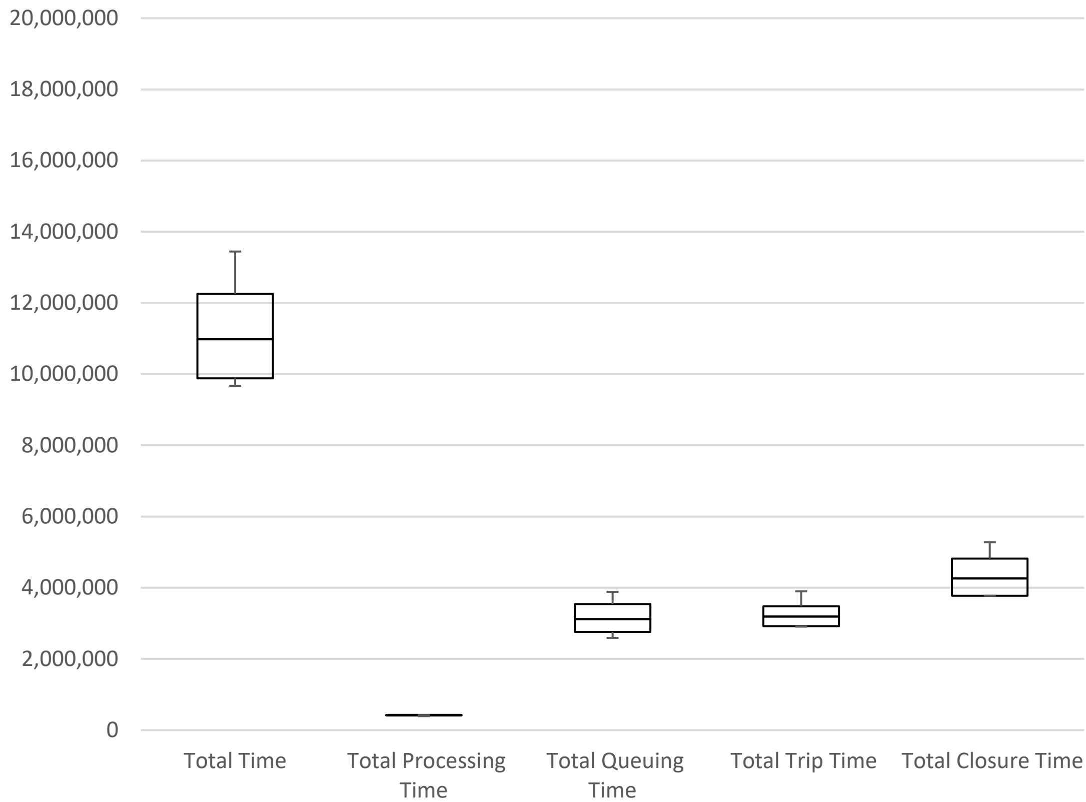
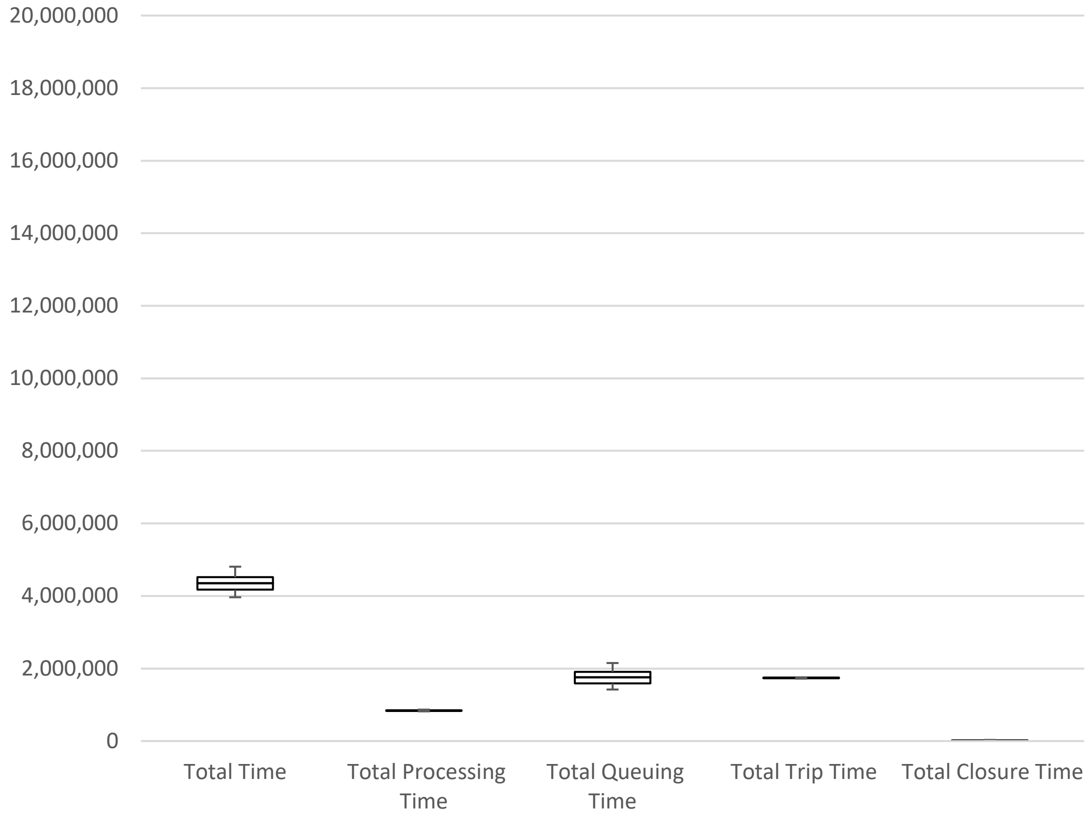


Figure 18 : Transit Cost Savings, Tentatively Selected Plan, CRL



2.6.5.3.1 Sensitivity Analysis

The percentage of tows in the existing condition which by operator policy trip single barges through both projects regardless of river condition or project restriction is a significant input, and one in which not only does reliable data not exist, but one for which two possible data sources do not agree. The LPMS dataset used for a significant number of input parameters suggests the percentages of multiple barge tows which have historically operated this way is 31%, however shipper interviews performed by Martin and Associates indicated that this policy is much more widespread, and the percentage could be as high as 85%. Due to both the uncertainty around this input parameter and its significance is driving model outputs, a sensitivity analysis was performed in which the 85% assumption was used in the baseline condition runs. The result is a significant increase in baseline condition transit times and costs, and as a consequence a significant increase in transit cost savings among alternatives, in all of which the prevalence of this operating policy is expected to reduce to zero. The detailed benefit-cost analysis for the tentatively selected plan given this sensitivity case assumption is shown in Table 79 below.

Table 79 : Benefit - Cost Analysis, Tentatively Selected Plan, Sensitivity Case, System Total - 2.75% Federal Discount Rate

Benefit - SYSTEM TOTAL

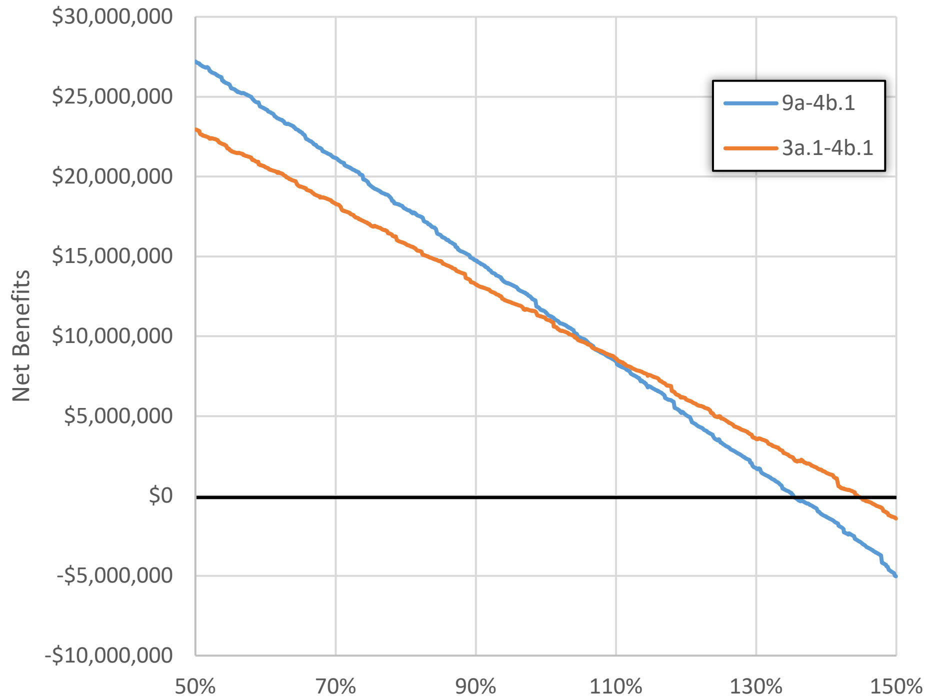
	FWOP	FWP	Benefit
Transit Time			
Processing Time	$4,140,095	$1,705,726	$2,434,369
Queuing Time	$13,875,423	$932,811	$12,942,612
Tripping Time	$13,519,599	$1,907,136	$11,612,463
Closure Delay Time	$6,405,151	$514,329	$5,890,822
Total	**$37,940,268**	**$5,060,001**	**$32,880,267**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$22,427,887	$0
Periodic Major Maintenance	$3,600,000	$1,800,000	$1,800,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$27,727,887**	**$1,800,000**
Accidents			
Accident Repair Cost	**$1,301,249**	**$184,578**	**$1,116,671**
Total Annual Benefit			**$35,796,938**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$7,076,669**	**$7,076,669**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$22,427,887	$98,522
Periodic Major Maintenance	$3,600,000	$1,800,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$27,727,887**	**$98,522**
Total Annual Cost			**$7,175,192**
NET BENEFIT			**$28,621,746**
BENEFIT-COST RATIO			**4.99**

A secondary sensitivity analysis was performed at the TSP milestone to evaluate the significance of sedimentation volumes and related dredge material disposal costs, in particular as it affects plan selection between the TSP and the open channel alternative, which has higher net benefits. To evaluate this, a range of dredge volume multipliers were evaluated, between 50% and 150%. The sedimentation volumes were multiplied by multipliers within this range to evaluate how plan selection would be impacted. The results are shown in the figure below.

Figure 19 – Sedimentation Rate Sensitivity



As shown in the figure, and increase of roughly 8% or results in a change of plan selection from the open channel alternative 9a-4b.1 to 3a.1-4b.1.

2.6.6 ADM Milestone Analysis

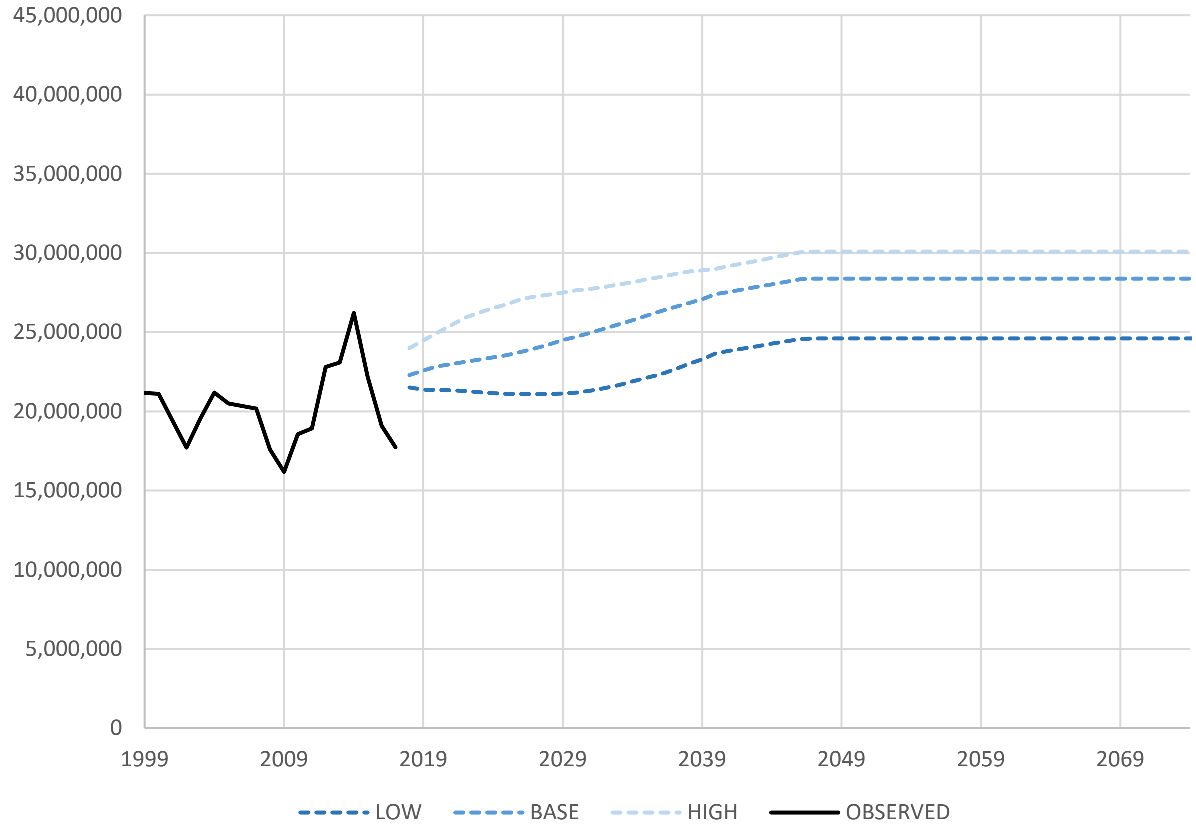
2.6.6.1 Analytical Refinements

2.6.6.1.1 Traffic Forecast

For the TSP milestone model runs, because initial traffic forecasts provided by Martin Associates appeared relatively flat, existing traffic was assumed constant over the analysis period. While this approach led to an underestimation of FWOP waterway costs and thus FWP benefits, the team believed this underestimation would proportionately impact each of the analyzed alternatives and so would not impact the comparison of alternatives or identification of the tentatively selected plan.

For the ADM milestone analysis, traffic forecasts were incorporated into the modeling. The range of forecasts used are illustrated in Figure 17 below.

Figure 20 – Traffic Forecast Scenarios, ADM Milestone Analysis



To incorporate these forecasts into the analysis, each model iteration was expanded to include the full 50 year analysis period. During each iteration, as the simulation progressed through the analysis period, forecasted traffic for the corresponding year was read from traffic forecast input files, and used to adjust simulated vessel traffic in that year in the model. The incorporation of traffic forecasts, as anticipated, led to a somewhat small increase in overall system benefits for the TSP.

Only the base forecast was incorporated into the analysis prior to post-ADM milestone refinements. The results of these base forecast runs are presented below.

2.6.6.1.2 Empty Barge Tow Configuration

From discussions with industry post-TSP milestone it was discovered that two barge tows pushing empty barges typically are configured with the empty barges side-by-side, which depending on the size of barges can result in multiple trips necessary to transit a 75 foot wide project. To account for this, a percentage of empty 2-barge tows transiting upbound and downbound at each project was identified from LPMS data, and these used to inform tow configurations upon creation of sampled tows in the simulation.

2.6.6.1.3 Barge Size Distribution

In the ADM milestone analysis, the simplistic sampling of barge sizes in the TSP milestone analysis was replaced with an empirical distribution of barge sizes taken from LPMS data. This change had virtually no impact on model results, as variations within the normal ranges of barge sizes did not influence the estimated number of trips necessary to transit a project in the vast majority of cases.

2.6.6.1.4 FWOP River Closure Proxy at CRL

Finally, after the TSP milestone discussions within the PDT indicated that existing and future river conditions at the Colorado River crossing would likely represent a far more significant impediment to traffic given an alternative in which gates are removed and thus with them the ability to lock traffic during adverse river conditions. To capture this, the engineering team developed a proxy, given the removal of the river side gates under the TSP alternative, for head differentials at the remaining gates which would necessitate the closure of the project to traffic. River velocities on the Colorado River were found to correlate well with head differentials at the project. A Colorado River velocity of 2.32 mph was assumed to correlate with head differentials at the remaining canal side gates through which traffic would not be able to process.

Table 80 : River Threshold Exceedance Frequency by Project

River Velocity	Operation	Frequency	
		BRFG	CRL
0 - 2 mph	Normal	89.85%	97.21%
2 - 5 mph	Single barge tripping	8.67%	2.50%
5 - 7 mph	Single barge tripping during daylight, closure at night	1.28%	0.28%
> 7 mph	Closure	0.20%	0.00%

Head Differential	Operation	Frequency	
		BRFG	CRL
0 - 0.7 ft	Normal	72.24%	?
0.7 - 1.8 ft	Single barge tripping	21.72%	
> 1.8 ft	Closure	6.04%	N/A*

**Because Colorado can act as a lock during high flow in the channel, it does not close currently due to head differential. It is estimated that Colorado must act as a lock to process traffic due to high flows in the GIWW channel through the project 16.2% of the time, roughly 1 - 2 hours per day on average.*

This assumption change had dramatic impacts on modeled system benefits, as will be discussed later.

2.6.6.2 Baseline Condition

2.6.6.2.1 Transit Cost

As with the previous model runs, total annual transit times are output from the WLCEN model, and from these annual transit costs are estimated. The box-and-whisker plots shown below as Figure 12 and Figure 13 illustrate the distribution of possible baseline condition transit costs for both projects, based on the ADM milestone model runs. In both of these figures, the box represents the mean (middle line) and 25th and 75th percentiles, while the whiskers represent the 5th and 95th percentiles. The mean is shown as the central line in each box rather than the more common median, or 50th percentile, as the mean value from output distributions is used as the expected value for this analysis, and thus is the basis of all benefit cost analysis.

Figure 21 : Transit Cost Uncertainty Distribution, Existing Condition, Brazos River Floodgates

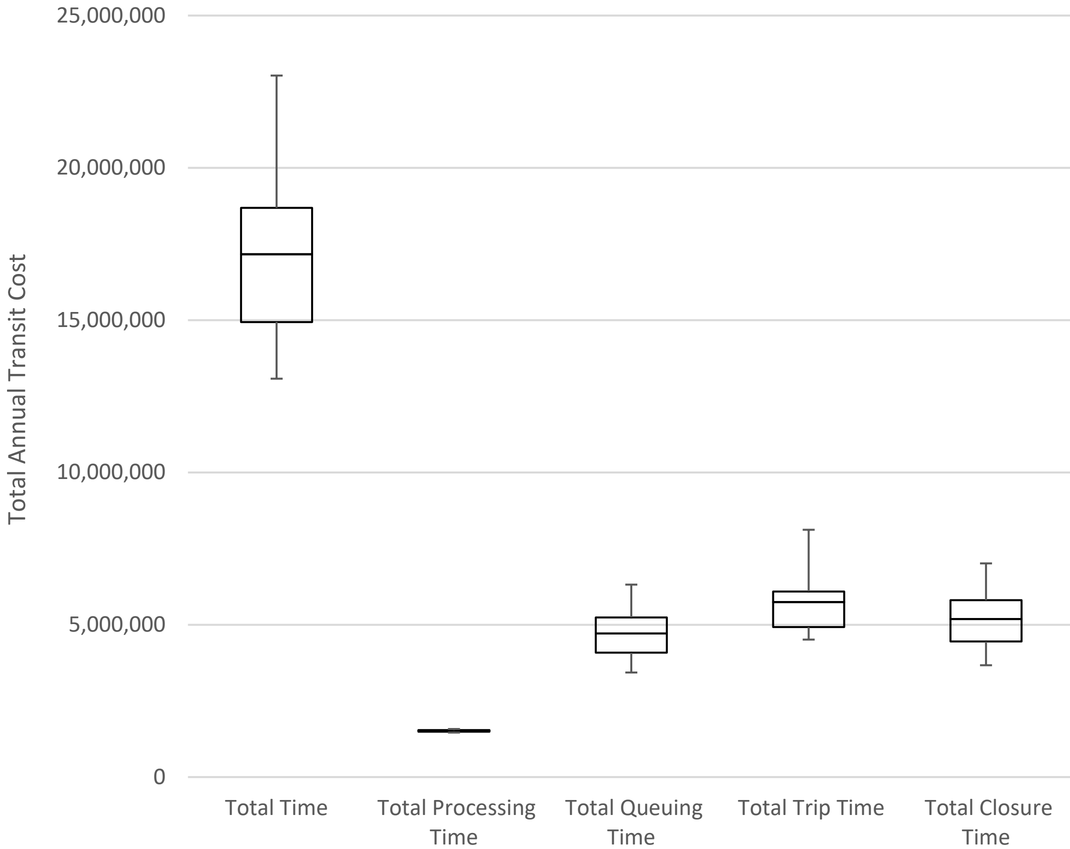
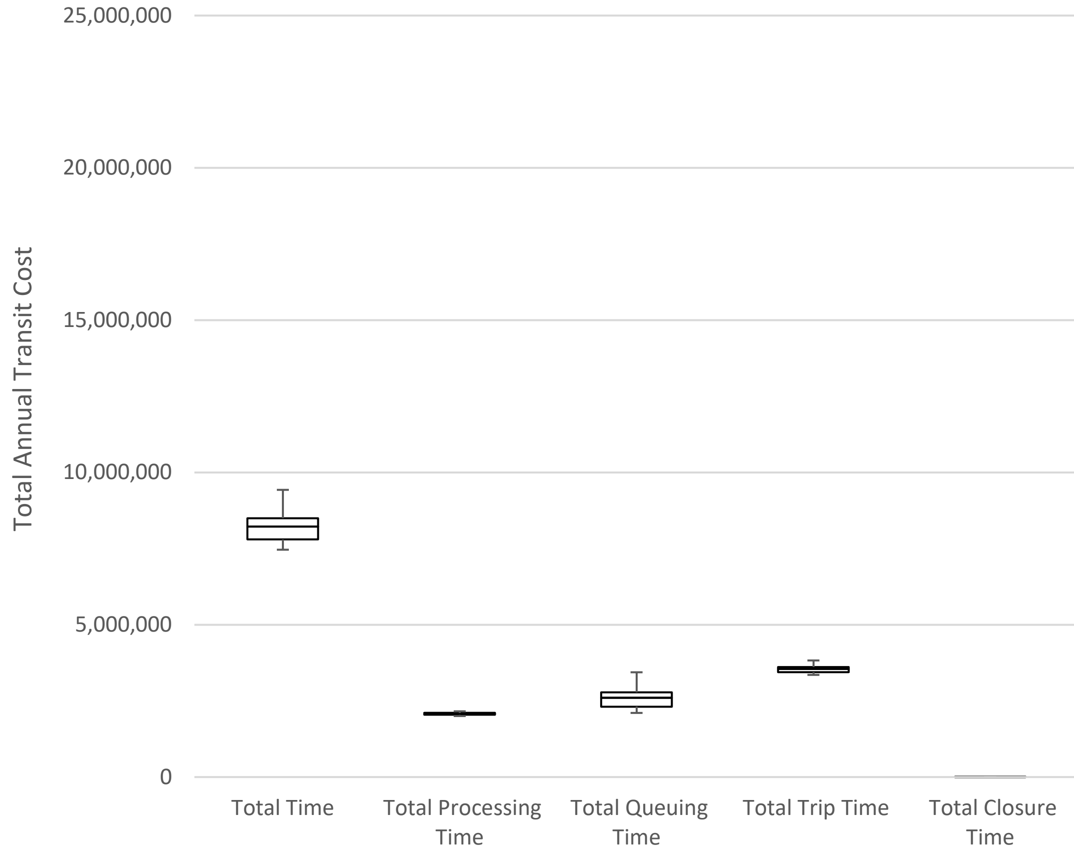


Figure 22 : Transit Cost Uncertainty Distribution, Existing Condition, Colorado River Locks



The mean values for each of these categories are shown for both projects and for the combined system in below.

Table 81 : Existing Condition Mean Transit Costs

	Brazos River Floodgates	Colorado River Locks	System
Processing Time	$1,517,206	$2,075,556	$3,592,762
Queuing Time	$4,718,047	$2,605,679	$7,323,726
Tripping Time	$5,744,345	$3,545,094	$9,289,440
Closure Delay Time	$5,186,089	$385	$5,186,474
Total	$17,165,688	$8,226,714	$25,392,402

Again, as in the TSP milestone analysis, transit costs are significantly higher at the BRFG than at the CRL. Average system transit cost is somewhat higher than in the previous set of runs, due largely to the incorporation forecasted traffic growth over the analysis period. Additional modeling changes, as previously discussed, include the assumption that 2 barge tows moving empty barges are configured side-by-side and in the FWOP will need to trip at both projects, and the inclusion of an empirical barge size distribution.

2.6.6.2.2 Accident Repair Cost

Accident repair costs were evaluated in the same manner as in the TSP milestone analysis. For the ADM milestone model runs, the baseline condition annual accident repair cost is $1,325,590 at the Brazos River Floodgates, and $540,632 at the Colorado River Locks.

2.6.6.2.3 OMRR&R

OMRR&R costs remain largely the same as in the previous, TSP milestone model runs.

2.6.6.2.3.1 Normal O&M

Normal O&M costs used in the economic analysis were fixed values provided by district operations. For both projects, an assumed annual normal O&M cost of $1,750,000 was assumed.

2.6.6.2.3.2 Maintenance Dredging

Maintenance dredging cost assumptions were not adjusted from those used during the TSP milestone analysis.

2.6.6.2.3.3 Periodic Major Maintenance

Periodic major maintenance costs were also not adjusted from those used during the TSP milestone analysis.

2.6.6.2.4 Total Baseline Condition Cost

The total baseline condition costs for the analyzed system include costs of all above categories at both the BRFG and the CRL. The tables below itemize the total annualized costs for each category, for both projects separately (Table 52 and Table 53) and for the system as a whole (Table 54).

Table 82 : Total Baseline Condition Costs, Brazos River Floodgates - 2.75% Federal Discount Rate

Transit Time	
Processing Time	$1,483,321
Queuing Time	$4,293,966
Tripping Time	$5,465,301
Closure Delay Time	$4,926,700
Total	**$16,169,288**
Accidents	
Accident Repair Cost	**$1,325,590**
O&M	
Normal O&M	$1,750,000
Maintenance Dredging	$17,904,989
Periodic Major Maintenance	$1,200,000
Maintenance Closure Impact Costs	$0
Total	**$20,854,989**
Total Annual Benefit	**$38,349,867**

Note: 2.75% - 2018 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

Table 83 : Total Baseline Condition Costs, Colorado River Locks - 2.75% Federal Discount Rate

Transit Time	
Processing Time	$2,029,050
Queuing Time	$2,371,199
Tripping Time	$3,463,886
Closure Delay Time	$355
Total	**$7,864,491**
Accidents	
Accident Repair Cost	**$540,632**
O&M	
Normal O&M	$1,750,000
Maintenance Dredging	$4,424,376
Periodic Major Maintenance	$2,400,000
Maintenance Closure Impact Costs	$0
Total	**$8,574,376**
Total Annual Benefit	**$16,979,498**

Note: 2.75% - 2018 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

Table 84 : Total Baseline Condition Costs, System Total - 2.75% Federal Discount Rate

Transit Time	
Processing Time	$3,512,371
Queuing Time	$6,665,165
Tripping Time	$8,929,187
Closure Delay Time	$4,927,055
Total	**$24,033,779**
Accidents	
Accident Repair Cost	**$1,866,221**
O&M	
Normal O&M	$3,500,000
Maintenance Dredging	$22,329,365
Periodic Major Maintenance	$3,600,000
Maintenance Closure Impact Costs	$0
Total	**$29,429,365**
Total Annual Benefit	**$55,329,365**

Note: 2.75% - 2018 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

2.6.6.3 Evaluation of Alternatives

After the selection of the TSP, FWP modeling of alternatives was confined primarily to the tentatively selected plan itself, adjustments or modifications to the TSP, and sensitivity scenarios. For the ADM milestone model runs only two FWP scenarios were analyzed, the TSP (3a.1-4b.1), as well as a Brazos River only alternative with no action at Colorado (3a.1-EC).

Table 85 : Alternative Analysis - 2.75% Federal Discount Rate

Alt ID	Brazos River Floodgates	Colorado River Locks	Total Annual Cost	Total Annual Benefit	Net Benefit	Benefit-Cost Ratio
EC-EC	Existing	Existing	-	-	-	-
3a.1-4b.1	125' Gate East/Open West	Inner Gate Removal	9,199,000	(13,997,000)	(23,197,000)	(1.5)
3a.1-EC	125' Gate East/Open West	Existing	**8,766,000**	**14,713,000**	**5,947,000**	**1.7**

Note: 2.75% - 2018 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

The previously identified TSP benefit-cost ratio fell to -1.5, that is $1.5 of *disbenefit* for every $1 invested, due entirely to the inability to lock traffic during adverse river conditions at the Colorado River, given the removal of the riverside gates. This result will be described in greater detail in the sections below.

Because of this outcome, the TSP alternative component at the Brazos River (removal of the West gate, replacement of the East gate with a 125’ gate), combined with no action at the Colorado River, was evaluated as a potential replacement for the previously identified TSP.

2.6.6.3.1 Transit Cost

As with the baseline condition, transit costs for each alternative condition were evaluated using the WLCEN model. Transit costs across the four time categories; processing, tripping, queuing, and closure delay, were estimated for each alternative condition by altering the input parameters which define the system to reflect the prevailing condition under these alternatives. The total vessel hours and transit costs for each alternative are shown in Table 56 below. Applied vessel operating costs were assumed the same between the baseline and all alternative conditions.

Table 86 : Transit Cost, Alternative Conditions

Alt ID	Brazos River Floodgates	Colorado River Locks	Processing Time	Queuing Time	Tripping Time	Closure Delay Time
EC-EC	Existing	Existing	3,512,371	6,665,165	8,929,187	4,927,055
3a.1-4b.1	125' Gate East/Open West	Inner Gate Removal	2,055,660	8,037,911	22,929,961	8,454,696
3a.1-EC	125' Gate East/Open West	Existing	2,975,837	2,739,101	4,811,160	502,948

Note: 2.75% - 2018 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

The table illustrates that for the TSP, queuing cost, tripping cost, and closure delay cost all increase relative to the existing condition. This increase is driven entirely by the Colorado River Locks, where removal of gates leads to a net increase in the percentage of a given year that project will be closed to traffic due to river conditions. The closure delay time nearly doubles relative to the FWOP condition, while tripping time nearly triples. The alternative with no action at the Colorado River, 3a.1-EC, shows a net decrease in transit cost across all categories.

2.6.6.3.2 Accident Repair Cost

Accident repair cost was calculated in the same manner as in the baseline condition. Accident frequencies from the WLCEN model runs were multiplied by the average cost per accident from the accident history.

2.6.6.3.3 OMRR&R

Operation and maintenance costs were evaluated for each alternative condition in the same manner as in the FWOP condition, and assumptions remain the same as for the TSP milestone analysis.

2.6.6.3.4 Total Baseline Condition Cost

The calculation of alternative cost is shown for each alternative in the tables below. As with benefits, costs associated with each alternative are comprised of the net increase in cost among all categories between the alternative condition and the without-project condition.

Table 87 : Cost Calculation - 2.75% Federal Discount Rate

	3a.1	4b.1	Total
Construction Cost			
Total First Cost	**168,850,000**	**63,149,000**	**231,999,000**
Interest During Construction			
Construction Duration	2.25	1.75	2
Interest During Construction	**10,627,571**	**3,070,315**	**13,697,886**
Annualized Construction Cost			
Annualized First Cost	6,254,359	2,339,097	8,593,456
Annualized IDC	393,655	113,727	507,382
Total	**6,648,014**	**2,452,824**	**9,100,839**
Operation and Maintenance			0
Normal O&M	1,750,000	1,750,000	3,500,000
Maintenance Closure Impact Costs	0	0	0
Periodic Major Maintenance	600,000	1,200,000	1,800,000
Maintenance Dredging			
Freeport	1,607,341	0	1,607,341
East of Brazos to Freeport	6,510,804	0	6,510,804
Brazos Channel & Crossing	3,847,911	0	3,847,911
West of Brazos	8,057,127	0	8,057,127
East of CRL to GIWW	0	828,968	828,968
CRL Channel and Crossing	0	746,768	746,768
West of CRL	0	828,968	828,968
Total	**22,373,182**	**5,354,705**	**27,727,887**
Total Annual Cost	**29,021,197**	**7,807,529**	**36,828,726**

2.6.6.3.5 Alternative Cost-Benefit Analysis

The system total benefit cost analysis of each of the analyzed alternatives are shown in the tables below.

Table 88 : Benefit-Cost Analysis, 3a.1-4b.1, BRFG - 2.75% Federal Discount Rate

Benefit - BRAZOS RIVER FLOODGATES

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$1,483,321	$947,669	$535,652
Queuing Time	$4,293,966	$721,591	$3,572,375
Tripping Time	$5,465,301	$1,413,217	$4,052,084
Closure Delay Time	$4,926,700	$516,576	$4,410,124
Total	**$16,169,288**	**$3,599,053**	**$12,570,235**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$17,904,989	$20,023,182	$0
Periodic Major Maintenance	$1,200,000	$600,000	$600,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$20,854,989**	**$22,373,182**	**$600,000**
Accidents			
Accident Repair Cost	**$1,325,590**	**$219,185**	**$1,106,405**
Total Annual Benefit			**$14,276,640**

Incremental Cost - BRAZOS RIVER FLOODGATES

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$6,648,014**	**$6,648,014**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$17,904,989	$20,023,182	$2,118,193
Periodic Major Maintenance	$1,200,000	$600,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$20,854,989**	**$22,373,182**	**$2,118,193**
Total Annual Cost			**$8,766,207**
NET BENEFIT			**$5,510,433**
BENEFIT-COST RATIO			**1.63**

Table 89 : Benefit-Cost Analysis, 3a.1-4b.1, CRL - 2.75% Federal Discount Rate

Benefit - COLORADO RIVER LOCKS

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,029,050	$1,107,991	$921,059
Queuing Time	$2,371,199	$7,316,321	-$4,945,121
Tripping Time	$3,463,886	$21,516,743	-$18,052,857
Closure Delay Time	$355	$7,938,120	-$7,937,765
Total	**$7,864,491**	**$37,879,175**	**-$30,014,684**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$4,424,376	$2,404,705	$2,019,671
Periodic Major Maintenance	$2,400,000	$1,200,000	$1,200,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$8,574,376**	**$5,354,705**	**$3,219,671**
Accidents			
Accident Repair Cost	**$540,632**	**$0**	**$540,632**
Total Annual Benefit			**-$26,254,382**

Incremental Cost - COLORADO RIVER LOCKS

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$2,452,824**	**$2,452,824**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$4,424,376	$2,404,705	$0
Periodic Major Maintenance	$2,400,000	$1,200,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$8,574,376**	**$5,354,705**	**$0**
Total Annual Cost			**$2,452,824**

NET BENEFIT			**-$28,707,206**
BENEFIT-COST RATIO			**-10.70**

Table 90 : Benefit-Cost Analysis, 3a.1-4b.1, System Total - 2.75% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$3,512,371	$2,055,660	$1,456,711
Queuing Time	$6,665,165	$8,037,911	-$1,372,746
Tripping Time	$8,929,187	$22,929,961	-$14,000,773
Closure Delay Time	$4,927,055	$8,454,696	-$3,527,641
Total	**$24,033,779**	**$41,478,229**	**-$17,444,450**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$22,427,887	$0
Periodic Major Maintenance	$3,600,000	$1,800,000	$1,800,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$27,727,887**	**$1,800,000**
Accidents			
Accident Repair Cost	**$1,866,221**	**$219,185**	**$1,647,037**
Total Annual Benefit			**-$13,997,413**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$9,100,839**	**$9,100,839**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$22,427,887	$98,522
Periodic Major Maintenance	$3,600,000	$1,800,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$27,727,887**	**$98,522**
Total Annual Cost			**$9,199,361**
NET BENEFIT			**-$23,196,773**
BENEFIT-COST RATIO			**-1.52**

Table 91 : Benefit-Cost Analysis, 3a.1-EC, BRFG - 2.75% Federal Discount Rate

Benefit - BRAZOS RIVER FLOODGATES

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$1,483,321	$947,003	$536,319
Queuing Time	$4,293,966	$630,583	$3,663,383
Tripping Time	$5,465,301	$1,353,473	$4,111,828
Closure Delay Time	$4,926,700	$502,630	$4,424,070
Total	**$16,169,288**	**$3,433,688**	**$12,735,599**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$17,904,989	$20,023,182	$0
Periodic Major Maintenance	$1,200,000	$600,000	$600,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$20,854,989**	**$22,373,182**	**$600,000**
Accidents			
Accident Repair Cost	**$1,325,590**	**$219,157**	**$1,106,433**
Total Annual Benefit			**$14,442,032**

Incremental Cost - BRAZOS RIVER FLOODGATES

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$6,648,014**	**$6,648,014**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$17,904,989	$20,023,182	$2,118,193
Periodic Major Maintenance	$1,200,000	$600,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$20,854,989**	**$22,373,182**	**$2,118,193**
Total Annual Cost			**$8,766,207**

NET BENEFIT			**$5,675,825**
BENEFIT-COST RATIO			**1.65**

Table 92 : Benefit-Cost Analysis, 3a.1-EC, CRL - 2.75% Federal Discount Rate

Benefit - COLORADO RIVER LOCKS

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,029,050	$2,028,835	$216
Queuing Time	$2,371,199	$2,108,518	$262,681
Tripping Time	$3,463,886	$3,457,686	$6,200
Closure Delay Time	$355	$318	$37
Total	**$7,864,491**	**$7,595,357**	**$269,134**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$4,424,376	$4,424,376	$0
Periodic Major Maintenance	$2,400,000	$2,400,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$8,574,376**	**$8,574,376**	**$0**
Accidents			
Accident Repair Cost	**$540,632**	**$538,684**	**$1,947**
Total Annual Benefit			**$271,081**

Table 93 : Benefit-Cost Analysis, 3a.1-EC, System Total - 2.75% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$3,512,371	$2,975,837	$536,534
Queuing Time	$6,665,165	$2,739,101	$3,926,065
Tripping Time	$8,929,187	$4,811,160	$4,118,028
Closure Delay Time	$4,927,055	$502,948	$4,424,107
Total	**$24,033,779**	**$11,029,046**	**$13,004,733**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$24,447,558	$0
Periodic Major Maintenance	$3,600,000	$3,000,000	$600,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$30,947,558**	**$600,000**
Accidents			
Accident Repair Cost	**$1,866,221**	**$757,841**	**$1,108,380**
Total Annual Benefit			**$14,713,113**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$6,648,014**	**$6,648,014**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$22,329,365	$24,447,558	$2,118,193
Periodic Major Maintenance	$3,600,000	$3,000,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$29,429,365**	**$30,947,558**	**$2,118,193**
Total Annual Cost			**$8,766,207**

NET BENEFIT			**$5,946,906**
BENEFIT-COST RATIO			**1.68**

Figure 23 : Transit Cost Savings, 3a.1-4b.1, BRFG

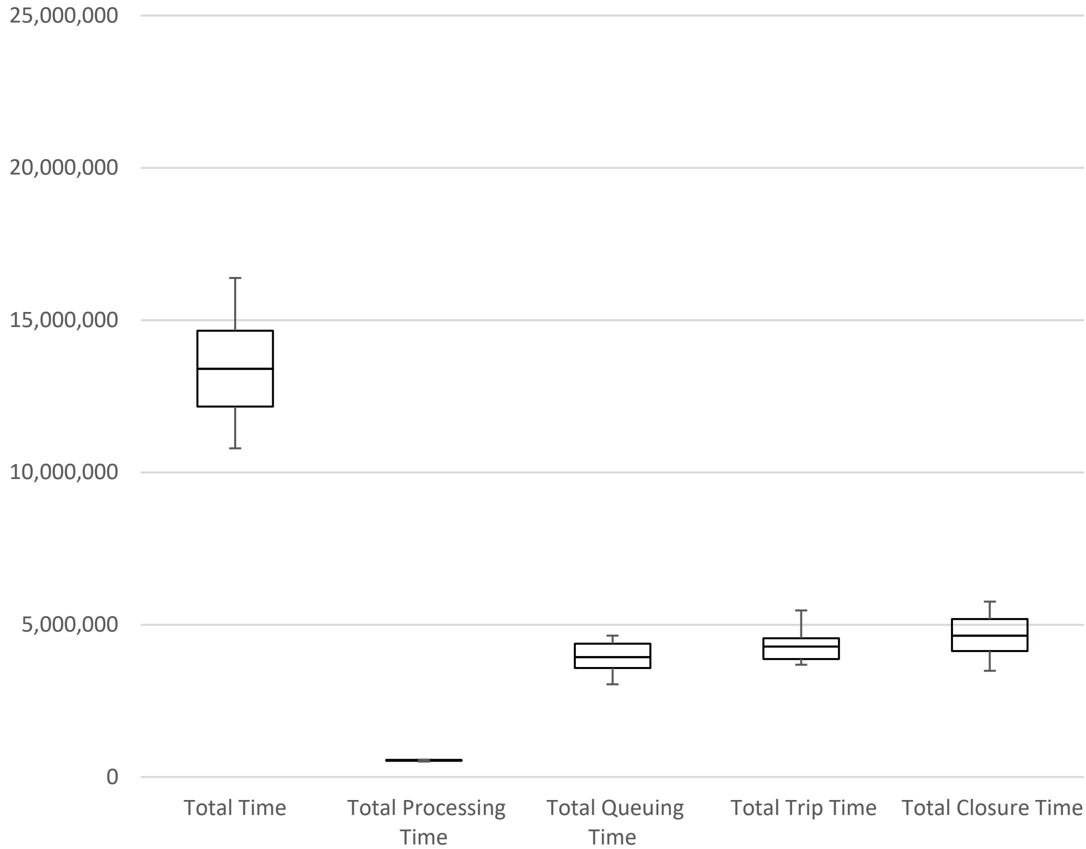
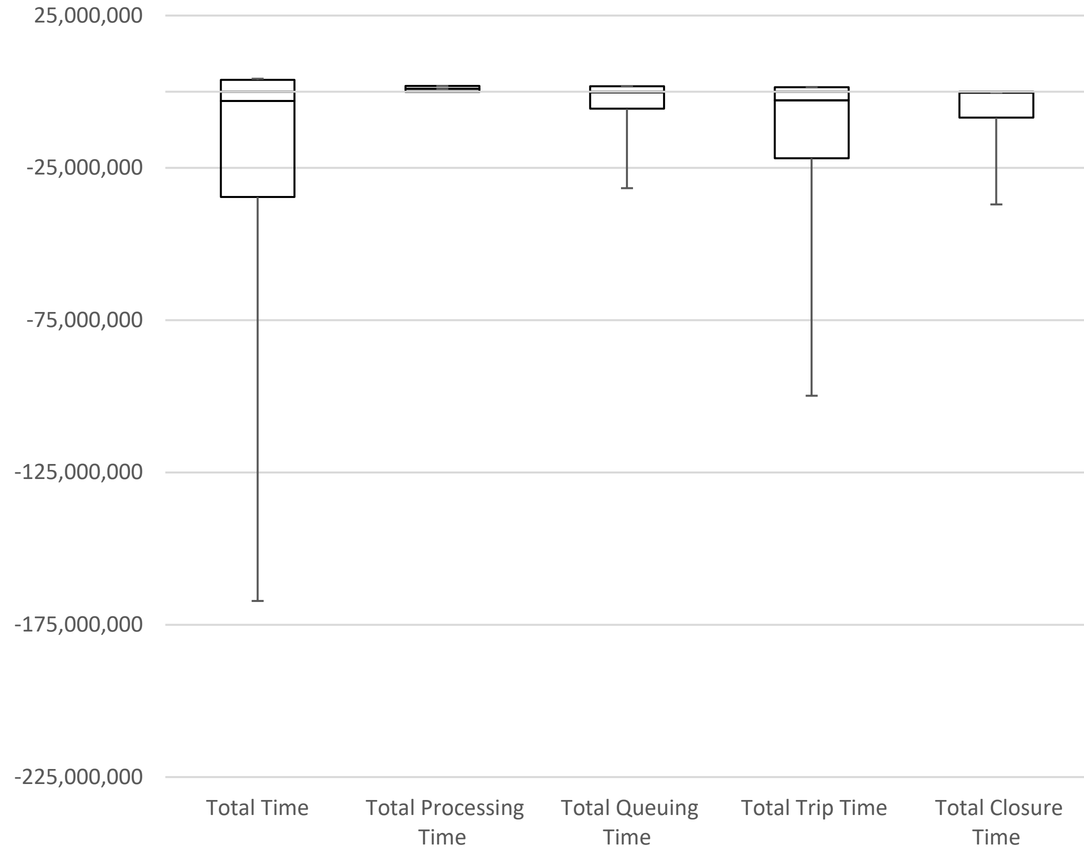


Figure 24 : Transit Cost Savings, 3a.1-4b.1, CRL



2.6.7 Post-ADM Milestone Analysis

2.6.7.1 Analytical Refinements

Following the ADM milestone analysis and the impacts on the feasibility of the identified TSP of river closures at Colorado given the inability to operate the project as a lock and process traffic during adverse river conditions, the TSP was reformulated to include the same features as the previously identified plan, with the additional replacement of the canal side gates at the Colorado River with 125' sector gates. The wider gate opening was intended to alleviate the velocity and head differential issues that would necessitate project closures without the ability to operate as a lock. The engineering team believed the wider gate opening would almost entirely mitigate velocities through the gates that would impede traffic.

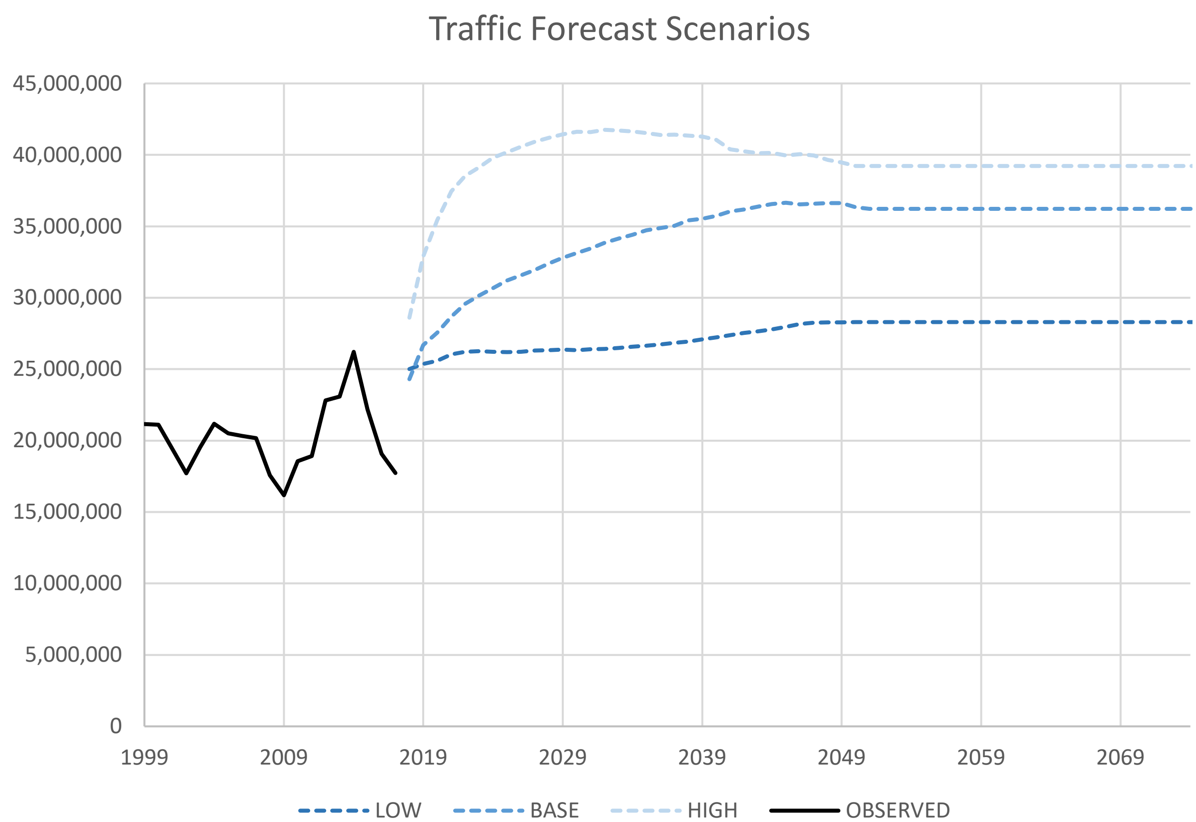
The other three major analytical refinements relative to the ADM milestone analysis were revised traffic forecasts, a revised proxy for closure thresholds at Colorado, and revised assumptions regarding dredge material disposal costs. These refinements will be described in greater detail below. Additionally cost estimates were updated by the engineering team, and per the signing of EGM 19-01 on 17 October 2018, the federal discount rate was revised from the 2.75% used in previous analyses to 2.875%. The post-ADM model runs and all subsequent analysis has been performed using the FY 2019 federal discount rate of 2.875%, and at the FY19 price level.

2.6.7.1.1 Traffic Forecast

Prior to the initial set of ADM milestone WLCEN model runs, per SWD review comments, alternate regional traffic forecast scenarios were developed which assumed a much more aggressive growth of traffic over the analysis period, driven in large part based on assumptions regarding the transportation of shale oil. This is described in greater detail in Addendum 1.

The PDT elected to use these revised regional forecasts over those used in the ADM milestone runs. Because of these adjustments, the model was re-run post ADM milestone for the TSP and the TSP alternate with no action at Colorado. For this post-ADM milestone analysis, each FWP scenario as well as the baseline FWOP scenario were analyzed at 5 separate forecast scenarios; the base forecast scenario, a high sensitivity forecast scenario, a low forecast scenario, a no traffic growth scenario, and a no traffic growth after 20 years scenario. The low, base, and high forecasts are illustrated in Figure 17 below.

Figure 25 – Traffic Forecast Scenarios, ADM Milestone Analysis



2.6.7.1.2 FWOP River Closure Proxy at CRL

For the ADM milestone analysis, a threshold of river velocity on the Colorado River was used as a proxy for adverse river conditions that would close the project without the ability to lock traffic. For the post-ADM milestone runs, a proxy threshold based on GIWW channel velocity was used in place of this previous proxy. Industry representatives had communicated to the study team that velocity through the gates would represent the greatest obstacle to processing traffic during adverse river conditions given removal of the riverside gates. To test the impact of this revised proxy, the previous TSP with 75' canal side gates at Colorado was reanalyzed. The results of this reanalysis are presented in the sensitivity section below.

2.6.7.1.3 Dredge Material Disposal Cost

The other notable change in modeling assumptions post ADM was the estimation of costs necessary to expand and maintain existing upland disposal site capacity for future dredge material disposal. In the TSP and ADM milestone analyses, these costs were estimated as biannual fixed investment costs, however upon review by the PDT, these costs were revisited and ultimately replaced with an additional unit cost per cubic yard of disposed material. Additionally the 1:1 ratio of dredge material disposed to reduction is disposal site capacity was abandoned in favor of a 1:3 ratio, resulting in depletion of existing dredge material disposal sooner in the analysis period.

2.6.7.2 Baseline Condition

2.6.7.2.1 Transit Cost

As with the previous model runs, total annual transit times are output from the WLCEN model, and from these annual transit costs are estimated. The box-and-whisker plots shown below as Figure 12 and Figure 13 illustrate the distribution of possible baseline condition transit costs for both projects, based on the post-ADM milestone model runs. In both of these figures, the box represents the mean (middle line) and 25th and 75th percentiles, while the whiskers represent the 5th and 95th percentiles. The mean is shown as the central line in each box rather than the more common median, or 50th percentile, as the mean value from output distributions is used as the expected value for this analysis, and thus is the basis of all benefit cost analysis.

Figure 26 : Transit Cost Uncertainty Distribution, Existing Condition, Brazos River Floodgates – 2.875% Discount Rate

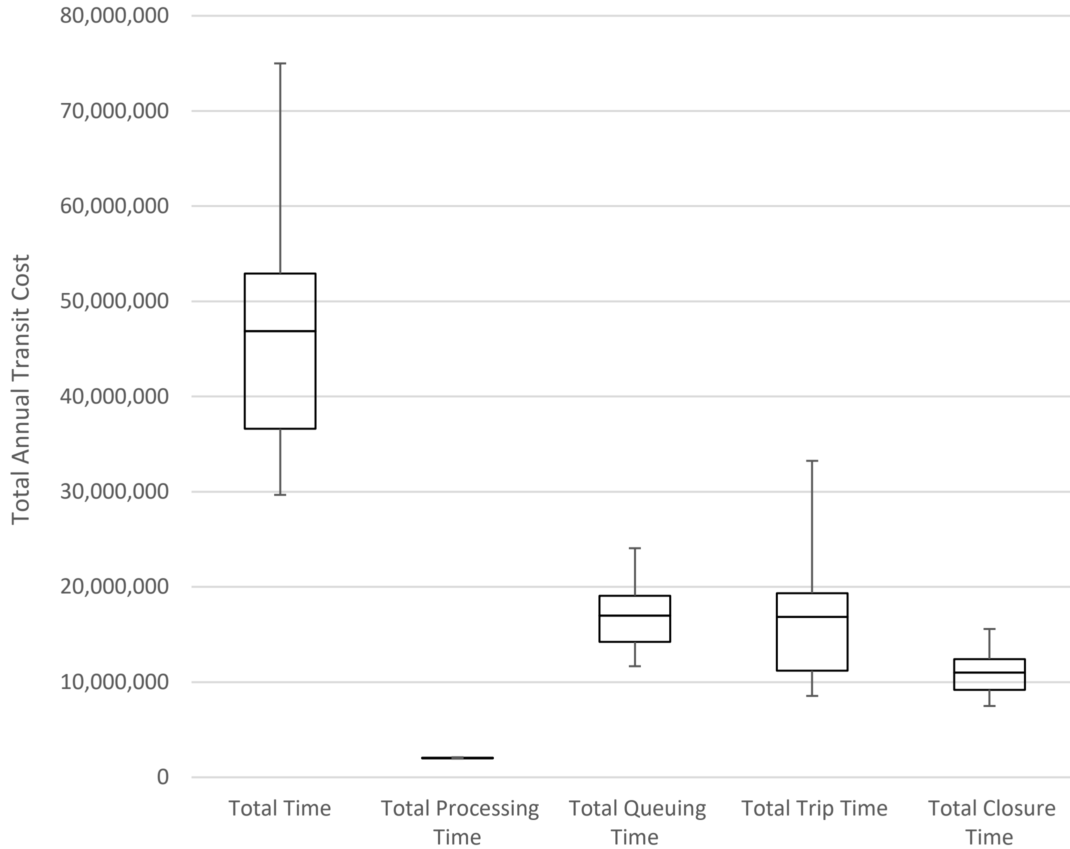
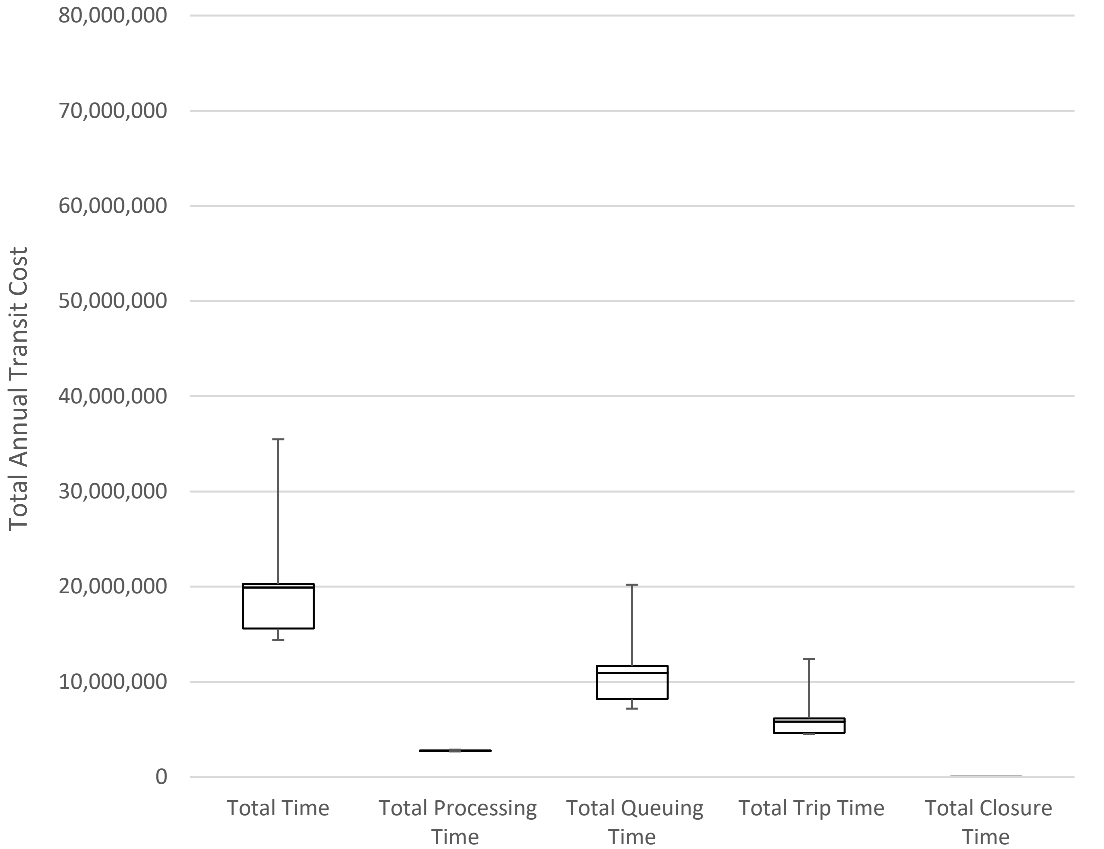


Figure 27 : Transit Cost Uncertainty Distribution, Existing Condition, Colorado River Locks – 2.875% Discount Rate



The mean values for each of these categories are shown for both projects and for the combined system in below.

Table 94 : Existing Condition Mean Transit Costs – 2.875% Discount Rate

	Brazos River Floodgates	Colorado River Locks	System
Processing Time	$2,030,137	$2,776,152	$4,806,289
Queuing Time	$16,978,927	$10,947,867	$27,926,794
Tripping Time	$16,850,481	$6,166,779	$23,017,260
Closure Delay Time	$11,003,311	$1,473	$11,004,785
Total	$46,862,856	$19,892,271	$66,755,127

For the post-ADM model runs, system transit costs are significantly higher than in previous runs. The Post-ADM total system transit costs are 2.6x higher than those for the ADM model runs using the previous traffic forecasts. This is due largely to the increased congestion effects (tripping and queuing time) of the additional traffic, but also to a lesser degree due to increased accident risk resulting from the additional traffic.

2.6.7.2.2 Accident Repair Cost

Accident repair costs were evaluated in the same manner as in the TSP milestone analysis. For the ADM milestone model runs, the baseline condition annual accident repair cost is $1,768,274 at the Brazos River Floodgates, and $720,282 at the Colorado River Locks.

2.6.7.2.3 OMRR&R

OMRR&R costs remain largely the same as in the previous, TSP milestone model runs.

2.6.7.2.3.1 Normal O&M

Normal O&M costs used in the economic analysis were fixed values provided by district operations. For both projects, an assumed annual normal O&M cost of $1,750,000 was assumed.

2.6.7.2.3.2 Maintenance Dredging

Maintenance dredging costs were revisited for the post-ADM model runs, and upland disposal capacity costs converted from biannual fixed investments to additional unit cost. The result of this adjustment is an overall decrease in maintenance dredging costs relative to previous model runs. A comparison between the ADM milestone and post-ADM milestone dredging costs is shown below.

Table 95 : Maintenance Dredging Cost Comparison – 2.875% Discount Rate

	ADM Milestone		Post-ADM Milestone	
Maintenance Dredging				
Freeport	$1,519,647	$0	$2,375,897	$0
East of Brazos to Freeport	$6,456,504	$0	$5,984,450	$0
Brazos Channel & Crossing	$3,219,189	$0	$1,352,582	$0
West of Brazos	$6,709,649	$0	$6,922,401	$0
East of CRL to GIWW	$0	$1,434,506	$0	$1,106,393
CRL Channel and Crossing	$0	$1,555,364	$0	$986,150
West of CRL	$0	$1,434,506	$0	$1,139,739

2.6.7.2.3.3 Periodic Major Maintenance

Periodic major maintenance costs were also not adjusted from those used during the ADM milestone analysis.

2.6.7.2.4 Total Baseline Condition Cost

The total baseline condition costs for the analyzed system include costs of all above categories at both the BRFG and the CRL. The tables below itemize the total annualized costs for each category, for both projects separately (Table 52 and Table 53) and for the system as a whole (Table 54).

Table 96 : Total Baseline Condition Costs, Brazos River Floodgates - 2.875% Discount Rate

Transit Time	
Processing Time	$2,030,137
Queuing Time	$16,978,927
Tripping Time	$16,850,481
Closure Delay Time	$11,003,311
Total	**$46,862,856**
Accidents	
Accident Repair Cost	**$1,768,274**
O&M	
Normal O&M	$1,750,000
Maintenance Dredging	$16,635,331
Periodic Major Maintenance	$1,200,000
Maintenance Closure Impact Costs	$0
Total	**$19,585,331**
Total Annual Benefit	**$68,216,461**

Note: 2.875% - 2019 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

Table 97 : Total Baseline Condition Costs, Colorado River Locks - 2.875% Discount Rate

Transit Time	
Processing Time	$2,776,152
Queuing Time	$10,947,867
Tripping Time	$6,166,779
Closure Delay Time	$1,473
Total	**$19,892,271**
Accidents	
Accident Repair Cost	**$720,282**
O&M	
Normal O&M	$1,750,000
Maintenance Dredging	$3,232,283
Periodic Major Maintenance	$2,400,000
Maintenance Closure Impact Costs	$0
Total	**$7,382,283**
Total Annual Benefit	**$27,994,836**

Note: 2.875% - 2019 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

Table 98 : Total Baseline Condition Costs, System Total - 2.875% Discount Rate

Transit Time	
Processing Time	$4,806,289
Queuing Time	$27,926,794
Tripping Time	$23,017,260
Closure Delay Time	$11,004,785
Total	**$66,755,127**
Accidents	
Accident Repair Cost	**$2,488,556**
O&M	
Normal O&M	$3,500,000
Maintenance Dredging	$19,867,614
Periodic Major Maintenance	$3,600,000
Maintenance Closure Impact Costs	$0
Total	**$26,967,614**
Total Annual Benefit	**$96,211,297**

Note: 2.875% - 2019 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

2.6.7.3 Evaluation of Alternatives

For the post-ADM milestone model runs the same scenarios analyzed for the ADM milestone were evaluated. Additional scenarios were analyzed as sensitivity scenarios; these are detailed in the sensitivity analysis section below.

Table 99 : Alternative Analysis - 2.875% Federal Discount Rate

Alt ID	Brazos River Floodgates	Colorado River Locks	Total Annual Cost	Total Annual Benefit	Net Benefit	Benefit-Cost Ratio
EC-EC	Existing	Existing	-	-	-	-
3a.1-4b.1 rev.	125' Gate East/Open West	Inner Gate Removal/125' Canal Side	**18,487,000**	**60,090,000**	**41,603,000**	**3.3**
3a.1-EC	125' Gate East/Open West	Existing	**8,773,000**	**46,220,000**	**37,447,000**	**5.3**

Note: 2.875% - 2019 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

Due to both the refinement of the TSP to include replacement of the canal side gates at the Colorado River with 125’ sector gates and to the revised traffic forecasts, the TSP of alternative 3a.1 at the Brazos River, and 4b.1 at the Colorado River again has a benefit-cost ratio of over unity. The revised traffic forecasts result in a pronounced growth in FWOP transit cost, due to increased system congestion as well as accident risk, and this increase in turn yields higher system benefits of analyzed alternatives. This increase in benefit is sufficient to more than cover the increase in annualized construction cost resulting from the additional 125’ gates. The addition of these gates almost entirely mitigates the river related closure costs seen in the ADM milestone model runs. While the 3a.1 at Brazos/no action at

Colorado alternative yields a higher benefit-cost ratio, the revised 3a.1-4b.1 maximized net benefits, as shown in Table 55 above.

2.6.7.3.1 Transit Cost

As with previous iterations of the analysis, total vessel hours and transit costs for each alternative are shown in Table 56 below. Applied vessel operating costs were assumed the same between the baseline and all alternative conditions, and match those used in the previous analyses.

Table 100 : Transit Cost, Alternative Conditions – 2.875% Discount Rate

Alt ID	Brazos River Floodgates	Colorado River Locks	Processing Time	Queuing Time	Tripping Time	Closure Delay Time
EC-EC	Existing	Existing	4,806,289	27,926,794	23,017,260	11,004,785
3a.1-4b.1 rev.	125' Gate East/Open West	Inner Gate Removal/125' Canal Side	2,292,057	3,007,883	4,027,640	1,350,510
3a.1-EC	125' Gate East/Open West	Existing	3,949,581	10,508,786	7,407,644	761,975

Note: 2.875% - 2019 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

Unlike the ADM milestone analysis, both analyzed system-level alternatives result in significant reductions in system transit costs across all categories. The biggest differences between the alternatives are the additional reductions in queuing and tripping time for the TSP, relative to 3a1-EC. These are due in large part to the wider channel at Colorado, which allows the majority of tows to transit the crossing without tripping.

2.6.7.3.2 Accident Repair Cost

Accident repair cost was calculated in the same manner as in the baseline condition. Accident frequencies from the WLCEN model runs were multiplied by the average cost per accident from the accident history.

2.6.7.3.3 OMRR&R

Operation and maintenance costs were evaluated for each alternative condition in the same manner as in the FWOP condition.

2.6.7.3.4 Alternative Cost

The calculation of alternative cost is shown for each alternative in the tables below. The Existing condition costs are also shown, as final OMRR&R costs are computed as net increases relative to this existing condition only. Net decreases in OMRR&R cost relative to the existing condition are itemized as benefits.

Table 101 : Cost Calculation - 2.875% Federal Discount Rate

	EC	3a.1	4b.1	Total
Construction Cost				
Total First Cost	**0**	**154,270,000**	**245,457,000**	**399,727,000**
Interest During Construction				
Construction Duration	0	2.25	2.25	2
Interest During Construction	**0**	**6,716,651**	**10,686,776**	**17,403,427**
Annualized Construction Cost				
Annualized First Cost	0	5,854,251	9,314,623	15,168,875
Annualized IDC	0	254,884	405,543	660,427
Total	**0**	**6,109,135**	**9,720,166**	**15,829,301**
Operation and Maintenance				
Normal O&M	3,500,000	1,750,000	1,750,000	3,500,000
Maintenance Closure Impact Costs	0	0	0	0
Periodic Major Maintenance	3,600,000	600,000	1,200,000	1,800,000
Maintenance Dredging				
Freeport	2,375,897	2,463,591	0	2,463,591
East of Brazos to Freeport	5,984,450	6,270,360	0	6,270,360
Brazos Channel & Crossing	1,352,582	1,951,974	0	1,951,974
West of Brazos	6,922,401	8,613,104	0	8,613,104
East of CRL to GIWW	1,106,393	0	1,106,393	1,106,393
CRL Channel and Crossing	986,150	0	982,883	982,883
West of CRL	1,139,739	0	1,137,331	1,137,331
Total	**26,967,614**	**21,649,029**	**6,176,608**	**27,825,636**
Total Annual Cost	**26,967,614**	**27,758,164**	**15,896,774**	**43,654,938**

2.6.7.3.5 Alternative Cost-Benefit Analysis

The system total benefit-cost analysis of each of the analyzed alternatives are shown in the tables below. Each is presented at the base traffic scenario. A comparison of benefit-cost ratios for all analyzed traffic forecast scenarios will be presented in the sensitivity analysis section.

Table 102 : Benefit-Cost Analysis, 3a.1-4b.1, Base Traffic Scenario, BRFG - 2.875% Federal Discount Rate

Benefit - BRAZOS RIVER FLOODGATES

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,030,137	$1,172,585	$857,552
Queuing Time	$16,978,927	$1,479,604	$15,499,323
Tripping Time	$16,850,481	$1,452,182	$15,398,299
Closure Delay Time	$11,003,311	$755,241	$10,248,071
Total	**$46,862,856**	**$4,859,611**	**$42,003,245**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$16,635,331	$19,299,029	$0
Periodic Major Maintenance	$1,200,000	$600,000	$600,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$19,585,331**	**$21,649,029**	**$600,000**
Accidents			
Accident Repair Cost	**$1,768,274**	**$275,235**	**$1,493,039**
Total Annual Benefit			**$44,096,284**

Incremental Cost - BRAZOS RIVER FLOODGATES

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$6,109,135**	**$6,109,135**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$16,635,331	$19,299,029	$2,663,698
Periodic Major Maintenance	$1,200,000	$600,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$19,585,331**	**$21,649,029**	**$2,663,698**
Total Annual Cost			**$8,772,834**

NET BENEFIT			**$35,323,451**
BENEFIT-COST RATIO			**5.03**

Table 103 : Benefit-Cost Analysis, 3a.1-4b.1, Base Traffic Scenario, CRL - 2.875% Federal Discount Rate

Benefit - COLORADO RIVER LOCKS

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,776,152	$1,119,472	$1,656,680
Queuing Time	$10,947,867	$1,528,280	$9,419,587
Tripping Time	$6,166,779	$2,575,458	$3,591,320
Closure Delay Time	$1,473	$595,269	-$593,796
Total	**$19,892,271**	**$5,818,480**	**$14,073,791**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$3,232,283	$3,226,608	$5,675
Periodic Major Maintenance	$2,400,000	$1,200,000	$1,200,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$7,382,283**	**$6,176,608**	**$1,205,675**
Accidents			
Accident Repair Cost	**$720,282**	**$0**	**$720,282**
Total Annual Benefit			**$15,999,748**

Incremental Cost - COLORADO RIVER LOCKS

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$9,720,166**	**$9,720,166**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$3,232,283	$3,226,608	$0
Periodic Major Maintenance	$2,400,000	$1,200,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$7,382,283**	**$6,176,608**	**$0**
Total Annual Cost			**$9,720,166**

NET BENEFIT			**$6,279,582**
BENEFIT-COST RATIO			**1.65**

Table 104 : Benefit-Cost Analysis, 3a.1-4b.1, Base Traffic Scenario, System Total - 2.875% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$4,806,289	$2,292,057	$2,514,231
Queuing Time	$27,926,794	$3,007,883	$24,918,910
Tripping Time	$23,017,260	$4,027,640	$18,989,620
Closure Delay Time	$11,004,785	$1,350,510	$9,654,275
Total	**$66,755,127**	**$10,678,091**	**$56,077,036**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$19,867,614	$22,525,636	$0
Periodic Major Maintenance	$3,600,000	$1,800,000	$1,800,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$26,967,614**	**$27,825,636**	**$1,800,000**
Accidents			
Accident Repair Cost	**$2,488,556**	**$275,235**	**$2,213,321**
Total Annual Benefit			**$60,090,357**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$15,829,301**	**$15,829,301**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$19,867,614	$22,525,636	$2,658,023
Periodic Major Maintenance	$3,600,000	$1,800,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$26,967,614**	**$27,825,636**	**$2,658,023**
Total Annual Cost			**$18,487,324**

NET BENEFIT			**$41,603,033**
BENEFIT-COST RATIO			**3.25**

Table 105 : Benefit-Cost Analysis, 3a.1-EC, Base Traffic Scenario, BRFG - 2.875% Federal Discount Rate

Benefit - BRAZOS RIVER FLOODGATES

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,030,137	$1,172,922	$857,215
Queuing Time	$16,978,927	$1,492,440	$15,486,487
Tripping Time	$16,850,481	$1,456,737	$15,393,744
Closure Delay Time	$11,003,311	$760,798	$10,242,514
Total	**$46,862,856**	**$4,882,896**	**$41,979,960**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$16,635,331	$19,299,029	$0
Periodic Major Maintenance	$1,200,000	$600,000	$600,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$19,585,331**	**$21,649,029**	**$600,000**
Accidents			
Accident Repair Cost	**$1,768,274**	**$276,502**	**$1,491,773**
Total Annual Benefit			**$44,071,732**

Incremental Cost - BRAZOS RIVER FLOODGATES

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$6,109,135**	**$6,109,135**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$16,635,331	$19,299,029	$2,663,698
Periodic Major Maintenance	$1,200,000	$600,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$19,585,331**	**$21,649,029**	**$2,663,698**
Total Annual Cost			**$8,772,834**

NET BENEFIT			**$35,298,899**
BENEFIT-COST RATIO			**5.02**

Table 106 : Benefit-Cost Analysis, 3a.1-EC, Base Traffic Scenario, CRL - 2.875% Federal Discount Rate

Benefit - COLORADO RIVER LOCKS

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,776,152	$2,776,659	-$507
Queuing Time	$10,947,867	$9,016,346	$1,931,521
Tripping Time	$6,166,779	$5,950,907	$215,872
Closure Delay Time	$1,473	$1,177	$297
Total	**$19,892,271**	**$17,745,089**	**$2,147,182**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$3,232,283	$3,232,283	$0
Periodic Major Maintenance	$2,400,000	$2,400,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$7,382,283**	**$7,382,283**	**$0**
Accidents			
Accident Repair Cost	**$720,282**	**$719,059**	**$1,223**
Total Annual Benefit			**$2,148,405**

Table 107 : Benefit-Cost Analysis, 3a.1-EC, Base Traffic Scenario, System Total - 2.875% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$4,806,289	$3,949,581	$856,708
Queuing Time	$27,926,794	$10,508,786	$17,418,008
Tripping Time	$23,017,260	$7,407,644	$15,609,616
Closure Delay Time	$11,004,785	$761,975	$10,242,810
Total	**$66,755,127**	**$22,627,985**	**$44,127,142**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$19,867,614	$22,531,312	$0
Periodic Major Maintenance	$3,600,000	$3,000,000	$600,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$26,967,614**	**$29,031,312**	**$600,000**
Accidents			
Accident Repair Cost	**$2,488,556**	**$995,560**	**$1,492,996**
Total Annual Benefit			**$46,220,138**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$6,109,135**	**$6,109,135**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$19,867,614	$22,531,312	$2,663,698
Periodic Major Maintenance	$3,600,000	$3,000,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$26,967,614**	**$29,031,312**	**$2,663,698**
Total Annual Cost			**$8,772,834**
NET BENEFIT			**$37,447,304**
BENEFIT-COST RATIO			**5.27**

Figure 28 : Transit Cost Savings, Base Traffic Scenario, 3a.1-4b.1, BRFG – 2.875% Discount Rate

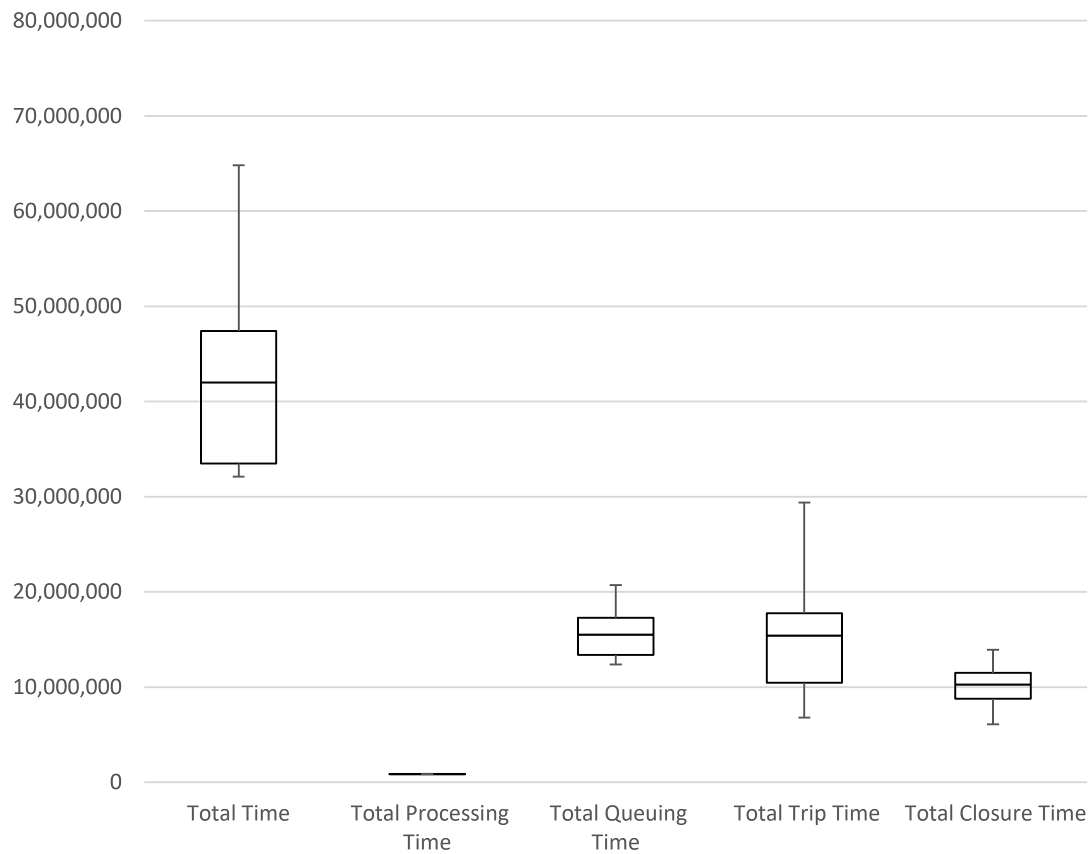


Figure 29 : Transit Cost Savings, Base Traffic Scenario, 3a.1-4b.1, CRL – 2.875% Discount Rate

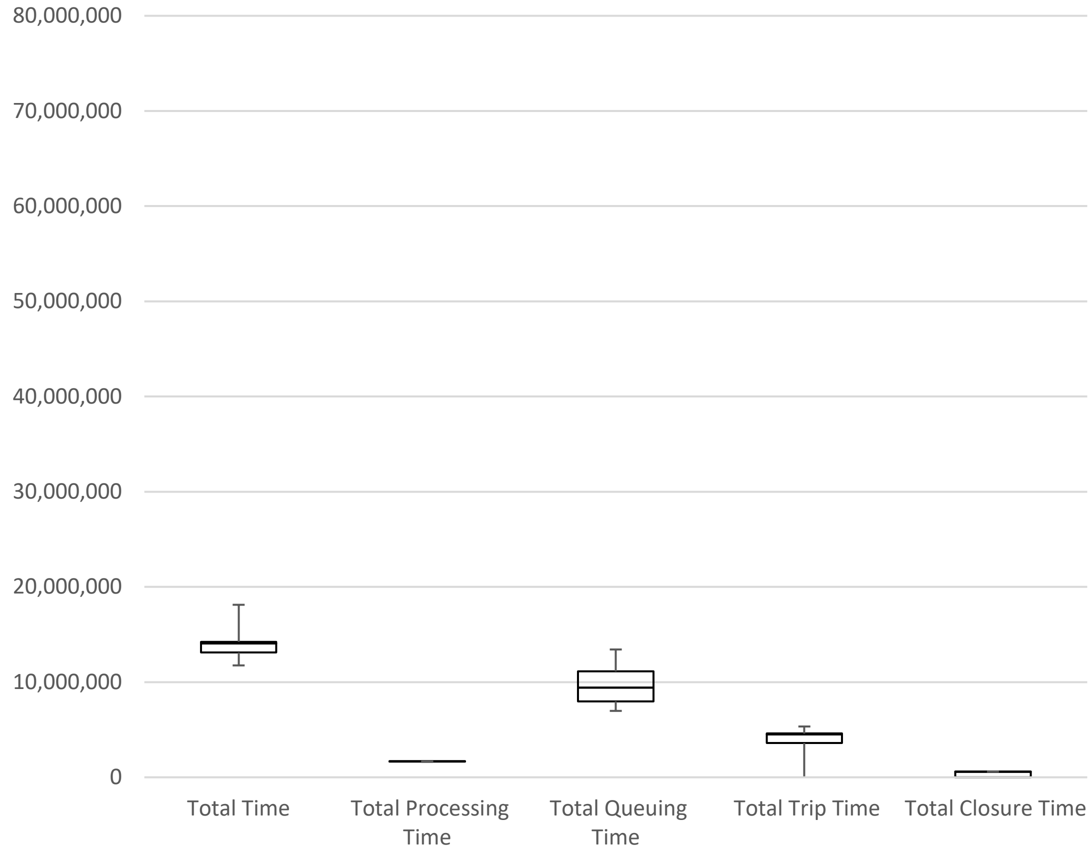


Figure 30 : Transit Cost Savings, Base Traffic Scenario, 3a.1-EC, BRFG – 2.875% Discount Rate

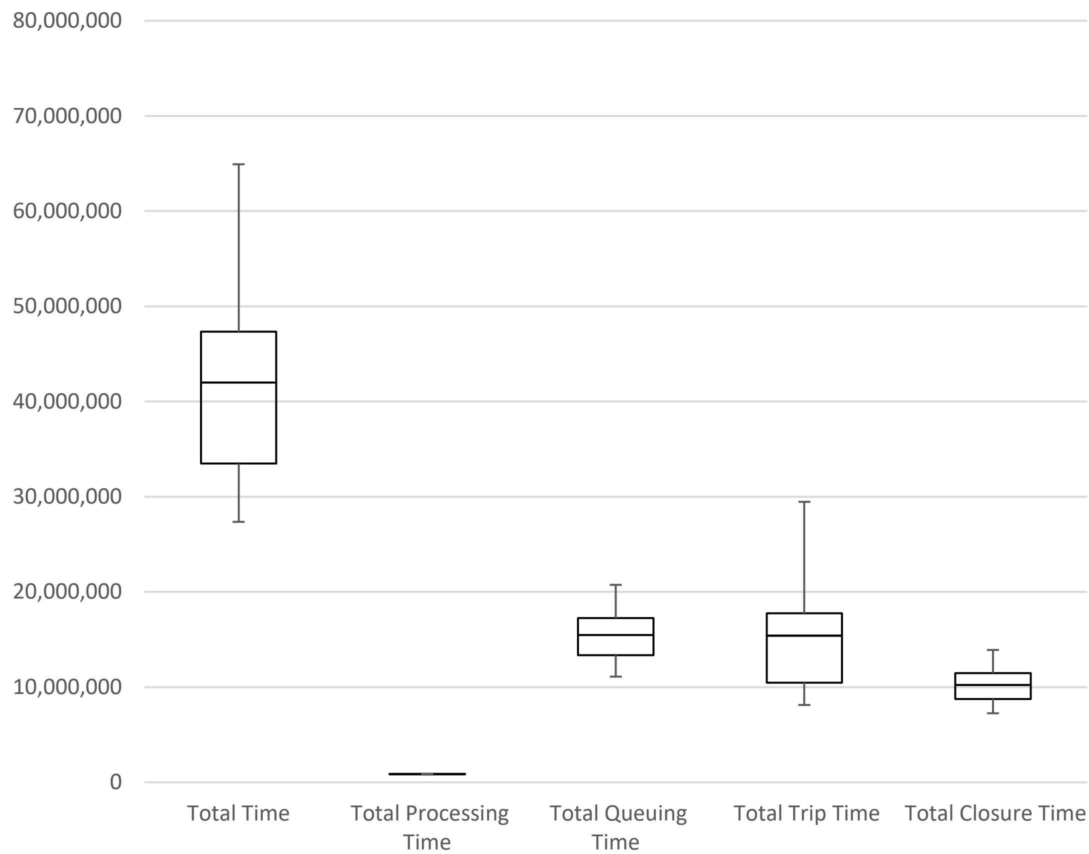
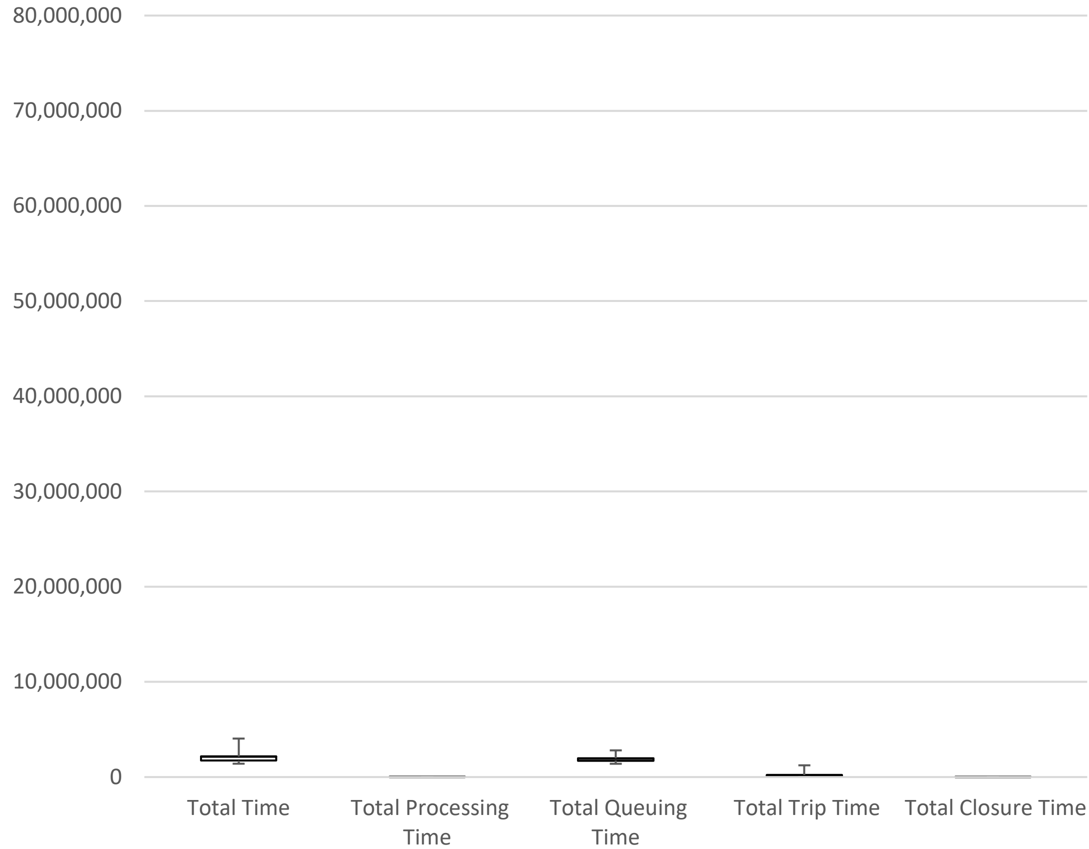


Figure 31 : Transit Cost Savings, Base Traffic Scenario, 3a.1-EC, CRL – 2.875% Discount Rate



2.6.7.3.6 Sensitivity Analysis

This section will detail the results of the traffic forecast sensitivity scenario analyses, as well as the reanalysis of the TSP milestone selected plan with the post-ADM milestone traffic forecasts and river closure threshold proxy.

2.6.7.3.6.1 Traffic Forecast Comparison

In addition to the base traffic forecast scenario, 4 additional traffic forecast sensitivity scenarios were analyzed in the WLCEN model; a low forecast scenario, a high forecast scenario, a no growth forecast scenario in which traffic remains at static at observed levels over the analysis period, and a no growth after 20 years scenario in which traffic follows the base forecast and flattens 20 years after the start of the planning horizon. The results of these analyses are shown in Table 108 and Table 109 below.

Table 108 : Transit Cost, Traffic Forecast Comparison – 2.875% Discount Rate

Alt ID	Traffic Forecast Scenario	Processing Time	Queuing Time	Tripping Time	Closure Delay Time
EC-EC	Base	4,806,289	27,926,794	23,017,260	11,004,785
EC-EC	Low	3,625,800	7,629,395	9,401,638	5,298,685
EC-EC	High	5,349,893	76,334,676	68,114,520	19,774,192
EC-EC	No Growth	3,219,178	4,787,167	7,757,137	4,140,031
EC-EC	No Growth after 20 Years	4,562,654	23,720,391	19,696,007	9,945,943
3a.1-4b.1 rev.	Base	2,292,057	3,007,883	4,027,640	1,350,510
3a.1-4b.1 rev.	Low	1,728,584	1,126,596	2,230,703	912,437
3a.1-4b.1 rev.	High	2,549,254	5,486,796	5,816,515	1,683,491
3a.1-4b.1 rev.	No Growth	1,534,909	747,374	1,746,550	755,659
3a.1-4b.1 rev.	No Growth after 20 Years	2,176,223	2,691,084	3,743,244	1,283,047
3a.1-EC	Base	3,949,581	10,508,786	7,407,644	761,975
3a.1-EC	Low	2,978,393	2,925,166	4,419,886	454,884
3a.1-EC	High	4,395,604	29,330,435	15,068,536	1,012,596
3a.1-EC	No Growth	2,645,478	1,894,492	3,876,386	364,733
3a.1-EC	No Growth after 20 Years	3,749,396	8,909,026	6,652,253	697,295

Note: 2.875% - 2019 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

Table 109 : Cost-Benefit Analysis, Traffic Forecast Comparison - 2.875% Federal Discount Rate

Alt ID	Traffic Forecast Scenario	Total Annual Cost	Total Annual Benefit	Net Benefit	Benefit-Cost Ratio
3a.1-4b.1 rev.	Base	**18,487,324**	**60,090,357**	**41,603,033**	**3.25**
3a.1-4b.1 rev.	Low	**18,487,324**	**23,473,221**	**4,985,896**	**1.27**
3a.1-4b.1 rev.	High	**18,487,324**	**158,363,451**	**139,876,127**	**8.57**
3a.1-4b.1 rev.	No Growth	18,487,324	18,440,268	(47,056)	1.00
3a.1-4b.1 rev.	No Growth after 20 Years	**18,487,324**	**51,987,888**	**33,500,564**	**2.81**
3a.1-EC	Base	**8,772,834**	**46,220,138**	**37,447,304**	**5.27**
3a.1-EC	Low	**8,772,834**	**16,937,406**	**8,164,573**	**1.93**
3a.1-EC	High	**8,772,834**	**122,072,418**	**113,299,585**	**13.91**
3a.1-EC	No Growth	**8,772,834**	**12,750,030**	**3,977,197**	**1.45**
3a.1-EC	No Growth after 20 Years	**8,772,834**	**39,971,913**	**31,199,080**	**4.56**

Note: 2.875% - 2019 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

At all analyzed traffic forecast scenarios the TSP remains feasible with a benefit-cost ratio of above unity, with the exception of the no growth forecast, where the BCR is slightly below unity. 3a.1-EC remains justified at all forecast scenarios, however for the low forecast and the no growth forecast, 3a.1-EC becomes the alternative which maximized net benefits. This is because with the low and no growth forecasted traffic, the Colorado River locks component of the TSP is no longer independently justified. This can be seen in Table 110 and Table 111 below, which break out the cost-benefit analysis by project. In Table 110 it can be seen that at the Brazos River the 3a.1 project-level alternative remains justified. In Table 111 however it can be seen that at the low and no growth forecasted traffic levels, the 4b.1 project-level alternative has higher annual costs than annual benefits. In this sense, the TSP is very sensitive to future traffic growth on the GIWW, but only the Colorado River portion of the TSP. Even if traffic does not grow at all over the analysis period, the Brazos River portion of the TSP remains justified.

Table 110 : Cost-Benefit Analysis, Traffic Forecast Comparison, BRFG - 2.875% Federal Discount Rate

Alt ID	Traffic Forecast Scenario	Total Annual Cost	Total Annual Benefit	Net Benefit	Benefit-Cost Ratio
3a.1-4b.1 rev.	Base	**8,772,834**	**44,096,284**	**35,323,451**	**5.03**
3a.1-4b.1 rev.	Low	**8,772,834**	**16,610,451**	**7,837,618**	**1.89**
3a.1-4b.1 rev.	High	**8,772,834**	**114,208,646**	**105,435,812**	**13.02**
3a.1-4b.1 rev.	No Growth	**8,772,834**	**12,575,663**	**3,802,830**	**1.43**
3a.1-4b.1 rev.	No Growth after 20 Years	**8,772,834**	**38,371,851**	**29,599,018**	**4.37**
3a.1-EC	Base	**8,772,834**	**44,071,732**	**35,298,899**	**5.02**
3a.1-EC	Low	**8,772,834**	**16,590,038**	**7,817,204**	**1.89**
3a.1-EC	High	**8,772,834**	**114,000,601**	**105,227,767**	**12.99**
3a.1-EC	No Growth	**8,772,834**	**12,577,764**	**3,804,931**	**1.43**
3a.1-EC	No Growth after 20 Years	**8,772,834**	**38,371,230**	**29,598,396**	**4.37**

Note: 2.875% - 2019 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

Table 111 : Cost-Benefit Analysis, Traffic Forecast Comparison, CRL - 2.875% Federal Discount Rate

Alt ID	Traffic Forecast Scenario	Total Annual Cost	Total Annual Benefit	Net Benefit	Benefit-Cost Ratio
3a.1-4b.1 rev.	Base	**9,720,166**	**15,999,748**	**6,279,582**	**1.65**
3a.1-4b.1 rev.	Low	9,720,166	6,868,445	(2,851,722)	0.71
3a.1-4b.1 rev.	High	**9,720,166**	**44,160,481**	**34,440,315**	**4.54**
3a.1-4b.1 rev.	No Growth	9,720,166	5,870,280	(3,849,886)	0.60
3a.1-4b.1 rev.	No Growth after 20 Years	**9,720,166**	**13,621,712**	**3,901,546**	**1.40**

Note: 2.875% - 2019 Federal Discount Rate - Section 80 WRDA 1974 (Public Law 93-251)

2.6.7.3.6.2 TSP Milestone Alternative Reanalysis

To ensure consistency between iterations of the analysis, the previous TSP with 75' foot canal side gates at Colorado was reanalyzed using the post-ADM milestone traffic forecasts and river threshold proxy at Colorado. The result of this reanalysis are shown below.

Table 112 : Benefit-Cost Analysis, 3a.1-4b.1, TSP Milestone, Base Traffic Scenario, BRFG - 2.875% Federal Discount Rate

Benefit - BRAZOS RIVER FLOODGATES

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,030,137	$1,172,024	$858,113
Queuing Time	$16,978,927	$1,767,827	$15,211,100
Tripping Time	$16,850,481	$1,546,579	$15,303,903
Closure Delay Time	$11,003,311	$775,731	$10,227,580
Total	**$46,862,856**	**$5,262,161**	**$41,600,696**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$16,635,331	$19,299,029	$0
Periodic Major Maintenance	$1,200,000	$600,000	$600,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$19,585,331**	**$21,649,029**	**$600,000**
Accidents			
Accident Repair Cost	**$1,768,274**	**$276,149**	**$1,492,125**
Total Annual Benefit			**$43,692,821**

Incremental Cost - BRAZOS RIVER FLOODGATES

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$6,109,135**	**$6,109,135**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$16,635,331	$19,299,029	$2,663,698
Periodic Major Maintenance	$1,200,000	$600,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$19,585,331**	**$21,649,029**	**$2,663,698**
Total Annual Cost			**$8,772,834**

NET BENEFIT			**$34,919,987**
BENEFIT-COST RATIO			**4.98**

Table 113 : Benefit-Cost Analysis, 3a.1-4b.1, TSP Milestone, Base Traffic Scenario, CRL - 2.875% Federal Discount Rate

Benefit - COLORADO RIVER LOCKS

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,776,152	$2,228,353	$547,799
Queuing Time	$10,947,867	$21,384,351	-$10,436,484
Tripping Time	$6,166,779	$33,114,813	-$26,948,034
Closure Delay Time	$1,473	$11,885,450	-$11,883,977
Total	**$19,892,271**	**$68,612,967**	**-$48,720,697**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$3,232,283	$3,226,608	$5,675
Periodic Major Maintenance	$2,400,000	$1,200,000	$1,200,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$7,382,283**	**$6,176,608**	**$1,205,675**
Accidents			
Accident Repair Cost	**$720,282**	**$0**	**$720,282**
Total Annual Benefit			**-$46,794,739**

Incremental Cost - COLORADO RIVER LOCKS

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$9,720,166**	**$9,720,166**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$3,232,283	$3,226,608	$0
Periodic Major Maintenance	$2,400,000	$1,200,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$7,382,283**	**$6,176,608**	**$0**
Total Annual Cost			**$9,720,166**

NET BENEFIT			**-$56,514,905**
BENEFIT-COST RATIO			**-4.81**

Table 114 : Benefit-Cost Analysis, 3a.1-4b.1, TSP Milestone, Base Traffic Scenario, System Total - 2.875% Federal Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$4,806,289	$3,400,377	$1,405,912
Queuing Time	$27,926,794	$23,152,178	$4,774,616
Tripping Time	$23,017,260	$34,661,391	-$11,644,131
Closure Delay Time	$11,004,785	$12,661,181	-$1,656,397
Total	**$66,755,127**	**$73,875,128**	**-$7,120,001**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$19,867,614	$22,525,636	$0
Periodic Major Maintenance	$3,600,000	$1,800,000	$1,800,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$26,967,614**	**$27,825,636**	**$1,800,000**
Accidents			
Accident Repair Cost	**$2,488,556**	**$276,149**	**$2,212,407**
Total Annual Benefit			**-$3,107,594**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$15,829,301**	**$15,829,301**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$19,867,614	$22,525,636	$2,658,023
Periodic Major Maintenance	$3,600,000	$1,800,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$26,967,614**	**$27,825,636**	**$2,658,023**
Total Annual Cost			**$18,487,324**
NET BENEFIT			**-$21,594,918**
BENEFIT-COST RATIO			**-0.17**

2.6.7.3.7 Cost-Benefit Analysis at OMB 7.0% Discount Rate

All results presented in this appendix to this point have been at the federal discount rate. TSP and ADM milestone analysis were performed using the FY 2018 discount rate of 2.75%, while post-ADM milestone analyses were performed using the FY 2019 discount rate of 2.875%. For budgeting purposes however, the OMB 7.0% discount rate is also important for evaluation of analysis results. The final analysis of the TSP and all attendant tables are reproduced below at the 7.0% discount rate.

Table 115 : Cost Calculation – 7.0% OMB Discount Rate

	EC	3a.1	4b.1	Total
Construction Cost				
Total First Cost	**0**	**154,270,000**	**245,457,000**	**399,727,000**
Interest During Construction				
Construction Duration	0	2.25	2.25	2
Interest During Construction	**0**	**16,576,312**	**26,374,355**	**42,950,666**
Annualized Construction Cost				
Annualized First Cost	0	11,178,381	17,785,777	28,964,158
Annualized IDC	0	1,201,117	1,911,082	3,112,199
Total	**0**	**12,379,498**	**19,696,859**	**32,076,357**
Operation and Maintenance	0			0
Normal O&M	3,500,000	1,750,000	1,750,000	3,500,000
Maintenance Closure Impact Costs	0	0	0	0
Periodic Major Maintenance	3,600,000	600,000	1,200,000	1,800,000
Maintenance Dredging				
Freeport	2,474,170	2,565,491	0	2,565,491
East of Brazos to Freeport	5,222,215	5,509,481	0	5,509,481
Brazos Channel & Crossing	1,419,364	1,817,398	0	1,817,398
West of Brazos	6,603,732	8,513,002	0	8,513,002
East of CRL to GIWW	1,162,992	0	1,162,992	1,162,992
CRL Channel and Crossing	1,040,300	0	1,038,760	1,038,760
West of CRL	1,199,267	0	1,198,369	1,198,369
Total	**26,222,040**	**20,755,372**	**6,350,121**	**27,105,493**
Total Annual Cost	**26,222,040**	**33,134,870**	**26,046,980**	**59,181,850**

Table 116 : Benefit-Cost Analysis, 3a.1-4b.1, Base Traffic Scenario, BRFG – 7.0% OMB Discount Rate

Benefit - BRAZOS RIVER FLOODGATES

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,066,347	$1,193,613	$872,735
Queuing Time	$15,786,676	$1,407,223	$14,379,453
Tripping Time	$15,565,204	$1,431,512	$14,133,692
Closure Delay Time	$10,671,391	$750,844	$9,920,547
Total	**$44,089,619**	**$4,783,191**	**$39,306,427**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$15,719,482	$18,405,372	$0
Periodic Major Maintenance	$1,200,000	$600,000	$600,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$18,669,482**	**$20,755,372**	**$600,000**
Accidents			
Accident Repair Cost	**$1,800,497**	**$279,835**	**$1,520,663**
Total Annual Benefit			**$41,427,090**

Incremental Cost - BRAZOS RIVER FLOODGATES

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$12,379,498**	**$12,379,498**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$15,719,482	$18,405,372	$2,685,890
Periodic Major Maintenance	$1,200,000	$600,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$18,669,482**	**$20,755,372**	**$2,685,890**
Total Annual Cost			**$15,065,388**

NET BENEFIT			**$26,361,702**
BENEFIT-COST RATIO			**2.75**

Table 117 : Benefit-Cost Analysis, 3a.1-4b.1, Base Traffic Scenario, CRL - 7.0% OMB Discount Rate

Benefit - COLORADO RIVER LOCKS

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$2,825,991	$1,139,480	$1,686,512
Queuing Time	$9,997,386	$1,430,032	$8,567,354
Tripping Time	$5,972,242	$2,473,768	$3,498,475
Closure Delay Time	$1,350	$591,359	-$590,009
Total	**$18,796,970**	**$5,634,639**	**$13,162,332**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$3,402,558	$3,400,121	$2,438
Periodic Major Maintenance	$2,400,000	$1,200,000	$1,200,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$7,552,558**	**$6,350,121**	**$1,202,438**
Accidents			
Accident Repair Cost	**$732,915**	**$0**	**$732,915**
Total Annual Benefit			**$15,097,685**

Incremental Cost - COLORADO RIVER LOCKS

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$19,696,859**	**$19,696,859**
FWP O&M			
Normal O&M	$1,750,000	$1,750,000	$0
Maintenance Dredging	$3,402,558	$3,400,121	$0
Periodic Major Maintenance	$2,400,000	$1,200,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$7,552,558**	**$6,350,121**	**$0**
Total Annual Cost			**$19,696,859**

NET BENEFIT			**-$4,599,174**
BENEFIT-COST RATIO			**0.77**

Table 118 : Benefit-Cost Analysis, 3a.1-4b.1, Base Traffic Scenario, System Total - 7.0% OMB Discount Rate

Benefit - SYSTEM TOTAL

	FWOP	FWP	Benefit
Transit Time			
Processing Time	$4,892,338	$2,333,092	$2,559,246
Queuing Time	$25,784,063	$2,837,255	$22,946,808
Tripping Time	$21,537,446	$3,905,279	$17,632,167
Closure Delay Time	$10,672,741	$1,342,203	$9,330,538
Total	**$62,886,589**	**$10,417,830**	**$52,468,759**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$19,122,040	$21,805,493	$0
Periodic Major Maintenance	$3,600,000	$1,800,000	$1,800,000
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$26,222,040**	**$27,105,493**	**$1,800,000**
Accidents			
Accident Repair Cost	**$2,533,413**	**$279,835**	**$2,253,578**
Total Annual Benefit			**$56,522,337**

Incremental Cost - SYSTEM TOTAL

	FWOP	FWP	Cost
Investment Cost			
Annualized Construction Cost w/ IDC	**$0**	**$32,076,357**	**$32,076,357**
FWP O&M			
Normal O&M	$3,500,000	$3,500,000	$0
Maintenance Dredging	$19,122,040	$21,805,493	$2,683,452
Periodic Major Maintenance	$3,600,000	$1,800,000	$0
Maintenance Closure Impact Costs	$0	$0	$0
Total	**$26,222,040**	**$27,105,493**	**$2,683,452**
Total Annual Cost			**$34,759,810**

NET BENEFIT			**$21,762,528**
BENEFIT-COST RATIO			**1.63**

Table 119 : Cost-Benefit Analysis, Traffic Forecast Comparison – 7.0% OMB Discount Rate

Alt ID	Traffic Forecast Scenario	Total Annual Cost	Total Annual Benefit	Net Benefit	Benefit-Cost Ratio
3a.1-4b.1 rev.	Base	**34,759,810**	**56,522,337**	**21,762,528**	**1.63**
3a.1-4b.1 rev.	Low	34,759,810	23,717,372	(11,042,438)	0.68
3a.1-4b.1 rev.	High	**34,759,810**	**178,504,184**	**143,744,375**	**5.14**
3a.1-4b.1 rev.	No Growth	34,759,810	19,261,250	(15,498,559)	0.55
3a.1-4b.1 rev.	No Growth after 20 Years	**34,759,810**	**50,596,938**	**15,837,128**	**1.46**
3a.1-EC	Base	**15,065,388**	**43,369,626**	**28,304,237**	**2.88**
3a.1-EC	Low	**15,065,388**	**17,068,299**	**2,002,911**	**1.13**
3a.1-EC	High	**15,065,388**	**137,410,156**	**122,344,768**	**9.12**
3a.1-EC	No Growth	15,065,388	13,320,805	(1,744,583)	0.88
3a.1-EC	No Growth after 20 Years	**15,065,388**	**38,941,913**	**23,876,525**	**2.58**

Addendum 1

Commodity Projections

Contents

1.0 Introduction

Appendix C presents commodity forecasts for traffic through the Brazos River Floodgates and Colorado River Locks (BRFG-CLR) developed by Martin Associates with the assistance of economists from the USACE Regional Environmental and Planning Center-Southwestern Division (RPEC-SWD)**.** Martin Associates performed work in accordance with Texas Department of Transportation (TXDOT) Contract Number 94-5SDP5001 ERP No. 4818 for the Brazos River Floodgates project and summarizes the results of the work performed under Subtask 100.3.4 of the Contract. Two sets of projections are presented: 1) draft study projections, and 2) final study projections.

The major distinction between the draft and final study projections centers on projections for crude oil and petroleum products, and the final study figures incorporate trends related to recent and significant output growth in Texas oil and gas industry (see Section 4.1.1). USACE developed the discussion regarding the Texas oil industry and prepared this appendix that incorporates documentation submitted by Martin Associates. In addition, RPEC-SWD included a discussion of the potential for induced tonnage under the with-project condition. Baseline without-project cargo projections are used with the baseline cost model to estimate the discounted value of transportation costs in the without project condition. Differences between the discounted present value of baseline transportation costs and discounted present value of with-project transportation cost are National Economic Development Benefits (NED) used in plan formulation.

Several important assumptions and caveats are warranted:

1) Interviews with key shippers using the BRFG and CRL indicated that delays under the without project case do not result in the use of surface modes, due to the fact that their waterborne movements are essentially a part of the production process for chemicals and petroleum products, and in contrast to shippers of crude petroleum, these shippers lack the ability to use truck or rail as a substitute. BFRG-CRL customers are notified when a barge shipment is within 4 hours of delivery, and at that time the process of berth availability at a shipper's facility is planned. Only in very isolated instances, such as a week or more delay, would inventory stocks be jeopardized, and since the average delay time is less than 6 hours, the impact of delays on supply chain logistics is negligible. This suggests that a reduction in delay times and resulting savings in logistics costs would not result in a diversion of traffic from truck or rail to barge in the future.

2) Commodity traffic is assumed to be driven by economic growth and commodity supply.

3) Given time and budget constraints, projections assume constant modal shares, and although, the projections analysis includes a discussion of modal shifts as they relate to crude oil, the discussion is qualitative in nature.

4) There is a considerable amount of uncertainty in the final commodity projections with respect to future crude oil shipments on the waterways. Section 4.1.3 discusses this uncertainty in detail.

2.0 Historical Commodity Flows through the BRFG-CRL

USACE provided Martin Associates with commodity flow data by commodity category for cargo moving up-bound and down-bound through the BRFG and CRL (Tables 1 through 3 and Figures 1 through 3). With respect to up-bound traffic, total traffic tonnage has doubled from 8.6 million tons to 16.5 million in 2016.

Growth is largely driven by increases in up-bound crude oil tonnage. Crude oil traffic increased from 369,445 tons in 2010 to 2.2 million tons in 2011 and to 10.7 million tons in 2014 reflecting growth in the production of domestic crude. Similarly, up-bound shipments of refined petroleum products have also increased since 1991. Traffic of other commodities does not show significant trends. Crude oil, petroleum products and chemical products moving up-bound through the BRFG and CRL accounted for nearly 80 percent of traffic volume. Due to the decline of aggregates moving up through the BRFG and CRL over the period, in 2016, chemicals, crude oil and petroleum products accounted for 86 percent of up-bound movements. Overall, there was not significant growth in down-bound traffic in which chemical products, petroleum products and crude oil also predominate. Over the historical period, these three commodity groups accounted for 91 percent of the total down-bound moves. In 2016, these three commodity groups accounted for 92 percent of tonnage moving down-bound through the BRFG and CRL.

Table 1
Historical Tonnage through Brazos River Flood Gates and Colorado River Locks (1000s on tons, 1991 through 2016)

Year	Down	Up	Total
1991	5,101	8,615	13,716
1992	5,740	9,414	15,155
1993	5,522	9,675	15,197
1994	5,280	11,902	17,182
1995	5,541	12,098	17,639
1996	4,682	12,314	16,996
1997	6,416	12,985	19,401
1998	5,217	14,081	19,297
1999	5,707	13,063	18,771
2000	5,757	13,482	19,239
2001	5,401	12,976	18,377
2002	5,336	11,380	16,716
2003	5,393	13,172	18,565
2004	5,878	13,157	19,035
2005	5,099	13,076	18,175
2006	5,464	13,267	18,730
2007	5,945	12,924	18,869
2008	5,287	11,723	17,011
2009	4,720	10,369	15,090
2010	5,250	12,307	17,557
2011	5,658	11,919	17,577
2012	6,296	15,014	21,310
2013	5,272	17,075	22,348
2014	6,998	19,426	26,424
2015	5,348	16,660	22,008
2016	5,699	13,554	19,253

Source: USACE Lock Performance Monitoring System

Table 2
Historical Down-bound Tonnage through Brazos River Flood Gates and Colorado River Locks
(1000s of tons, 1991 through 2016)

Year	Aggregates	Chemicals	Coal	Crude petroleum	Grains and grain products	Iron ore, iron and steel products	Non-metallic minerals	Petroleum products	Misc.	Total by year
1991	9	2,737	44	372	47	366	36	1,365	124	5,101
1992	19	2,804	9	1,114	20	159	52	1,400	163	5,740
1993	56	2,692	16	794	62	74	32	1,729	67	5,522
1994	113	2,527	9	375	36	82	47	2,040	50	5,280
1995	43	2,628	43	272	6	149	38	2,334	29	5,541
1996	18	2,355	70	401	10	159	39	1,611	19	4,682
1997	53	2,648	16	201	4	186	142	3,140	27	6,416
1998	29	2,264	0	132	47	203	34	2,488	20	5,217
1999	47	2,255	6	50	30	168	32	3,072	47	5,707
2000	194	2,184	5	58	0	142	27	3,095	52	5,757
2001	57	1,667	2	72	2	182	34	3,367	20	5,401
2002	30	1,773	7	140	46	209	18	3,105	7	5,336
2003	33	1,670	13	175	28	451	15	2,977	32	5,393
2004	102	1,578	0	154	11	203	587	3,201	42	5,878
2005	107	1,269	8	47	17	251	18	3,370	12	5,099
2006	41	1,117	13	43	9	140	17	4,058	25	5,464
2007	0	979	7	29	11	372	28	4,498	20	5,945
2008	0	963	25	9	29	428	61	3,742	31	5,287
2009	16	743	18	61	61	99	21	3,688	13	4,720
2010	33	1,426	27	2	57	258	25	3,374	48	5,250
2011	223	1,397	15	11	92	319	25	3,507	69	5,658
2012	695	1,492	3	150	30	182	78	3,621	45	6,296
2013	471	1,481	8	83	11	159	7	3,029	23	5,272
2014	1,228	1,550	23	585	2	87	49	3,459	15	6,998
2015	557	1,317	33	253	3	97	10	3,056	22	5,348
2016	184	1,650	26	242	19	159	9	3,375	34	5,699
Total by commodity	4,357	47,167	446	5,824	691	5,281	1,482	77,703	1,056	144,008

Source: U.S. Army Corps of Engineers Lock Performance Monitoring System

Table 3
Historical Up-bound Tonnage through Brazos River Flood Gates and Colorado River Locks (1000s of tons, 1991 through 2016)

Year	Aggregates	Chemicals	Coal	Crude petroleum	Grains and grain products	Iron ore, iron and steel products	Non-metallic minerals	Petroleum products	Misc.	Total by year
1991	976	2,617	75	473	29	14	873	3,432	125	8,489
1992	1,496	2,981	77	488	8	1	937	3,325	98	9,315
1993	1,407	2,930	127	291	11	12	1,000	3,708	186	9,487
1994	1,594	3,504	26	410	54	20	1,106	4,977	209	11,690
1995	1,713	4,351	4	459	13	26	1,075	4,276	178	11,918
1996	1,551	4,300	6	664	26	74	1,053	4,500	138	12,174
1997	1,581	4,315	8	645	33	135	1,109	5,030	128	12,856
1998	1,900	4,046	12	640	8	52	1,054	6,261	104	13,974
1999	2,344	3,656	14	657	3	88	1,143	4,995	163	12,899
2000	2,462	3,829	14	380	2	100	1,250	5,307	136	13,344
2001	2,450	3,838	10	764	2	117	674	4,864	256	12,718
2002	2,393	3,696	10	477	0	49	595	3,936	222	11,156
2003	2,696	3,812	5	479	0	31	1,178	4,757	213	12,957
2004	1,346	4,096	28	899	2	83	1,306	5,154	241	12,914
2005	1,270	3,880	77	421	0	67	1,259	5,903	197	12,877
2006	1,707	3,782	75	333	0	52	1,086	5,983	246	13,019
2007	1,401	3,749	82	362	0	82	808	6,222	215	12,707
2008	1,434	3,221	70	313	0	104	727	5,648	204	11,517
2009	960	2,984	26	231	5	100	370	5,535	156	10,211
2010	873	3,278	8	369	25	133	545	6,952	122	12,183
2011	737	3,360	49	2,207	0	290	492	4,618	165	11,752
2012	446	3,200	26	5,347	0	253	549	5,059	131	14,881
2013	507	2,858	42	7,377	0	241	525	5,378	145	16,929
2014	349	2,919	63	10,068	0	179	492	5,189	166	19,258
2015	856	2,890	56	7,149	16	115	550	4,890	136	16,522
2016	1,433	2,773	89	3,363	33	43	112	5,562	143	13,409
Total by commodity	75,764	181,737	2,164	90,532	539	4,921	43,733	262,921	8,840	662,311

Source: U.S. Army Corps of Engineers Lock Performance Monitoring System

Figure 1
Total Commodity Traffic through Study Area
(1991 through 2016, tons)

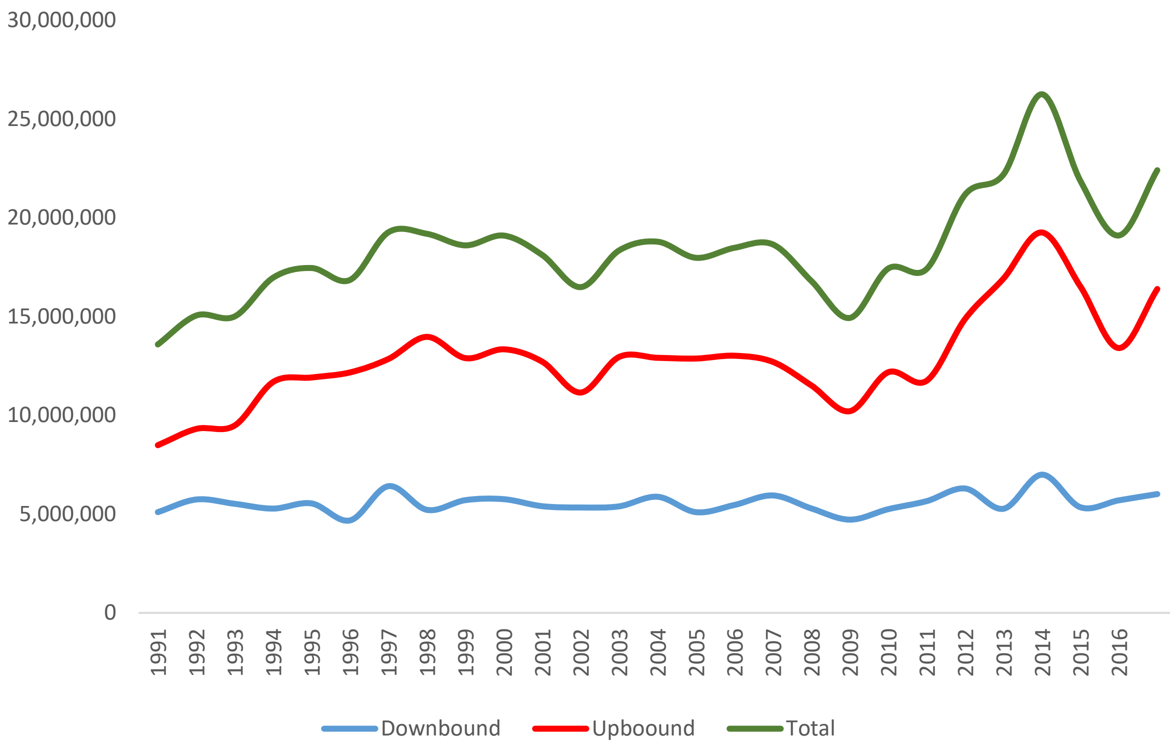


Figure 2
Primary Down-bound Commodities by Tonnage
(Approxinately 95 percent of total tonnage 1991-2016)

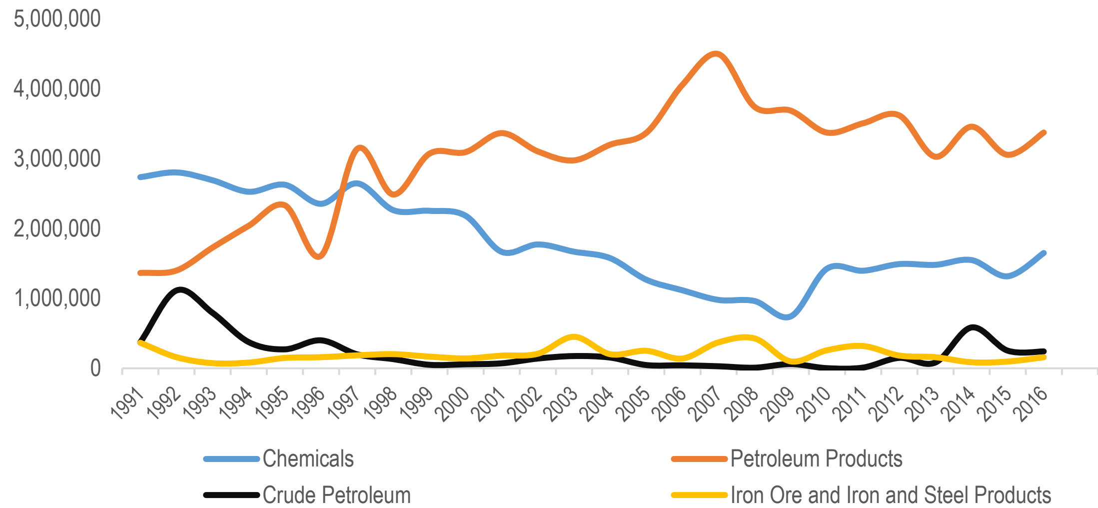
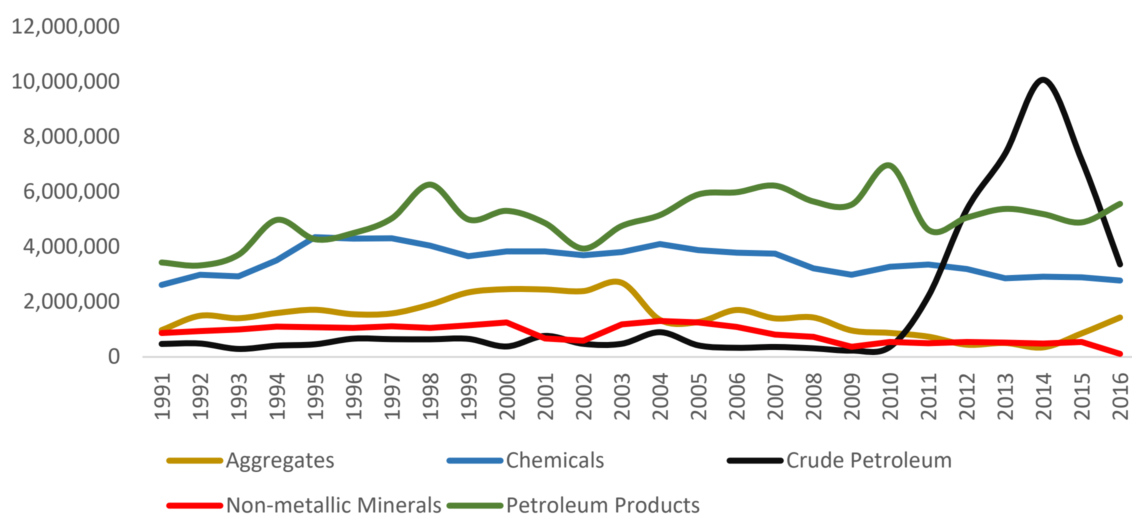


Figure 3
Primary Up-bound Commodities by Tonnage
(approximately 98 percent of total tonnage 1991-2016)



3.0 Draft Study Commodity Flow Projections

Given the fact that crude oil, petroleum products and chemicals account for most traffic moving through the BRFG and CRL in both directions, the projections focus on these three commodities. Tonnage flows of other cargoes are small in relation, and annual volumes of aggregates, coal, grain, iron ore and steel, non-metallic ores and minerals and other cargo have been relatively small and often show large variations year to year.

Martin Associates evaluated several sources of industry projections developed for crude petroleum, petroleum products, and chemical products. The U.S. Energy Information Administration (EIA) develops projections for crude oil production and petroleum products. These projections are based on millions of barrels produced per day for crude oil and petroleum products under several different scenarios - a baseline or reference forecast, a high economy forecast, a low economy forecast, a high oil price scenario, and a low oil price scenario. For draft crude oil projections, national level EIA forecasted oil extraction is the driver for crude oil shipments and national level EIA projections for petroleum products drive growth in refined product shipments. EIA projections run through 2040, and due to the high level of uncertainty after the year 2040, traffic levels are assumed to remain constant through the end of the planning period (i.e., 2067). Table 4 shows EIA projections for crude oil and petroleum products. The range of forecasts based on assumed economic growth and oil prices serves as the basis for the base case, low and high cargo forecasts. As noted earlier, draft projections do not factor in recent developments in the Texas oil and industry, which are discussed in detail later in this report in Section 4.4.1.

Table 4
Projected Production of U.S. Crude Oil and Petroleum Products

Petroleum products	2016	2020	2035	2040	Percent	CAGR*
Reference case	18.61	18.84	17.84	17.99	-3%	-0.1%
High economic growth	18.54	19.43	19.51	20.28	9%	0.4%
Low economic growth	18.5	18.29	16.39	16.08	-13%	-0.6%
High oil prices	18.42	18.14	16.09	16.25	-12%	-0.5%
Low oil prices	18.53	19.32	18.96	19.5	5%	0.2%
Crude oil	2016	2020	2035	2040	Percent	CAGR
Reference case	8.36	8.96	10.48	11.11	33%	1.2%
High economic growth	8.34	8.98	10.55	11.25	35%	1.3%
Low economic growth	8.36	8.93	10.36	11.01	32%	1.2%
High oil prices	9.6	10.75	11.51	10.88	13%	0.5%
Low oil prices	8.31	7.72	7.71	8.61	4%	0.1%

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

Although historical traffic in petrochemicals through the study area has be relatively flat since the 1980s, changes related to tight gas and oil extraction may increase future demand for tanker barges on the GIWW. Shale gas in Texas (Eagle Ford, Barnett Shale and Permian Basin), and elsewhere in the nation including the Bakken and Marcellus formations has generated lower and more stable prices of natural gas, which is a primary feedstock in the chemical manufacturing sector. With the advent of the abundant low cost feedstock, the U.S. chemical industry is investing heavily in new capacity, particularly along the Gulf.

Last year, the American Chemical Council tallied and evaluated about 100 expansion projects in the chemical manufacturing sector, and the mix of projects is heavily slanted towards bulk petrochemicals, mainly steam crackers for ethylene and also propylene.[8] The geographic spread of the chemical industry is highly concentrated along the Gulf Coast including areas of Texas and Louisiana on the GIWW (i.e., “refinery row”). New investments arising from shale gas are largely occur in the Gulf Coast. The Louisiana State University Center for Energy Studies tracked Gulf Coast industrial expansions over the past several years and identified a total of $240 billion dollars of either already completed or announced capital expenditures in Texas and Louisiana.[9] IHS Chemical estimates that the bulk petrochemical industry in the U.S. will add capacity for 49 million metric tons of new bulk liquid chemical production over the period of 2010 to 2025, mostly along the Gulf, which will account for 89 percent of production increases.[10] A good example is the expansion of Formosa Plastic’s Point Comfort 2,500 acre complex with 16 production units, which is slightly south of the BRFG-CRL study area on the GIWW. According to a recent press release, Formosa is in the process of adding a third olefins unit, a propane dehydrogenation unit, two resin plants and an additional polypropylene line.

Rail and waterborne transport are the predominant mode for domestic traffic of bulk liquid chemicals from Gulf Coast petrochemical refineries. Annual shipments are currently totaling about 4 million tons per year through the BRFG, but as in the industry continues to expand, the GIWW should see notable growth in waterborne chemical traffic.

For chemical products projections, Martin Associates relied on chemical products projections developed by the American Chemistry Council in their 2017 Mid-Year Situation and Outlook. This publication provides projections through 2022 for the U.S. chemical industry value of shipments and chemical industry annual production levels. In addition, Martin Associates purchased chemical industry gross product production values for Texas from Moody’s.com, which has the value of chemical industry production levels based on 2009 dollar values through 2047. For chemical products cargo flows on the BRFG and CRL, three sets of projections are developed using the above noted metrics for the chemical industry. For forecasts developed by the American Chemical Council (through 2022), growth rates developed by Moody’s.com for the Texas chemical industry from 2022 through 2047 are used after 2022. From 2047 through 2067, chemical products traffic is projected to remain constant. Due to the high level of uncertainty in long-term forecasts, study projections assume that after 2047 the chemical products are held constant. Table 5 shows industry projections for U.S. chemical production.

To incorporate uncertainty for chemical traffic projections, Moody’s.com forecasts for chemical domestic product for the state of Texas was used. For the low scenario, the American Chemistry Council annual change in production was used and for the high scenario, growth in the value of chemical industry shipments from the American Chemistry Council was applied. Moody’s.com forecasts were used for all three scenarios for years after 2022.

---

[8] American Chemistry Council, “Shale Gas, Competitiveness, and New US Chemical Industry Investment: An Analysis Based on Announced Projects.” May 2017.

[9] “Gulf Coast Energy Outlook.” Center for Energy Studies Economics & Policy Research Group, Louisiana State University, Spring 2017.

[10] IHG Chemical, “U.S. Bulk Chemical Trade and Logistics in Shale Gas Era.” August, 2016.

Table 5
Industry Projections for the U.S. Chemical Products Production

Year	Gross state product for the chemical industry in Texas (constant 2009 dollars)	Percentage change in U.S. chemical production	Percentage change in the value of U.S. chemical production
2014	7.7	-1.011	1.02
2015	9.21	1.018	-1.045
2016	9.95	1.007	1.021
2017	10.11	1.011	1.035
2018	10.12	1.038	1.06
2019	10.33	1.035	1.059
2020	10.64	1.028	1.052
2021	11.01	1.024	1.047
2022	11.43	1.023	1.047
2028	13.47		
2034	15.47		
2040	17.53		
2041	17.87		
2042	18.2		
2043	18.55		
2044	18.89		
2045	19.23		
2046	19.57		
2047	19.89		
Percent change	158%		
CAGR*	2.9%		

*Compound annual growth rate
Source: Moody's Analytics and the American Chemical Industry Council

Table 6 and Figure 4 display draft cargo projections through the study area aggregated across all commodities, and Tables 7 and 8 show forecasts by commodity group for the base case, low and high scenarios.

Table 6
Draft BFRG-CRL Commodity Flow Projections (all commodities, 1000s of tons, 2016 through 2067)

Historical			
	Down	Up	Total
2002	5,336	11,380	16,716
2003	5,393	13,172	18,565
2004	5,878	13,157	19,035
2005	5,099	13,076	18,175
2006	5,464	13,267	18,731
2007	5,945	12,924	18,869
2008	5,287	11,723	17,010
2009	4,720	10,369	15,089
2010	5,250	12,307	17,557
2011	5,658	11,919	17,577
2012	6,296	15,014	21,310
2013	5,272	17,075	22,347
2014	6,998	19,426	26,424
2015	5,348	16,660	22,008

Projected									
	Down			Up			Total		
	Base	Low	High	Base	Low	High	Base	Low	High
2016	5,461	5,331	5,405	16,462	16,205	17,261	21,923	21,537	22,666
2020	5,614	5,423	5,885	17,221	15,926	19,071	22,836	21,349	24,955
2025	5,784	5,505	6,210	17,759	15,594	20,559	23,543	21,099	26,769
2030	5,978	5,581	6,453	18,745	15,615	21,195	24,724	21,196	27,647
2035	6,232	5,749	6,769	19,793	16,364	21,563	26,025	22,113	28,332
2040	6,520	6,033	7,148	20,879	17,641	21,856	27,399	23,675	29,004
2045	6,765	6,265	7,417	21,415	18,150	22,447	28,180	24,415	29,864
2050	6,859	6,355	7,521	21,519	18,249	22,561	28,378	24,604	30,083
2055	6,859	6,355	7,521	21,519	18,249	22,561	28,378	24,604	30,083
2060	6,859	6,355	7,521	21,519	18,249	22,561	28,378	24,604	30,083
2067	6,859	6,355	7,521	21,519	18,249	22,561	28,378	24,604	30,083
Percent change (2016-2067)	25.6%	19.2%	39.2%	30.7%	12.6%	30.7%	29.4%	14.2%	32.7%
CAGR* (2016-2067)	0.5%	0.4%	0.7%	0.5%	0.2%	0.5%	0.5%	0.3%	0.6%

*Compound annual growth rate

Figure 4
Draft Historical and Projected BRFG-CLR Tonnage
(all commodities, 1991 through 2067)

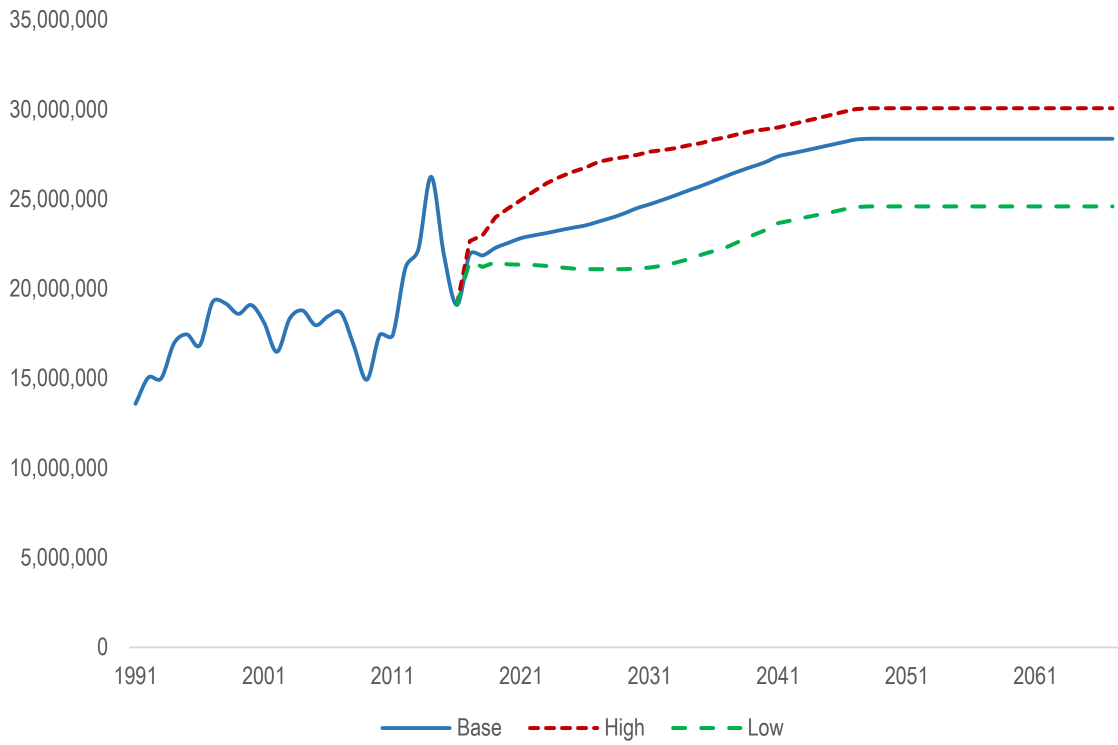


Table 7

Draft Down-Bound Projected Tonnage through Brazos River Flood Gates and Colorado River Locks by Commodity (1000s of tons, 1991 through 2067)

Year	Aggregates	Chemicals	Coal	Crude petroleum	Grains and grain products	Iron ore, iron and steel products	Non-metallic minerals	Petroleum products	Misc.	Total
Down-bound Historical (2002 through 2016)										
2002	30	1,773	7	140	46	209	18	3,105	7	5,336
2003	33	1,670	13	175	28	451	15	2,977	32	5,393
2004	102	1,578	0	154	11	203	587	3,201	42	5,878
2005	107	1,269	8	47	17	251	18	3,370	12	5,099
2006	41	1,117	13	43	9	140	17	4,058	25	5,464
2007	0	979	7	29	11	372	28	4,498	20	5,945
2008	0	963	25	9	29	428	61	3,742	31	5,287
2009	16	743	18	61	61	99	21	3,688	13	4,720
2010	33	1,426	27	2	57	258	25	3,374	48	5,250
2011	223	1,397	15	11	92	319	25	3,507	69	5,658
2012	695	1,492	3	150	30	182	78	3,621	45	6,296
2013	471	1,481	8	83	11	159	7	3,029	23	5,272
2014	1,228	1,550	23	585	2	87	49	3,459	15	6,998
2015	557	1,317	33	253	3	97	10	3,056	22	5,348
Down-bound Projections (Base Case)										
2016	557	1,424	33	237	3	97	10	3,078	22	5,461
2020	557	1,522	33	254	3	97	10	3,116	22	5,614
2025	557	1,777	33	258	3	97	10	3,027	22	5,784
2030	557	2,020	33	278	3	97	10	2,959	22	5,978
2035	557	2,263	33	297	3	97	10	2,951	22	6,232
2040	557	2,508	33	315	3	97	10	2,976	22	6,520
2045	557	2,753	33	315	3	97	10	2,976	22	6,765
2050	557	2,847	33	315	3	97	10	2,976	22	6,859
2055	557	2,847	33	315	3	97	10	2,976	22	6,859
2060	557	2,847	33	315	3	97	10	2,976	22	6,859
2067	557	2,847	33	315	3	97	10	2,976	22	6,859
Percent change	0.0%	99.9%	0.0%	32.9%	0.0%	0.0%	0.0%	-3.3%	0.0%	25.6%
CAGR [1]	0.0%	1.4%	0.0%	0.6%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.5%
Down-bound Projections (Low Scenario)										
2016	557	1,327	33	235	3	97	10	3,048	22	5,331
2020	557	1,481	33	218	3	97	10	3,002	22	5,423
2025	557	1,686	33	202	3	97	10	2,896	22	5,505
2030	557	1,916	33	201	3	97	10	2,742	22	5,581
2035	557	2,147	33	218	3	97	10	2,662	22	5,749
2040	557	2,380	33	244	3	97	10	2,689	22	6,033
2045	557	2,611	33	244	3	97	10	2,689	22	6,265
2050	557	2,701	33	244	3	97	10	2,689	22	6,355
2055	557	2,701	33	244	3	97	10	2,689	22	6,355
2060	557	2,701	33	244	3	97	10	2,689	22	6,355
2067	557	2,701	33	244	3	97	10	2,689	22	6,355
Percent change	0.0%	103.6%	0.0%	3.7%	0.0%	0.0%	0.0%	-11.8%	0.0%	19.2%
CAGR	0.0%	1.4%	0.0%	0.1%	0.0%	0.0%	0.0%	-0.3%	0.0%	0.4%
Down-bound Projections (High Scenario)										
2016	557	1,345	33	272	3	97	10	3,066	22	5,405
2020	557	1,644	33	304	3	97	10	3,215	22	5,885

Table 7
Draft Down-Bound Projected Tonnage through Brazos River Flood Gates and Colorado River Locks by Commodity (1000s of tons, 1991 through 2067)

Year	Aggregates	Chemicals	Coal	Crude petroleum	Grains and grain products	Iron ore, iron and steel products	Non-metallic minerals	Petroleum products	Misc.	Total
2025	557	1,958	33	334	3	97	10	3,197	22	6,210
2030	557	2,226	33	337	3	97	10	3,169	22	6,453
2035	557	2,494	33	326	3	97	10	3,228	22	6,769
2040	557	2,764	33	308	3	97	10	3,355	22	7,148
2045	557	3,033	33	308	3	97	10	3,355	22	7,417
2050	557	3,137	33	308	3	97	10	3,355	22	7,521
2055	557	3,137	33	308	3	97	10	3,355	22	7,521
2060	557	3,137	33	308	3	97	10	3,355	22	7,521
2067	557	3,137	33	308	3	97	10	3,355	22	7,521
Percent change	0.0%	133.2%	0.0%	13.3%	0.0%	0.0%	0.0%	9.4%	0.0%	39.2%
CAGR	0.0%	1.7%	0.0%	0.3%	0.0%	0.0%	0.0%	0.2%	0.0%	0.7%

1 Compound annual growth rate

Table 8
Draft Up-Bound Projected Tonnage through Brazos River Flood Gates and Colorado River Locks by Commodity (1000s of tons, 1991 through 2067)

Year	Aggregates	Chemicals	Coal	Crude petroleum	Grains and grain products	Iron ore, iron and steel products	Non-metallic minerals	Petroleum products	Misc.	Total
Up-bound Historical (2002 through 2016)										
2002	2,393	3,696	10	477	0	49	595	3,936	222	11,380
2003	2,696	3,812	5	479	0	31	1,178	4,757	213	13,172
2004	1,346	4,096	28	899	2	83	1,306	5,154	241	13,157
2005	1,270	3,880	77	421	0	67	1,259	5,903	197	13,076
2006	1,707	3,782	75	333	0	52	1,086	5,983	246	13,267
2007	1,401	3,749	82	362	0	82	808	6,222	215	12,924
2008	1,434	3,221	70	313	0	104	727	5,648	204	11,723
2009	960	2,984	26	231	5	100	370	5,535	156	10,369
2010	873	3,278	8	369	25	133	545	6,952	122	12,307
2011	737	3,360	49	2,207	0	290	492	4,618	165	11,919
2012	446	3,200	26	5,347	0	253	549	5,059	131	15,014
2013	507	2,858	42	7,377	0	241	525	5,378	145	17,075
2014	349	2,919	63	10,068	0	179	492	5,189	166	19,426
2015	856	2,890	56	7,149	16	115	550	4,890	136	16,660
Up-bound Projections (Base Case)										
2016	856	3,124	56	6,684	16	115	550	4,925	136	16,462
2020	856	3,340	56	7,167	16	115	550	4,986	136	17,221
2025	856	3,898	56	7,288	16	115	550	4,843	136	17,759
2030	856	4,432	56	7,852	16	115	550	4,733	136	18,745
2035	856	4,965	56	8,379	16	115	550	4,720	136	19,793
2040	856	5,502	56	8,886	16	115	550	4,761	136	20,879
2045	856	6,039	56	8,886	16	115	550	4,761	136	21,415

Table 8
Draft Up-Bound Projected Tonnage through Brazos River Flood Gates and Colorado River Locks by Commodity (1000s of tons, 1991 through 2067)

Year	Aggregates	Chemicals	Coal	Crude petroleum	Grains and grain products	Iron ore, iron and steel products	Non-metallic minerals	Petroleum products	Misc.	Total
2050	856	6,143	56	8,886	16	115	550	4,761	136	21,519
2055	856	6,143	56	8,886	16	115	550	4,761	136	21,519
2060	856	6,143	56	8,886	16	115	550	4,761	136	21,519
2067	856	6,143	56	8,886	16	115	550	4,761	136	21,519
Percent change	0.0%	96.6%	0.0%	32.9%	0.0%	0.0%	0.0%	-3.3%	0.0%	30.7%
CAGR [1]	0.0%	1.4%	0.0%	0.6%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.5%
Up-bound Projections (Low Scenario)										
2016	856	2,910	56	6,641	16	115	550	4,925	136	16,205
2020	856	3,250	56	6,170	16	115	550	4,778	136	15,926
2025	856	3,698	56	5,694	16	115	550	4,474	136	15,594
2030	856	4,204	56	5,671	16	115	550	4,011	136	15,615
2035	856	4,710	56	6,166	16	115	550	3,758	136	16,364
2040	856	5,220	56	6,888	16	115	550	3,804	136	17,641
2045	856	5,729	56	6,888	16	115	550	3,804	136	18,150
2050	856	5,828	56	6,888	16	115	550	3,804	136	18,249
2055	856	5,828	56	6,888	16	115	550	3,804	136	18,249
2060	856	5,828	56	6,888	16	115	550	3,804	136	18,249
2067	856	5,828	56	6,888	16	115	550	3,804	136	18,249
Percent change	0.0%	100.2%	0.0%	3.7%	0.0%	0.0%	0.0%	-22.8%	0.0%	12.6%
CAGR	0.0%	1.4%	0.0%	0.1%	0.0%	0.0%	0.0%	-0.5%	0.0%	0.2%
Up-bound Projections (High Scenario)										
2016	856	2,951	56	7,676	16	115	550	4,906	136	17,261
2020	856	3,607	56	8,592	16	115	550	5,143	136	19,071
2025	856	4,295	56	9,420	16	115	550	5,115	136	20,559
2030	856	4,883	56	9,514	16	115	550	5,069	136	21,195
2035	856	5,471	56	9,199	16	115	550	5,164	136	21,563
2040	856	6,063	56	8,697	16	115	550	5,367	136	21,856
2045	856	6,654	56	8,697	16	115	550	5,367	136	22,447
2050	856	6,769	56	8,697	16	115	550	5,367	136	22,561
2055	856	6,769	56	8,697	16	115	550	5,367	136	22,561
2060	856	6,769	56	8,697	16	115	550	5,367	136	22,561
2067	856	6,769	56	8,697	16	115	550	5,367	136	22,561
Percent change	0.0%	129.4%	0.0%	13.3%	0.0%	0.0%	0.0%	9.4%	0.0%	30.7%
CAGR	0.0%	1.7%	0.0%	0.3%	0.0%	0.0%	0.0%	0.2%	0.0%	0.5%

1 Compound annual growth rate

4.0 Final Commodity Flow Projections

The methodology and assumptions for final study projections are the same as those for draft figures with several exceptions: 1) regional level production forecasts for crude oil serve as drivers for crude oil traffic, and 2) baseline values for all commodity projections are an average of annual traffic volumes in years 2014, 2015 and 2016 as opposed to using 2016 as a baseline. Section 4.1.1 below discusses trends and factors driving the substantial increase in crude oil shipments through the project area over the past several years.

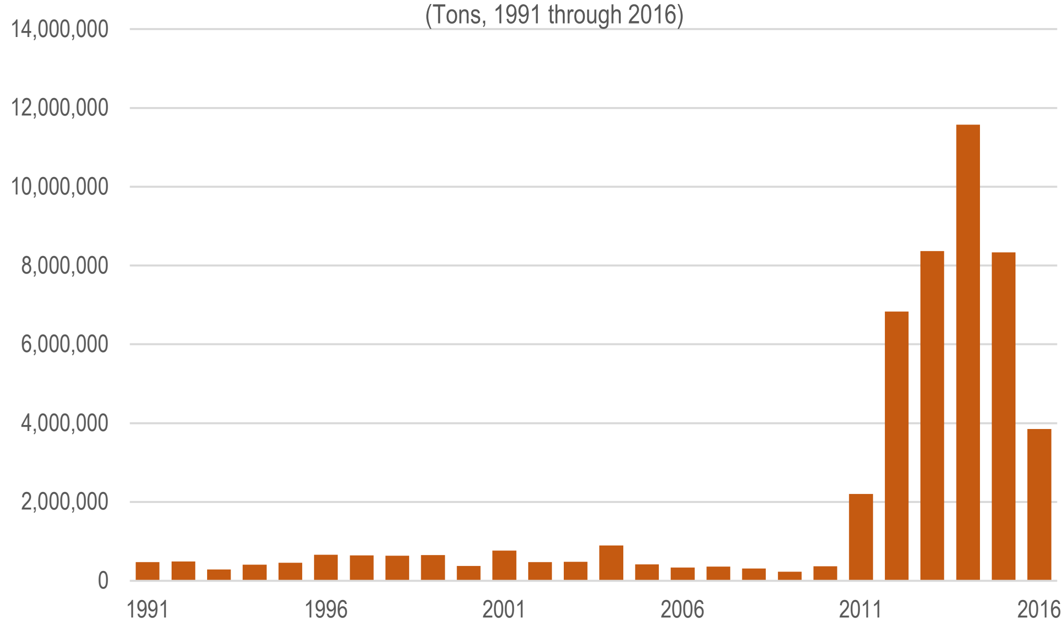
4.1.1 Regional Developments in the Texas Oil and Gas Industry

Over about the past 25 years up bound commodity traffic on the GIWW through the Brazos River Floodgates (BRG) and Colorado River Locks (CRL) has increased substantially. Based on data from the USACE Lock Performance Monitoring System, 8.6 million tons flowed through the study area in 1991, and in 2016 up bound tonnage doubled to roughly 16.7 million tons. Total down bound tonnage has shown no statistically significant trend over the same period. Growth in shipments of iron ore, petroleum projects and crude petroleum have driven increases in up bound traffic. In recent years, crude oil in particular has spiked rising from annual totals ranging from 300,000 to 500,000 tons to a high of nearly 11 million in 2014 (Figure 5). The large increase is due to changes in oil production in Texas, and its effects on domestic and international oil markets.

Tight oil and gas extraction (also known as shale gas and oil) has sparked a renaissance in the U.S. oil industry. In the late 20th century, engineers developed new technologies referred to as horizontal drilling and hydraulic fracturing, both of which allow mining companies to tap oil and gas trapped within shale formations that was previously unavailable via conventional vertical wells. As a result, crude oil production in the U.S. is booming. According to the U.S. Energy Information Administration (EIA), 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. This means that in the next few years, crude production will exceed the historical peak in domestic production reached in 1970.[11]

[11] U.S. Energy Information Administration (EIA), 2018 Annual Energy Outlook, February 2018. Unless otherwise referenced, oil production statistics are from the EIA.

Figure 5
Crude Oil Shipments through the Brazos River Floodgates and Colorado River Locks
(Tons, 1991 through 2016)



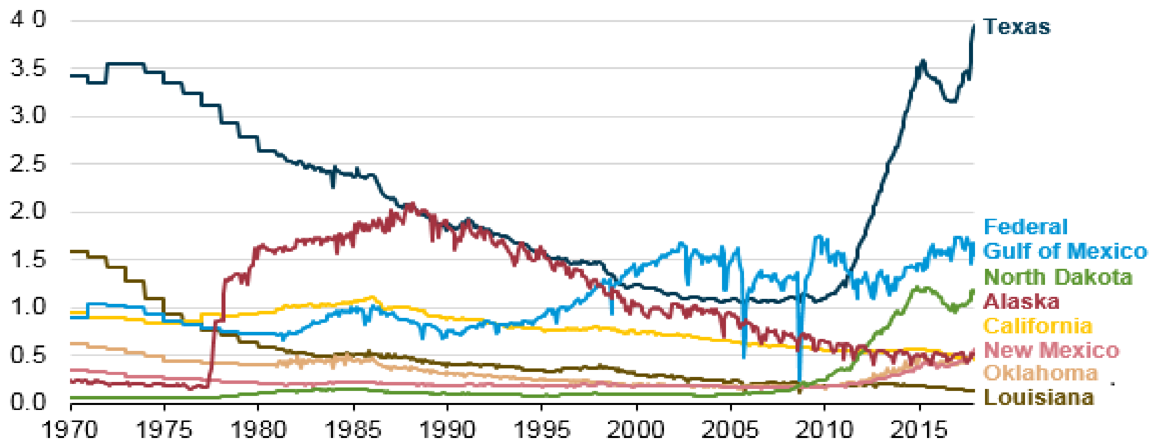
Source: USACE Lock Performance Monitoring System

Although much has changed since 1970, Texas continues to produce more crude oil than any other state or region of the U.S. (Figure 6). 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.

Historically, oil produced in Texas flows via pipeline to Cushing, Oklahoma where it is stored in tanks and eventually pumped to refineries to make gasoline. This production surge has led to a glut of oil, especially at Cushing where most central U.S. oil pipelines meet and where the price is set for the U.S. benchmark West Texas Intermediate (WTI) crude. From 2009 to 2013, petroleum stocks at U.S. storage facilities increased 10 percent, with two-thirds of the increase occurring at Cushing alone. Stocks at Cushing increased 50 percent in the period as it received more oil from the north and southwest than it was able to ship by pipeline to refiners.[12]

[12] Wilkerson, C. and Melek, C., "Getting Crude to Market: Central U.S. Oil Transportation Challenges." Main Street Economist, Federal Reserve Bank of Kansas, 2015.

Figure 6
Crude Oil Extraction in the United States by Producing Region (millions of barrels per day)

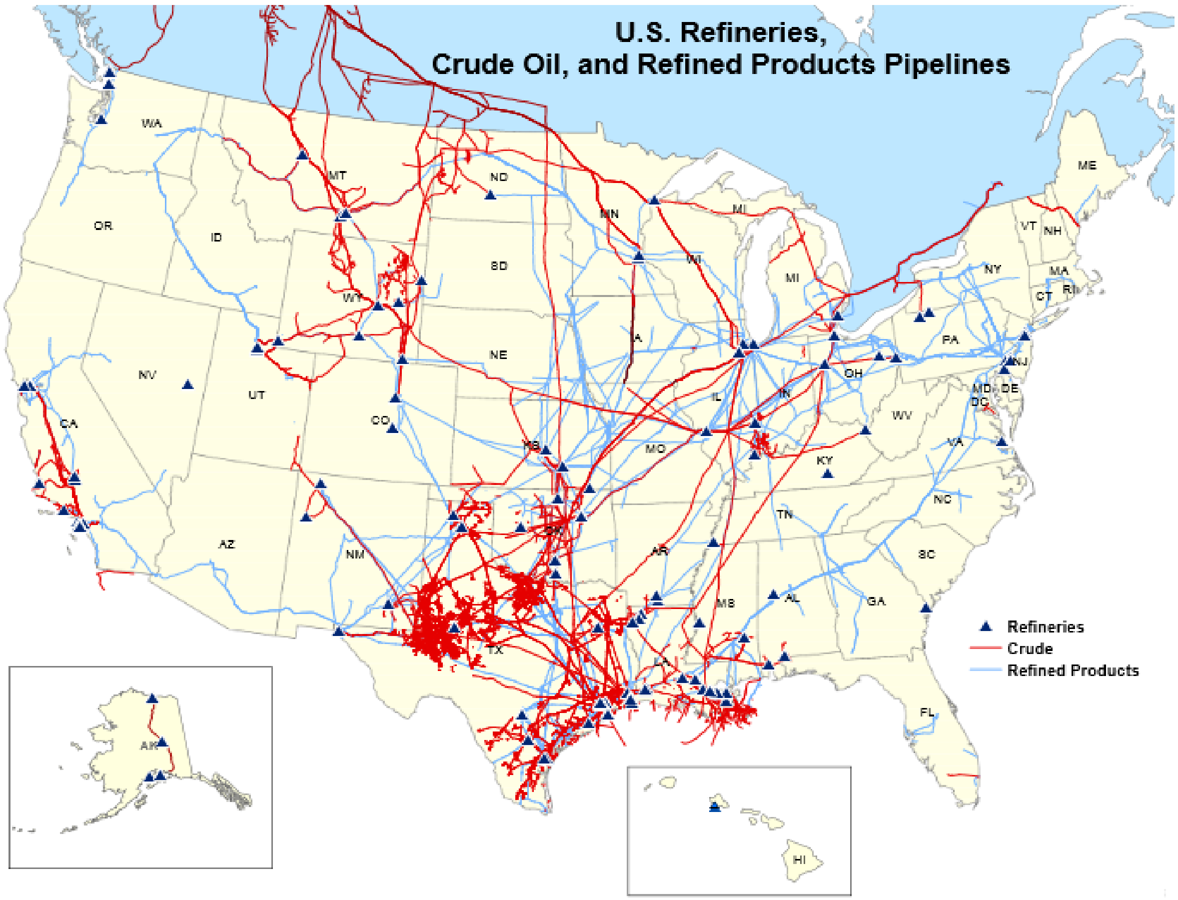


Source: U.S. Energy Administration Agency

In the past two decades, most WTI went to refineries in Oklahoma, Louisiana and West Texas as opposed to facilities along the Gulf Coast, which was evident given that there were not many pipelines going from Cushing to the Texas Gulf Coast. In fact, there were only a few running from the Permian Basin to the Gulf until about 2014 (Figure 7). This has changed for several reason. For one, not all refineries are alike. Their technical configuration determines the types of crude oil they process. Light "sweet" crudes including WTI and Brent oil from areas of Europe such as the North Sea are well suited for making gasoline, whereas heavy "sour" crudes are best suited for producing diesel fuel and fuel oils sold at discounts to run cargo trucks, ships or power plants. Refineries along the Gulf have invested in capital needed to refine heavier sour crudes imported from Saudi Arabia, Venezuela and Mexico. Refineries along the East Coast have traditionally relied on imports of high-priced light sweet crude oil (mainly from Nigeria, Angola and Algeria and Europe) that are refined using more conventional technology.[13] Second, until recently WTI was more expensive relative to heavy crude and Brent and other light oil until the production boom in the Permian and Eagle Ford formations.

[13] Lilian, L. "The Impact of the Shale Oil Revolution on U.S. Oil and Gasoline Prices." Center for Economic Policy Research, University of Michigan, 2016.

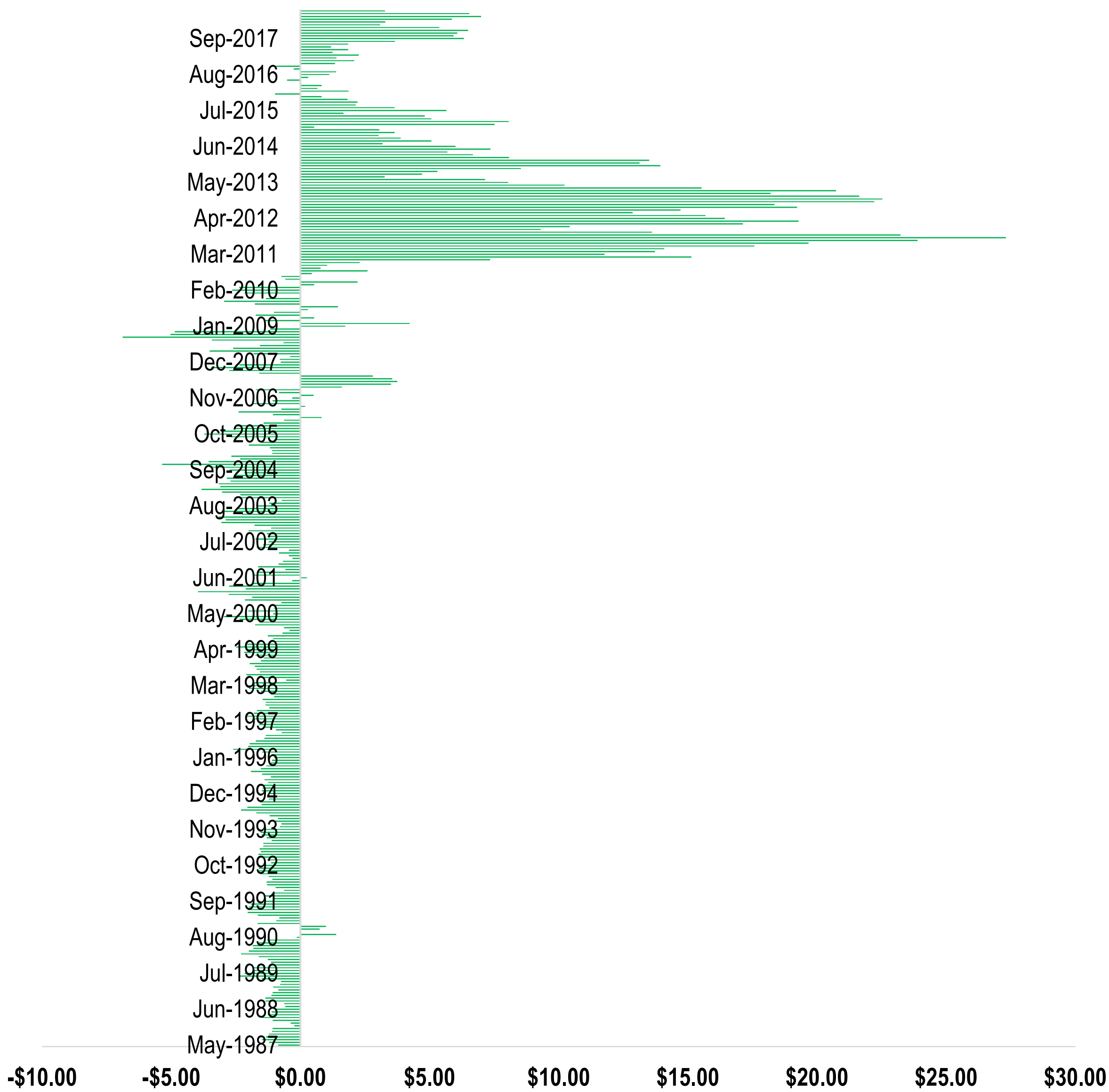
Figure 7
U.S. Refineries, Crude Oil and Refined Products Pipelines as of 2012



Source: American Energy Mapping (AEM) and American Petroleum Institute

As its price fell and because it costs less to refine, WTI became more attractive to refiners along the Gulf, and it has become cost effective to move by pipeline from the Eagle Ford and Permian Basin to Corpus and Christi and or Brownsville, and transfer to barge for shipment to refineries in Houston, Corpus Christi and Louisiana. As U.S. crude oil accelerated in 2011, price differentials between domestic and international oil grew to unprecedented levels. At its peak, the most widely cited U.S. light crude benchmark, WTI, was trading at more than a $25 discount to the international benchmark, Brent Crude, which was unheard of and a shock to the industry (Figure 8). For decades, WTI had consistently traded at a premium to Brent oils. In other words, it was almost always more expensive.

Figure 8
Price Deviation of Brent Crude from West Texas Intermediate
(U.S. dollars, 1987 through 2017)



Source: U.S. Energy Information Agency

Another important part of the story is the recent lifting of the embargo on U.S. crude exports. In 1975, the Energy Policy and Conservation Act prohibited export of domestically produced crude oil and created the Strategic Petroleum Reserve. Signed shortly after the OPEC oil embargo of 1973 and during a time when many feared the arrival of "global peak oil," the purpose of the ban was to keep domestic crude in the U.S.in the interest of energy security. In 2015, the U.S. Congress lifted the export ban as part of an omnibus spending bill, which opened the door for exports from West Texas. As Brent's premium has risen, WTI-based domestic sweet grades have become more competitive with Brent-based North Sea, Mediterranean and West African grades in export markets. Today, the U.S. today ships out almost one million barrels of oil each day compared with about 520,000 barrels in 2016, and exports are expected to triple to about 3 million barrels a day by 2025 according to IHS Markit.[14] Thus, a pivotal question is whether the price differential and demand for alternative shipping via barge or rail continue.

While markets for crude are complex, fundamentally there appears to be two factors keeping WTI cheap relative other Brent and other benchmarks - abundant supply and related infrastructure constraints in terms of getting WTI from West Texas to Gulf refineries and terminals, but new pipelines have come online in recent years, and several are under construction, or in the first stages of development. For example, in 2015 Sunco completed the Permian Express Phase II and added 200,000 barrels per day takeaway capacity, and Enterprise Products Partners L.P. completed a 416 mile expansion of the Midland to Sealy pipeline bringing a capacity of 540,000 barrels per day. Several pipelines are underway such as the $2 billion Gray Oak pipeline project sponsored by San Antonio based Andeavor that would connect both the Eagle Ford and Permian to Corpus Christi and Houston, and several more are planned.[15]

While there is a plethora of investments in new pipelines, pipelines are costly and time consuming to develop. Permitting, development, and construction, coupled with increasingly remote production sources, means alleviating newly found bottlenecks and chokepoints will take time, and for the most part will continue to lag in capacity until formations in West Texas reach a plateau in terms of production. As production matures and levels off (assuming it does in the near term through about 2030 through 2040) mid-stream companies will be reluctant to invest in additional pipeline capacity. Using existing assets and existing rights-of-way can save midstream companies capital and time. Regulatory procedures still exist, but the time from planning to construction is usually shortened if assets and rights-of-way already in place. But in general no one wants to spend billions of dollars on a pipeline that will be a quarter full when complete.

EIA's 2018 Annual Energy Outlook contains projections for changes in crude extraction in the U.S. on a regional basis (Figure 9). 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. Based on EIA's estimates, the Federal Reserve Bank of Dallas generated a chart showing expected production growth (the solid and dotted red line) plotted against existing pipeline capacity, pipelines under construction, and pipelines on the drawing board (Figure 10). Capacity remains tight until sometime in mid-2019, and that happens only if the speculative capacity is added as drawn up. Overall, it appears that planned pipeline capacity additions will

---

[14] Blum, J. "Most new Permian Oil Likely to be Exported from Houston and Corpus Christi." Houston Chronicle, August 21, 2017.

[15] Awalt, J. "Operators Race to Build Pipelines as Permian Nears Takeaway Capacity." Pipeline & Gas Journal. Vol. 245, No. 3, March 2018.

help alleviate existing bottlenecks and inefficiencies in the pipeline network, but congestion and inefficiencies may remain for the foreseeable future as production in the Permian ramps up ever more.

Figure 9
Projected Increase in Crude Oil Production in the U.S. by Region
(millions of barrels per day, 2016 through 2050)

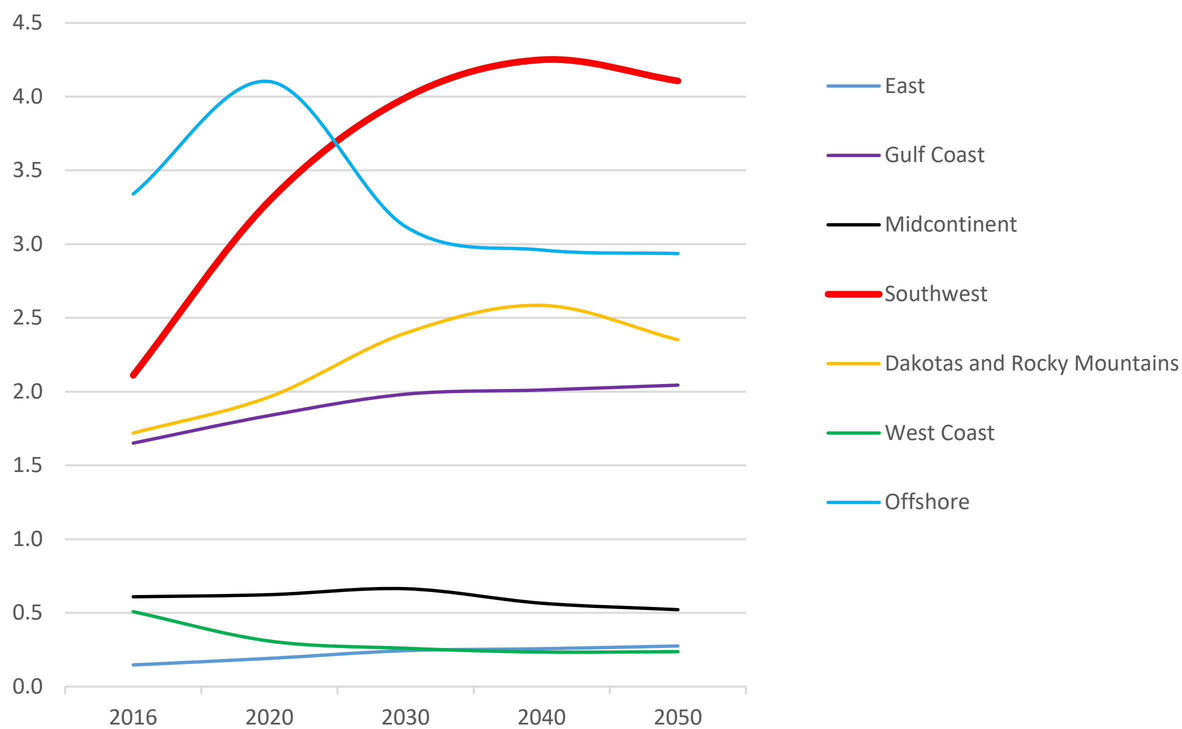
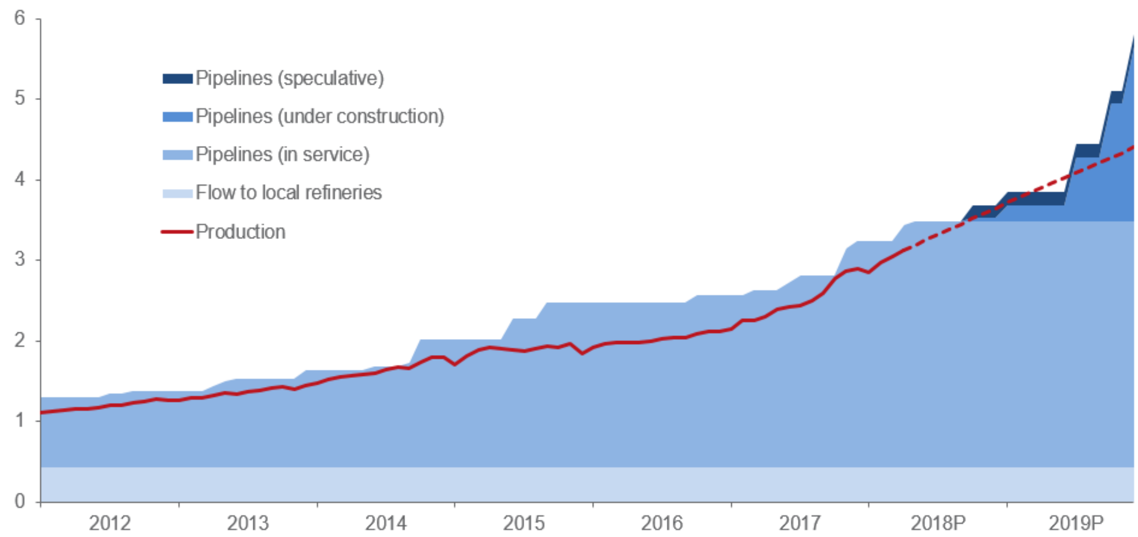


Figure 10
Permian Basin Crude Oil Production and Pipeline Capacity



Years followed by "P" indicate projections. The dashed line represents the Permian Basin production forecast.
Source: Kaplan, R.S. "A Perspective on Oil." Federal Reserve Bank of Dallas. July, 19, 2018.

Given projected increases in output and a squeeze on transportation infrastructure, it is not likely that U.S. oil exports will fall off a cliff even as the spread between WTI and Brent waxes and wanes.[16] It is likely that shipments remain well supported by regional price differences and other factors. Industry experts at the Oil Price Information Service noted that $4 per barrel is a level that one would expect the Brent-WTI spread to average over the course of a year; and, even at $4 a barrel there is enough buying incentive among foreign purchasers to keep U.S. exports at a million barrels a day at minimum.[17]

The Gulf Coast shipping industry is expecting that oil exports will continue as well, and is investing accordingly. The region's key shipping hubs - Corpus Christi, Houston and Beaumont in Texas, and St. James in Louisiana are planning to add at least 54 million barrels of storage capacity, and expand berthing capacity at 40 terminals.[18] In June of this year, The Port of Corpus Christi approved a bond resolution authorizing the Port to issue up to $217 million in revenue bonds to help finance major capital improvements, including the Corpus Christi Ship Channel that is slated for deepening from 45 to 54 feet, which can accommodate Suezmax and larger tankers (Very Large Crude Carriers or VLCCs). The

[16] According to its Short-term Energy Outlook (August 2019), EIA expects that WTI crude prices will average about $6 per barrel lower than Brent prices in 2018 and in 2019.

[17] DiChristopher, T. "U.S. Crude Discount to Brent is Shrinking, Creating Risk to Booming American Oil Exports." CNNB Markets. January, 29th 2018.

[18] Nussbaum, A. "Shale Surge Crashes Into Bottlenecks from Pipelines to Ports." Bloomberg Markets, May, 29th 2018.

financing will also allow the port to continue developing more terminals capacity needed to handle oil and gas from the Eagle Ford and Permian Basin. Inland carriers are also expanding. For instance, in 2014, Kirby Corporation invested $135 million to construct 66 new inland barges. Similarly, in 2016, the company spent $231 million for its expansion along the Gulf. Today, petrochemicals account for roughly one half of revenues of major industry players such as Kirby.[19]

As illustrated previously, traffic on the GIWW through the study area has increased in recent years driven primarily by increases in up bound crude oil, and this should continue at least through medium term as production in the Permian Basin and Eagle Ford shale formations increases. Most oil coming from these areas is going to one of several destinations - the Port Christi of Corpus Christi, the Port of Houston or terminals further east along the GIWW such as those in Beaumont and Port Arthur – where it is refined or exported to foreign markets or refineries along the U.S. East Coast.[20] Most west Texas oil is going to Corpus Christi, Houston, Beaumont Port Arthur or terminals in Louisiana. Options to move crude oil from west Texas wellheads domestic refineries consists of truck, pipeline, rail, and deep draft barge connections at Corpus Christi and Matagorda Ship Channels. Major ports and petrochemical refineries along the GIWW are well generally equipped for high volume intermodal liquid bulk cargo.

Oil shipped by GIWW inland barges through the study area is being transported by pipeline from West Texas well fields and trans-loaded onto barges or rail at terminals near Corpus Christi and the Matagorda Ship Channel. West Texas crude is also flowing to terminals and refineries via rail and ocean going Articulated Tug Barges (ATBs) and Jones Act tankers. Houston has become a refining hub and the Port of Corpus Christi is becoming an export hub for foreign markets and East Coast refineries. The Port of Brownsville may also become a significant exporter.[21] Refineries in East Texas, which had been importing most of their feedstock (heavy, medium and light crude) from foreign producers, have increasingly switched to domestic oil. For example, as shown in Table 9, imports of foreign crude to refineries in Texas and Louisiana have fallen by almost 50 percent in the past decade or so, and imports of light Brent crude from sources such well fields in the North Sea and Mideast have dropped off altogether. In other words, Gulf refiners have more or less switched to WTI because it's much cheaper, which has a significant impact to refinery profit margins. At the same time, Gulf Coast refineries are operating at near capacity (tables 10 and 11).

[19] Marine News, "Barge Market Report: 2016-2024," April 2018.

[20] According to the EIA, the East Coast is receiving the highest crude volumes by tanker and barge from the Gulf Coast since 2014, while crude by rail shipments from the Midwest have slumped 77 percent from a late-2014 peak. A build out of new fleets of tankers and barges along the Gulf Coast has made shipping crude oil to the East Coast by water less expensive. Trade press reports indicate that a number of coastwise-compliant vessels were built in the past several years, helping to lower the costs of transporting domestic crude oil from the Gulf to East Coast terminals. Source: Hallahan, K., Hamilton, M. and Mueller, K., "East Coast Refiners Receiving More Domestic Crude Oil from Gulf Coast by Tanker and Barge." U.S. Energy Information Administration Short-term Oil Outlook, September, 2018.

[21] JupiterMLP is constructing a 670 mile, dedicated crude oil pipeline originating Orla, Texas, with additional inject and offtake points at Pecos and Three Rivers, Texas. It will terminate at the Port of Brownsville at Jupiter's fully intermodal crude upgrading, processing and export terminal, which is currently under construction. The Port of Corpus Christi is teaming with the Carlyle Group to build a new crude export terminal capable of handling Very Large Crude Carriers (VLCCs), which are currently too large to access Gulf Coast ports.

Table 9
Annual Imports of Foreign Crude Oil to Coastal Refineries in Texas and Louisiana*
(2009 and 2017, 1000s of tons)

Oil Grade	2009	2017	Percent Change
Light	25,315	0	-100%
Medium	18,676	5,373	-71%
Heavy	44,757	34,196	-24%
Total	88,748	39,569	-55%

Excludes Canadian heavy oil. Source: U.S. Energy Information Agency

Table 10
Crude Refining Capacity for Louisiana Gulf Facilities
(millions of tons per year)

Year	Gross Inputs	Capacity	Excess	Utilization
2010	158.4	179.1	20.7	88%
2011	165.7	181.5	15.8	91%
2012	163.9	182.9	19.0	90%
2013	164.6	184.3	19.7	89%
2014	169.8	185.4	15.6	92%
2015	175.1	187.4	12.3	93%
2016	177.1	188.9	11.8	94%
2017	179.6	189.1	9.5	95%

Source: U.S. Energy Information Agency

Table 11
Crude Refining Capacity for Louisiana Texas Facilities
(millions of tons per year)

Year	Gross Inputs	Capacity	Excess	Utilization
2010	187.3	208.0	20.7	90%
2011	180.9	207.4	26.6	87%
2012	192.3	209.3	17.0	92%
2013	204.4	227.5	23.1	90%
2014	210.2	230.2	20.0	91%
2015	215.5	235.5	20.0	91%
2016	215.5	245.6	30.1	88%
2017	223.6	253.0	29.4	88%

Source: U.S. Energy Information Agency

Even as pipeline and port capacity expands, continual growth in oil production has caused the oil glut and the price spread to persist. As such, use of alternate transport modes (rail, truck and barge) to move crude from the Permian to the Gulf Coast will likely continue. Granted this will not be a "revolution" or "renaissance" for barge transportation on the GIWW. Most of the oil coming out West Texas will do so strictly through pipelines, but volumes shipped by barge on the GIWW will very likely increase well above historic levels typical of conditions before shale oil production in Texas began in earnest. In addition, implementation of a plan that increases the efficiency and safety of navigation through the CRL and BRFG (i.e., reduces delays and accidents) implicitly would reduce the costs of shipping by barge, which could further increase demands for barge shipping. However, there is significant uncertainty surrounding future crude oil traffic through the study area. Shipments rose sharply in 2010 through 2015, but have since dropped off considerably, although they are still well above historical averages since 1991.

Reasons for the drop off are not clear, but the primary factor was very likely the lifting of the embargo on exports of domestic crude in 2016. The ability to export has relieved supply pressures and much of the crude that was trying to find a home in the U.S, has ended up at refineries in Europe and Asia. At the time, Gulf coast refineries were (and are) operating near or at capacity, and there is only so much light crude that they can process or blend with heavier grades. At some point, inefficiencies in the refining process prevent adding more light oil to the mix. New pipeline capacity from West Texas to the Gulf probably played a role as well.

4.1.2 Final Projections with Regional Crude Oil and Petroleum Production Forecasts

Section 4.1.2 presents final study projections. As noted previously, assumptions are the same as those for the draft projections with the exception of using regional production forecasts for crude oil and petroleum products. In addition, three-year average (2014 through 2016) of traffic volumes serves as the forecast baseline. Table 11 shows EIA projections for crude and petroleum products, and Tables 12 through 14 and Figure 12 summarize final study projections.

Table 11
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 economic growth	14.81	20.57	23.62	22.41	20.93	41%	1.0%
Low economic growth	14.81	16.16	15.51	14.95	14.96	1%	0.03%
High oil prices	14.81	17.87	19.37	19.75	19.27	30%	0.8%
Low oil prices	14.81	20.57	23.62	22.41	20.93	41%	1.0%
Crude oil	2016	2020	2035	2040	2050	Percent Change	CAGR
Reference case	2.11	3.29	3.99	4.25	4.11	95%	2.0%
High economic growth	2.11	3.3	4.02	4.28	4.14	96%	2.0%
Low economic growth	2.11	3.29	3.96	4.13	3.86	83%	1.8%
High oil prices	2.11	4.63	5.36	4.9	4.28	103%	2.10%
Low oil prices	2.11	2.62	2.53	2.44	2.47	17%	0.46%

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

Table 12
Final BFRG-CRL Commodity Flow Projections (all commodities, 1000s of tons, 2016 through 2067)

Historical			
	Down	Up	Total
2002	5,336	11,380	16,716
2003	5,393	13,172	18,565
2004	5,878	13,157	19,035
2005	5,099	13,076	18,175
2006	5,464	13,267	18,731
2007	5,945	12,924	18,869
2008	5,287	11,723	17,010
2009	4,720	10,369	15,089
2010	5,250	12,307	17,557
2011	5,658	11,919	17,577
2012	6,296	15,014	21,310
2013	5,272	17,075	22,347
2014	6,998	19,426	26,424
2015	5,348	16,660	22,008
2016	5,699	13,554	19,253

Projected									
	Down			Up			Total		
	Base	Low	High	Base	Low	High	Base	Low	High
Base year (average 2014-2016)	6,015	6,015	6,015	16,553	16,553	16,553	22,568	22,568	22,568
2020	7,001	6,577	8,059	21,671	19,004	27,388	28,672	25,581	35,447
2025	7,574	6,804	9,064	23,995	19,393	31,127	31,569	26,197	40,191
2030	7,980	6,910	9,514	25,471	19,424	32,097	33,451	26,334	41,611
2035	8,325	7,077	9,693	26,555	19,570	31,824	34,880	26,647	41,517
2040	8,624	7,296	9,768	27,420	19,925	31,301	36,044	27,221	41,069
2045	8,823	7,560	9,781	27,715	20,407	30,191	36,538	27,967	39,972
2050	8,850	7,668	9,752	27,370	20,629	29,464	36,220	28,297	39,216
2055	8,850	7,668	9,752	27,370	20,629	29,464	36,220	28,297	39,216
2060	8,850	7,668	9,752	27,370	20,629	29,464	36,220	28,297	39,216
2067	8,850	7,668	9,752	27,370	20,629	29,464	36,220	28,297	39,216
Percent change (2016-2067)	47.1%	27.5%	62.1%	65.3%	24.6%	78.0%	60.5%	25.4%	73.8%
CAGR* (2016-2067)	0.8%	0.5%	1.0%	1.0%	0.4%	1.2%	1.0%	0.5%	1.1%

*Compound annual growth rate

Figure 12
Historical and Final Projected BRFG-CLR Tonnage
(all commodities, 1991 through 2067)

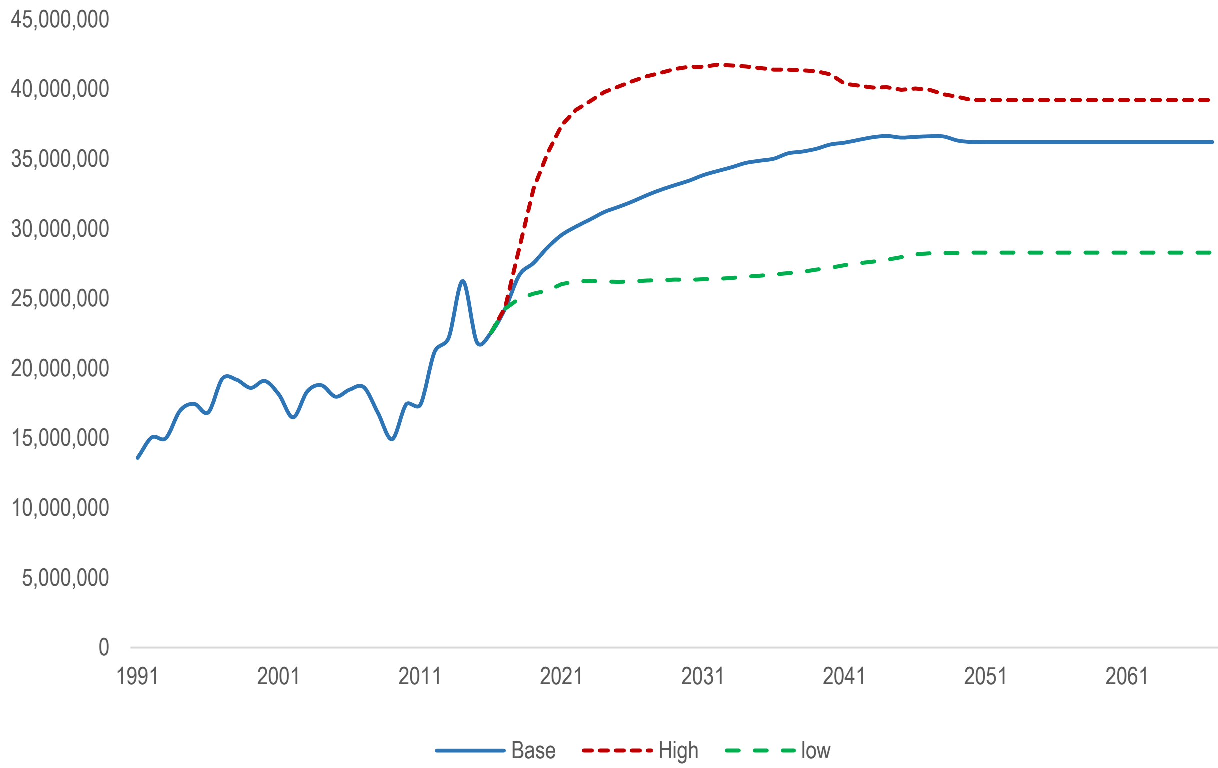


Table 13
Final Down-Bound Projected Tonnage through Brazos River Flood Gates and Colorado River Locks by Commodity (1000s of tons, 1991 through 2067)

Year	Aggregates	Chemicals	Coal	Crude Oil	Grains and grain products	Iron ore, iron and steel products	Non-metallic minerals	Petroleum products	Misc.	Total
Down-bound Historical (2002 through 2016)										
2002	30	1,773	7	140	46	209	18	3,105	7	5,336
2003	33	1,670	13	175	28	451	15	2,977	32	5,393
2004	102	1,578	0	154	11	203	587	3,201	42	5,878
2005	107	1,269	8	47	17	251	18	3,370	12	5,099
2006	41	1,117	13	43	9	140	17	4,058	25	5,464
2007	0	979	7	29	11	372	28	4,498	20	5,945
2008	0	963	25	9	29	428	61	3,742	31	5,287
2009	16	743	18	61	61	99	21	3,688	13	4,720
2010	33	1,426	27	2	57	258	25	3,374	48	5,250
2011	223	1,397	15	11	92	319	25	3,507	69	5,658
2012	695	1,492	3	150	30	182	78	3,621	45	6,296
2013	471	1,481	8	83	11	159	7	3,029	23	5,272
2014	1,228	1,550	23	585	2	87	49	3,459	15	6,998
2015	557	1,317	33	253	3	97	10	3,056	22	5,348
2016	184	1,650	26	242	19	159	9	3,375	34	5,699
Down-bound Projections (Base Case)										
Base year [1]	656	1,506	28	360	8	114	23	3,297	24	6,015
2020	656	1,610	28	562	8	114	23	3,977	24	7,001
2025	656	1,879	28	638	8	114	23	4,206	24	7,574
2030	656	2,136	28	681	8	114	23	4,311	24	7,980
2035	656	2,393	28	707	8	114	23	4,373	24	8,325
2040	656	2,652	28	725	8	114	23	4,395	24	8,624
2045	656	2,910	28	719	8	114	23	4,342	24	8,823
2050	656	3,010	28	700	8	114	23	4,287	24	8,850
2055	656	3,010	28	700	8	114	23	4,287	24	8,850
2060	656	3,010	28	700	8	114	23	4,287	24	8,850
2067	656	3,010	28	700	8	114	23	4,287	24	8,850
Percent change	0.0%	99.9%	0.0%	94.5%	0.0%	0.0%	0.0%	30.1%	0.0%	47.1%
CAGR [2]	0.0%	1.4%	0.0%	1.3%	0.0%	0.0%	0.0%	0.5%	0.0%	0.8%
Down-bound Projections (Low Scenario)										
Base year	656	1,506	28	360	8	114	23	3,297	24	6,015
2020	656	1,681	28	446	8	114	23	3,597	24	6,577
2025	656	1,914	28	444	8	114	23	3,594	24	6,804
2030	656	2,175	28	431	8	114	23	3,451	24	6,910
2035	656	2,437	28	419	8	114	23	3,369	24	7,077
2040	656	2,701	28	415	8	114	23	3,327	24	7,296
2045	656	2,964	28	414	8	114	23	3,329	24	7,560
2050	656	3,066	28	421	8	114	23	3,329	24	7,668
2055	656	3,066	28	421	8	114	23	3,329	24	7,668
2060	656	3,066	28	421	8	114	23	3,329	24	7,668
2067	656	3,066	28	421	8	114	23	3,329	24	7,668
Percent change	0.0%	103.6%	0.0%	16.9%	0.0%	0.0%	0.0%	1.0%	0.0%	27.5%
CAGR	0.0%	1.4%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%
Down-bound Projections (High Scenario)										
Base year [2]										

Table 13

Final Down-Bound Projected Tonnage through Brazos River Flood Gates and Colorado River Locks by Commodity (1000s of tons, 1991 through 2067)

Year	Aggregates	Chemicals	Coal	Crude Oil	Grains and grain products	Iron ore, iron and steel products	Non-metallic minerals	Petroleum products	Misc.	Total
2020	656	1,506	28	360	8	114	23	3,297	24	6,015
2025	656	1,841	28	789	8	114	23	4,577	24	8,059
2030	656	2,192	28	905	8	114	23	5,114	24	9,064
2035	656	2,492	28	915	8	114	23	5,255	24	9,514
2040	656	2,792	28	877	8	114	23	5,172	24	9,693
2045	656	3,094	28	835	8	114	23	4,986	24	9,768
2050	656	3,395	28	765	8	114	23	4,768	24	9,781
2055	656	3,512	28	730	8	114	23	4,658	24	9,752
2060	656	3,512	28	730	8	114	23	4,658	24	9,752
2067	656	3,512	28	730	8	114	23	4,658	24	9,752
Percent change	656	3,512	28	730	8	114	23	4,658	24	9,752
CAGR	0.0%	133.2%	0.0%	102.9%	0.0%	0.0%	0.0%	41.3%	0.0%	62.1%

1 Average of 2014 through 2016

2 Compound annual growth rate

Table 14
Final Up-Bound Projected Tonnage through Brazos River Flood Gates and Colorado River Locks by Commodity (1000s of tons, 1991 through 2067)

Year	Aggregates	Chemicals	Coal	Crude petroleum	Grains and grain products	Iron ore, iron and steel products	Non-metallic minerals	Petroleum products	Misc.	Total
Up-bound Historical (2002 through 2016)										
2002	2,393	3,696	10	477	0	49	595	3,936	222	11,380
2003	2,696	3,812	5	479	0	31	1,178	4,757	213	13,172
2004	1,346	4,096	28	899	2	83	1,306	5,154	241	13,157
2005	1,270	3,880	77	421	0	67	1,259	5,903	197	13,076
2006	1,707	3,782	75	333	0	52	1,086	5,983	246	13,267
2007	1,401	3,749	82	362	0	82	808	6,222	215	12,924
2008	1,434	3,221	70	313	0	104	727	5,648	204	11,723
2009	960	2,984	26	231	5	100	370	5,535	156	10,369
2010	873	3,278	8	369	25	133	545	6,952	122	12,307
2011	737	3,360	49	2,207	0	290	492	4,618	165	11,919
2012	446	3,200	26	5,347	0	253	549	5,059	131	15,014
2013	507	2,858	42	7,377	0	241	525	5,378	145	17,075
2014	349	2,919	63	10,068	0	179	492	5,189	166	19,426
2015	856	2,890	56	7,149	16	115	550	4,890	136	16,660
2016	1,433	2,773	89	3,363	33	43	112	5,562	143	13,554
Up-bound Projections (Base Case)										
Base year [1]	880	2,861	69	6,860	25	112	384	5,213	148	16,553
2020	880	3,058	69	10,705	25	112	384	6,290	148	21,671
2025	880	3,570	69	12,156	25	112	384	6,651	148	23,995
2030	880	4,058	69	12,977	25	112	384	6,818	148	25,471
2035	880	4,546	69	13,475	25	112	384	6,915	148	26,555
2040	880	5,038	69	13,812	25	112	384	6,951	148	27,420
2045	880	5,529	69	13,700	25	112	384	6,866	148	27,715
2050	880	5,625	69	13,346	25	112	384	6,781	148	27,370
2055	880	5,625	69	13,346	25	112	384	6,781	148	27,370
2060	880	5,625	69	13,346	25	112	384	6,781	148	27,370
2067	880	5,625	69	13,346	25	112	384	6,781	148	27,370
Percent change	0.0%	96.6%	0.0%	94.5%	0.0%	0.0%	0.0%	30.1%	0.0%	65.3%
CAGR 2	0.0%	1.4%	0.0%	1.3%	0.0%	0.0%	0.0%	0.5%	0.0%	1.0%
Up-bound Projections (Low Scenario)										
Base year	880	2,861	69	6,860	25	112	384	5,213	148	16,553
2020	880	3,194	69	8,502	25	112	384	5,688	148	19,004
2025	880	3,636	69	8,455	25	112	384	5,684	148	19,393
2030	880	4,133	69	8,214	25	112	384	5,458	148	19,424
2035	880	4,630	69	7,994	25	112	384	5,327	148	19,570
2040	880	5,132	69	7,913	25	112	384	5,262	148	19,925
2045	880	5,632	69	7,891	25	112	384	5,265	148	20,407
2050	880	5,729	69	8,017	25	112	384	5,265	148	20,629
2055	880	5,729	69	8,017	25	112	384	5,265	148	20,629
2060	880	5,729	69	8,017	25	112	384	5,265	148	20,629
2067	880	5,729	69	8,017	25	112	384	5,265	148	20,629
Percent change	0.0%	100.2%	0.0%	16.9%	0.0%	0.0%	0.0%	1.0%	0.0%	24.6%
CAGR	0.0%	1.4%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
Up-bound Projections (High Scenario)										
Base year [2]										

Table 14
Final Up-Bound Projected Tonnage through Brazos River Flood Gates and Colorado River Locks by Commodity (1000s of tons, 1991 through 2067)

Year	Aggregates	Chemicals	Coal	Crude petroleum	Grains and grain products	Iron ore, iron and steel products	Non-metallic minerals	Petroleum products	Misc.	Total
2020	880	2,861	69	6,860	25	112	384	5,213	148	16,553
2025	880	3,497	69	15,034	25	112	384	7,238	148	27,388
2030	880	4,164	69	17,256	25	112	384	8,088	148	31,127
2035	880	4,734	69	17,433	25	112	384	8,311	148	32,097
2040	880	5,304	69	16,722	25	112	384	8,180	148	31,824
2045	880	5,878	69	15,918	25	112	384	7,886	148	31,301
2050	880	6,451	69	14,581	25	112	384	7,541	148	30,191
2055	880	6,562	69	13,917	25	112	384	7,366	148	29,464
2060	880	6,562	69	13,917	25	112	384	7,366	148	29,464
2067	880	6,562	69	13,917	25	112	384	7,366	148	29,464
Percent change	880	6,562	69	13,917	25	112	384	7,366	148	29,464
CAGR	0.0%	129.4%	0.0%	102.9%	0.0%	0.0%	0.0%	41.3%	0.0%	78.0%

1 Average of 2014 through 2016
2 Compound annual growth rate

4.1.3 Potential for Modal Shifts

GIWW efficiencies and reliability including problems addressed in this study have dwindled overtime due to aging infrastructure, and will continues to do so under the future without project conditions. As discussed in this study and in the State of Texas's GIWW Master Plan increasing inefficiencies are a major concern for GIWW stakeholders. As inefficiencies worsen over the period of analysis, demand for shipping on the GIWW could decline. Under the with-project condition, system efficiency, safety and reliability increase, which implicitly reduces line haul shipping costs on the GIWW, and could result in a new equilibrium state for the region's transportation system where traffic moves from alternative modes to the inland waterway. Section 4.1.3 briefly discusses the potential for induced tonnage with focus on crude oil.

The potential for induced tonnage would depend on several factors. For one, as discussed in the theoretical underpinnings of the BFRG-CRL economic model, elasticity of demand, which is derived demand, for GIWW barges is the defining conceptual factor. Elastic demand implies a greater induced response to change in system transportation costs, and conversely inelastic demand means a smaller response to price. In general, demand for alternative modes is inelastic given that shipping costs make up a small part of the supply chain. For example, getting oil from a well to a car's gas tank is a long complicated and expensive process, and moving crude to refineries is minimal relative other costs such extraction and processing. There are also related practical considerations such as the relative cost of different modes, and whether there are capacity constraints both in terms of line haul and landside terminal transfer and storage. Lastly, the amount of cargo moving by different modes plays a role.

Budget and time constraints prohibit a detailed analysis of origin and destination pairs by mode, but some general data are available that give a good picture of modal shares. Table 15 displays crude oil movements to and from EIA's Petroleum Administration Defense District (PADD) 3, which consists of Gulf Coast states; and although the data do not include movements within PADD 3, the data do illustrate the predominance of pipelines.

Table 15
Movement of Crude Oil to and from Petroleum Administration Defense District 3 (PADD 3 – Gulf Coast) from other U.S. PADDs
(millions of tons, 2012 through 2017)

From PADD 3	2012	2013	2014	2015	2016	2017	Share 2017
Pipeline	48.31	45.75	45.09	41.69	48.56	50.48	96.8%
Rail	0.09	0.08	0.27	0.25	0.08	0.11	0.2%
Tanker and Barge	0.21	2.23	5.36	3.38	1.54	1.53	2.9%
Total	48.61	48.06	50.72	45.32	50.17	52.12	100.0%
To PADD 3							
Pipeline	12.03	20.19	31.64	46.01	48.08	68.03	96.3%
Rail	10.19	13.30	11.37	7.95	3.98	1.52	2.1%
Tanker and Barge	3.19	6.78	5.18	3.38	1.34	1.07	1.5%
Total	25.41	40.27	48.20	57.34	53.39	70.62	100.0%

Source: U.S. Energy Information Agency

For the purposes of this study, traffic within PADD 3 from West Texas to Gulf Coast is most relevant, particularly crude moving from West Texas to the Corpus Christi and Brownsville. With the exception rail movements, EIA does not publish intra-PADD data for tanker, barge and pipeline; however, as a rough estimate based on USACE data and other secondary sources, Table 16 provides of estimates of crude oil volumes flowing to Corpus Christi via existing pipelines, and transfers to domestic refineries by mode (i.e., rail, inland barge or ATB). Note that the total inbound tonnage for pipelines does not include pipeline capacity or terminal construction currently underway such as Jupiter MLP's pipeline and new terminal at the Port of Brownsville.

Table 16
Estimated West Texas Crude Oil Shipments to the South Texas Ports of Corpus Christi, Domestic Trans-shipments by Mode, and Foreign Exports
(2017, millions of tons)

	Millions of tons
Inbound Pipeline (Cactus)	33.07
Domestic Trans-shipments	
UP Rail Line (Brownsville to Corpus to Houston)	0.40
Up-bound inland barge on GIWW	3.00
Jones Act Tankers and Articulated Tug Barges	7.70
Total Trans-shipment to Domestic Terminals	13.70
Foreign Exports	17.37

Source: Based on data from the Waterborne Commerce Statistics Center, U.S. Energy Information Administration, Willauer, D.O. "North American Crude Oil Transportation." IEM Report, October 2014.

In theory, a clear candidate for induced tonnage would be a shift from rail to inland barge given economies of scale and some flexibility advantages of barges. While rail carriers do ship substantial amounts of refined product and chemicals to and from Gulf Coast terminals, they do not handle large volumes of crude. Table 17 shows rail movements of crude within PADD 3 (Gulf Coast), and when compared to pipeline or waterborne movements, they are relatively small and have declined by about 93 percent since 2012. Union Pacific operates the primary coastal line in Texas running from Brownsville to Houston and New Orleans. From Corpus or Brownsville, crude shipments by rail are currently minimal (estimated at 0.40 million tons per annum). This is likely due to capacity constraints as well as availability of GIWW barges and coast wise vessels including a ATBs.

Table 17
Crude Oil Rail Movements within PADD 3 (Gulf Coast)
(2012 through 2017, tons)

2012	2013	2014	2015	2016	2017	Percent Change (2012 through 2017)
2,411,869	2,836,698	1,913,643	717,462	97,817	166,576	-93%

Source: U.S. Energy Information Agency

Most trans-shipments from Corpus are via GIWW barges and ATBs. Improvements in efficiency in the with-project condition would likely have to lower costs substantially to induce tonnage from coastwise vessels to inland barges. When compared to inland barges, ATBs are much with capacities ranging up to 300,000 barrels of oil (compared with 30,000 for a large inland tank barge), and they are about four times as fast.[22] ATBs are relatively new to the scene, and in general, transportation modes all benefit from economies of scale whether in terms of the modes carrying the cargo or operational systems such as locks

[22] Harrison, R. "Impact of the Gulf Intracoastal Waterway (GIWW) on Freight Flows in the Texas-Louisiana Megaregion." Texas Transportation Institute Report 600451-00080-1, June 2015.

that allow greater size or length, and it is an important factor in modal selection.[23] Now the barge industry has a system that matches the economic benefits of other systems - providing a barge solution equivalent to longer, heavier trains, larger containerships or tankers. One disadvantage is that given their size ATBs are limited in terms of accessing inland terminals. Again, whether the with-project condition would induce tonnage away from ATBs is unclear and would require a rate analysis in addition to research regarding capacity constraints and planned future capacity for both inland barges and coastwise vessels. But they do have an advantage in moving oil coming directly into terminals at deep draft ports destined for refineries along the Gulf or U.S. East Coast.

While the focus here regarding induced tonnage involves crude oil, the with-project scenario could encourage shifts to the waterway for other commodities, particularly petrochemicals. As discussed previously, the petrochemical industry along the Gulf is expanding, and increases in efficiency on the waterway might divert cargo from rail onto barge.

5.0 Key Uncertainties in Final Study Projections

Reasons for the drop off are not entirely clear, but a primary factor was likely the lifting of the embargo on exports of domestic crude in 2015. The ability to export has relieved supply pressures and much of the crude that was trying to find a home in the U.S, has ended up at refineries in Europe and Asia. At the time, Gulf coast refineries were (and are) operating near or at capacity, and there is only so much light crude that they can process and blend with heavier grades. At some point, inefficiencies in the refining process prevent adding more light oil to the mix. New pipeline capacity from West Texas to the Gulf probably played a role as well as did the narrowing of the Brent and West Texas Intermediate oil benchmark prices.

While it is true that ports, carriers and pipeline operators are building capacity (i.e., trying to catch up with the glut of oil coming out of the ground) in response to increased West Texas oil production and the market for oil transportation is a state of flux, there may be periods of excess capacity and under capacity. In other words, the market is in disequilibrium, and there are a lot of moving parts related to both capacity, volumes and rates of oil production, and annual volumes shipped through the study may vary considerably. In general, several important risks and uncertainties with final study projections used to estimate NED benefits are warranted.

1) Future volumes of crude oil shipped through the BRFG-CRL will likely depend upon the ability and desire of energy companies to expand regional pipeline capacity. If pipelines are full, there will be overflow that probably ends up on inland barges moving up the GIWW. Whether pipelines will keep up with the amount of production is unclear.

2) Refining capacity will also be a factor. As noted previously, Gulf coast refineries are operating at near capacity and have eliminated imports of Brent crude completely. For crude oil volumes to both increase and sustain at projected levels, there may have to additional refining capacity and this is happening. For example, in January of 2019 Exxon announced construction of a new

[23] Based on terse review of trade publications, there are about 275 coastal tank barges operating in the U.S., including integrated tug-barges (ITBs) and ATBs. Kirby is the largest with 81 vessels followed by Vane Brothers with 50. Crowley Maritime is the leader in ATBs with 17.

crude-processing unit in Beaumont, Texas that will increase capacity by more than 65 percent, or 250,000 barrels per day. The decision to build this third crude unit within the facility's existing footprint will expand light crude oil refining, supported by increased crude oil production in the Permian Basin. Start-up is anticipated by 2022.

3) The price of Brent (European) light oil will have to remain higher than West Texas Intermediate (WTI) to sustain GIWW crude oil movements at projected levels. Historically, Brent has been much cheaper than WTI and Gulf refineries would import it for blending; however, Permian production has vastly increased U.S. supplies and since early 2010, WTI has priced below Brent by as much as $25 a barrel. This has made it very attractive to Gulf refineries that use light crude as feedstock.

4) Potential increases in traffic at levels projected may result in more congestion on the waterway, and thus additional queuing in the with-project scenario, which in turn could decrease efficiency or offset project benefits. Although, it is important to note that at peak historical volumes in 2014, there were no reports of major delays or congestion and the decline in shipments in subsequent years was likely due to factors discussed above.

In light of the risks and uncertainties surrounding study projections given the abrupt and dynamic nature of crude oil and natural gas supply and demand, future updates of study updates will be critical. As infrastructure develops and the regional transportation for crude petroleum market stabilizes (assuming it does), commodity forecasts that are important drivers of NED benefits and plan evaluation should be reevaluated.