GLMRIS – Brandon Road

Appendix D - Economic Analyses

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CONTENTS

D.1 INTRODUCTION **8**

D.2 ECONOMIC CONSEQUENCES OF SILVER AND BIGHEAD CARP ESTABLISHMENT IN LAKE ERIE **11**

D.2.1 Review of GLMRIS Report Findings: Baseline Economic Assessments of Fishing Activities in the Great Lakes Basin **12**

D.2.2 Total Values Versus Changes in Values **14**

D.2.3 New Environment in the Great Lakes Basin With AC Establishment **15**

D.2.4 Economic Activities Potentially Affected by Asian Carp Establishment in the Great Lakes Basin **16**

D.2.4.1 Description of What Can be Quantified 16
D.2.4.2 Summary of Key Species & Lake Erie NOAA Model 18
D.2.4.3 Overview of Differences between NED and RED 21

D.2.5 National Economic Development (NED) Analysis: Economic Consequences of AC Establishment in Lake Erie **22**

D.2.5.1 Overview of NED Approach 22
D.2.5.2 NED Analysis – Commercial Fishing 23
D.2.5.3 NED Analysis – Recreational Fishing 25
D.2.5.4 NED Analysis – Charter Fishing 26
D.2.5.5 Summary of NED Analysis 27

D.2.6 Regional Economic Development (RED) Analysis: Economic Consequences of AC Establishment in Lake Erie **29**

D.2.6.1 RED Approach Overview 29
D.2.6.2 RED Analysis – Great Lakes States' Commercial Fishing Industry 30
D.2.6.3 RED Analysis – Great Lakes States' Charter Fishing Industry 31
D.2.6.4 RED Analysis – Great Lakes States' Recreational Fishing Industry 32
D.2.6.5 Regional Economic Impact Summary and Conclusions 33

D.2.7 Summary and Conclusions **35**

D.3 IMPACTS TO NAVIGATION DUE TO GLMRIS-BR ALTERNATIVES **36**

D.3.1 Overview of GLMRIS-BR Alternative Plans & ANS Control Measures Used to Inform the Navigation Economic Analyses **38**

D.3.1.1 Review of ANS Control Measures and Considerations for Navigation at Brandon Road Lock and Dam 39

D.3.2 Historical Overview of Brandon Road Tonnage, Lock Size, and Tow Configurations **46**

D.3.2.1 Tonnage 46
D.3.2.2 Lock Size and Historic Tow Configurations 48

D.3.3 Impacts to Commercial Cargo Navigation due to GLMRIS-BR Alternatives: Methods and Results of NED Evaluation **51**

D.3.3.1 Methods 51
D.3.3.2 Waterway Analysis Model (WAM) 59
D.3.3.3 Navigation Investment Model (NIM) 60
D.3.3.4 Application of NIM Model for GLMRIS-BR 65
D.3.3.5 Results and Alternative Considerations 77

D.3.4 RED Evaluation: Impacts to Commercial Cargo Navigation due to GLMRIS-BR Alternatives **83**

D.3.4.1 RED Analysis Methods 84

D.3.4.2 Results 86
D.3.4.3 Conclusions 88
D.3.5 Safety Analysis: Impacts from Diversions of Commercial Cargo Navigation to Land Modes Due to GLMRIS-BR Alternatives 89
D.3.5.1 Evaluation Procedure 89
D.3.5.2 Data Sources 89
D.3.5.3 Impact Values 90
D.3.5.4 Incident Rates per Mile 91
D.3.5.5 Cost per Mile 91
D.3.5.6 Diverted Tonnage 93
D.3.5.7 Results 94
D.3.6 Impacts to Non-Cargo Navigation due to GLMRIS-BR Alternatives 97
D.3.6.1 Description of Impacts on Non-Cargo Users of Brandon Road Lock 97
D.4 AVERAGE ANNUAL COST OF ALTERNATIVE PLANS 102
D.4.1 Overview of Costs for Nonstructural and Structural ANS Control Measures and Features 104
D.4.1.1 Nonstructural Measures 104
D.4.1.2 Real Estate Acquisition....105
D.4.1.3 Boat Launches 105
D.4.1.4 Flushing Lock....105
D.4.1.5 Engineered Channel....106
D.4.1.6 Fish Entrainment Mitigation (Water Jets) 106
D.4.1.7 Complex Noise....107
D.4.1.8 Electric Barrier 107
D.4.1.9 Mooring Cells....108
D.4.1.10 Lock Closure (ANS Control Measure) 108
D.4.1.11 Mitigation During Construction 108
D.4.1.12 Monitoring and Adaptive Management....108
D.4.1.13 Operation, Maintenance, Repair, Rehabilitation, and Replacement (OMRR&R) 110
D.4.2 Estimates of AAC for Alternative Plans 112
D.4.2.1 AAC Estimate: No New Federal Action....113
D.4.2.2 AAC Estimate: Nonstructural Alternative....113
D.4.2.3 AAC Estimate: Technology Alternative – Electric Barrier 113
D.4.2.4 AAC Estimate: Technology Alternative – Complex Noise 113
D.4.2.5 AAC Estimate: Technology Alternative – Complex Noise with Electric Barrier .114
D.4.2.6 AAC Estimate: Technology Alternative – Lock Closure Alternative....114
D.4.2.7 Summary of AAC Estimates for the Final Array of GLMRIS-BR Alternatives....115
D.5 REFERENCES 116

TABLES

TABLE 1 NOAA MODEL SCENARIOS UTILIZED FOR ECONOMIC CONSEQUENCE ASSESSMENT OF ASIAN CARP ESTABLISHMENT IN LAKE ERIE 19

TABLE 2. PERCENTAGE CHANGE IN BIOMASS FOR LAKE ERIE SPECIES GROUPS ADVERSELY AFFECTED BY ASIAN CARP (FOR SCENARIOS CONSIDERED IN NOAA MODEL)* 19

TABLE 3 PERCENTAGE CHANGES IN BIOMASS FOR KEY RECREATIONAL AND CHARTER SPECIES IN LAKE ERIE (BASED ON NOAA MODEL)* 20

TABLE 4 LAKE ERIE COMMERCIAL FISHERY HARVEST (POUNDS) AND DOCKSIDE VALUE (DOLLARS) BY SPECIES – FIVE-YEAR AVERAGE (2009-2013) 24

TABLE 5 RESULTS OF NED ANALYSIS FOR COMMERCIAL FISHING IN LAKE ERIE – BASED ON BIOMASS CHANGES ESTIMATED BY THE NOAA MODEL (CONSEQUENCES OF ASIAN CARP ESTABLISHMENT) 25

TABLE 6 RESULTS OF NED ANALYSIS FOR RECREATIONAL FISHING IN LAKE ERIE – BASED ON BIOMASS CHANGES ESTIMATED BY THE NOAA MODEL (CONSEQUENCES OF ASIAN CARP ESTABLISHMENT) 26

TABLE 7 RESULTS OF NED ANALYSIS FOR CHARTER FISHING IN LAKE ERIE – BASED ON BIOMASS CHANGES ESTIMATED BY THE NOAA MODEL (CONSEQUENCES OF ASIAN CARP ESTABLISHMENT) 27

TABLE 8 SUMMARY OF RESULTS OF NED ANALYSIS FOR COMMERICAL, RECREATIONAL, AND CHARTER FISHING IN LAKE ERIE – BASED ON BIOMASS CHANGES ESTIMATED IN NOAA'S LAKE ERIE MODEL (CONSEQUENCES OF ASIAN CARP ESTABLISHMENT) /1 28

TABLE 9 REGIONAL ECONOMIC IMPACTS OF ASIAN CARP ESTABLISHMENT IN LAKE ERIE ON THE COMMERCIAL FISHING INDUSTRY IN GREAT LAKES REGION 31

TABLE 10. REGIONAL ECONOMIC IMPACTS OF AC ESTABLISHMENT IN LAKE ERIE ON THE CHARTER FISHING INDUSTRY IN GREAT LAKES REGION 32

TABLE 11 GREAT LAKES ANGLERS: SPENDING PER TRIP PER DAY ($) 32

TABLE 12 GREAT LAKES ANGLERS: DIRECT EXPENDITURES PER FISHING TRIP ($) 33

TABLE 13 REGIONAL ECONOMIC IMPACTS OF ASIAN CARP ESTABLISHMENT IN LAKE ERIE ON THE RECREATIONAL FISHING INDUSTRY IN THE GREAT LAKES REGION 33

TABLE 14 SUMMARY OF RESULTS – REGIONAL ECONOMIC IMPACTS OF AC ESTABLISHMENT IN LAKE ERIE ON COMMERCIAL, RECREATIONAL, AND CHARTER FISHING INDUSTRIES IN GREAT LAKES STATES 34

TABLE 15 ANS CONTROL MEASURES INCLUDED IN GLMRIS-BR ALTERNATIVE PLANS 38

TABLE 16 SUMMARY OF ESTIMATED CHANGES TO STANDARD BRANDON ROAD LOCK OPERATIONS DUE TO CONSTRUCTION OF ANS CONTROLS (DESCRIPTION, FREQUENCY, AND DURATION) A, B, C 44

TABLE 17 SUMMARY OF ASSUMED CHANGES TO STANDARD BRANDON ROAD LOCK OPERATIONS DUE TO OPERATION OF ANS CONTROLS A, B, C, D 45

TABLE 18 ESTIMATED CHANGES TO STANDARD BRANDON ROAD LOCK OPERATIONS DUE TO MAINTENANCE, REPAIR, REHABILITATION, AND/OR REPLACEMENT (MRR&R) OF ANS CONTROLS A, B, C 45

TABLE 19 BRANDON ROAD LOCK TONNAGE (THOUSANDS) 1994-2014 47

TABLE 20 BARGES PER TOW AT BRANDON ROAD LOCK (YEARS 2009-2014) A 49

TABLE 21 NUMBER OF BARGES PER TOW (PERCENT OF OCCURRENCES) AT BRANDON ROAD LOCK (YEARS 2009-2014)A 50

TABLE 22 CUT PERCENTAGE FOR COMMERCIAL CARGO LOCKAGES AT BRANDON ROAD (YEARS 2009-2014) A 50

TABLE 23 WATERBORNE COMMERCE DATA VERIFICATION FOR BRANDON ROAD LOCK TONNAGE (YEARS 2012-2014) 67

TABLE 24 TARGET TONNAGE ESCALATION FACTOR BY COMMODITY GROUP FOR BRANDON ROAD LOCK (AVERAGE TONNAGE FOR YEARS 2012-2014) 67

TABLE 25 BRANDON ROAD NIM CALIBRATION - TARGETS VS. MODEL OUTPUT 73

TABLE 26 TOW SIZE RESTRICTIONS WITH A CONTINUOUSLY OPERATING ELECTRIC BARRIER 76

TABLE 27 TOWBOAT RESTRICTIONS WITH A CONTINUOUSLY OPERATING ELECTRIC BARRIER 77

Table 28 Estimated Impacts to Navigation (NED Costs) for GLMRIS-BR Alternatives 81
Table 29 Estimated Impacts to Navigation (NED Costs) for GLMRIS-BR Alternatives (Assume No Plant Closures) 82
Table 30 Expected Increases in Transportation Costs by Commodity Group [A, B] 86
Table 31 Annual Regional Economic Impact in Chicago CSA Due to Increases in Long-Term Shipping Costs As a Result of GLMRIS-BR Alternative Plans [A, B, C, D] 87
Table 32 Summary of Annual Regional Economic Impacts in Chicago CSA Due to Increases in Long-Term Shipping Costs As a Result of GLMRIS-BR Alternative Plans 88
Table 33 Abbreviated Injury Scale Matrix 90
Table 34 Calculation of Truck Damage Costs per Mile (FY2016 Price Level) 91
Table 35 Calculation of Rail Damage Costs per Mile (FY2016 Price Level) 92
Table 36 Calculation of Waterway Damage Costs per Mile (FY2016 Price Level) 92
Table 37 Average Annual Ton Miles by Route and Mode (2021-2070) 94
Table 38 Average Annual Fatality Costs due to GLMRIS-BR Technology Alternatives 95
Table 39 Average Annual Injury Costs due to GLMRIS-BR Technology Alternatives 95
Table 40 Average Annual Property Damage Costs due to GLMRIS-BR Technology Alternatives 95
Table 41 Average Annual Fatality Costs due to Lock Closure Alternative 95
Table 42 Average Annual Injury Costs due to Lock Closure 95
Table 43 Average Annual Property Damages due to Lock Closure 96
Table 44 Brandon Road Lock: Non-Cargo Lockages by Vessel Type (2006-2015) 97
Table 45 Review of ANS Control Measures and Features per Alternative Plan 102
Table 46 Summary of Nonstructural Measures, Costs, and Schedule per Alternative 104
Table 47 Summary of Real Estate Acquisition Costs for GLMRIS-BR Technology Alternatives 105
Table 48 Summary of Schedule and Costs for Boat Launches for GLMRIS-BR Alternatives 105
Table 49 Summary of Schedule and Costs for Flushing Lock for GLMRIS-BR Technology Alternatives 106
Table 50 Summary of Schedule and Costs for Engineered Channel for GLMRIS-BR Technology Alternatives 106
Table 51 Summary of Schedule and Costs for Water Jets for GLMRIS-BR Technology Alternatives 106
Table 52 Summary of Schedule and Costs for Speaker Placement (Complex Noise) 107
Table 53 Summary of Schedule and Costs for Electric Barrier for GLMRIS-BR Alternatives 107
Table 54 Summary of Schedule and Costs for Downstream Approach Channel Mooring Cells for GLMRIS-BR Alternatives 108
Table 55 Summary of Schedule and Costs for Lock Closure (ANS Control Measure) 108
Table 56 Monitoring and Adaptive Management Costs for Technology Alternative – Electric Barrier 109
Table 57 Monitoring and Adaptive Management Costs for Technology Alternative – Complex Noise 109
Table 58 Monitoring and Adaptive Management Costs for Technology Alternative – Complex Noise with Electric Barrier 110
Table 59 Monitoring and Adaptive Management Costs for Lock Closure Alternative 110
Table 60 Summary of Annual O&M Costs for Alternative Plans 111
Table 61 Summary of RR&R Costs for Technology Alternatives 111
Table 62 Economic Values Used for AAC Estimation 112
Table 63 AAC Estimate for the Nonstructural Alternative 113

TABLE 64 AAC ESTIMATE FOR TECHNOLOGY ALTERNATIVE – ELECTRIC BARRIER 113
TABLE 65 AAC ESTIMATE FOR TECHNOLOGY ALTERNATIVE – COMPLEX NOISE 114
TABLE 66 AAC ESTIMATE: TECHNOLOGY ALTERNATIVE – COMPLEX NOISE WITH ELECTRIC BARRIER 114
TABLE 67 AAC ESTIMATE: TECHNOLOGY ALTERNATIVE – LOCK CLOSURE ALTERNATIVE 115
TABLE 68 AAC FOR FINAL ARRAY OF GLMRIS-BR ALTERNATIVES 115

FIGURES

Figure 1 Key Findings from GLMRIS Report Fisheries Baseline Economic Assessment* 12
Figure 2. Illustration of Linkages between Asian Carp Establishment and Economic Outcomes 14
Figure 3 Several Uses of Great Lakes and Tributaries that could be affected if Asian Carp Establish* 17
Figure 4 Key Species for Fishing in Each Great Lake 17
Figure 5 Linking AC Establishment to Changes the Fishery and to the Resulting Changes in NED and RED 21
Figure 6 Economic Consequences – Overview of Changes to NED and RED Accounts for Commercial, Recreational, and Charter Fishing in Lake Erie 21
Figure 7 Economic Consequences of Asian Carp Establishment in Lake Erie – Inputs and Outputs of Fisheries NED Model (and Inputs for Fisheries RED Model) 23
Figure 8 Flowchart of Regional Economic Development (RED) Analysis – Economic Consequences of Asian Carp Establishment in Lake Erie 30
Figure 9 Location of Brandon Road Lock and Dam within the Chicago Area Waterway System 37
Figure 10: Location of ANS Control Measures 40
Figure 11 Brandon Road Tonnage Density (2012-2014 WCSC Data) 47
Figure 12 Historical Brandon Road Tonnage and Commodity Percentages (1994-2014) 48
Figure 13 Example Tow Configuration of Eight 200-Foot by 35-Foot Barges In Transit on the Inland Marine Transportation System (700 Feet by 105 Feet) 49
Figure 14 Tow Configuration to Accommodate Standard Flotilla of Eight 200-Foot by 35-Foot Barges into the Brandon Road Lock Chamber (600 Feet by 110 Feet) 49
Figure 15 Cost to Shippers Due to Reduced Lock Capacity 54
Figure 16 Planning Period 56
Figure 17 Conceptual Waterway Movement Conditional Cost Curves 58
Figure 18 WAM Lockage Operation Times 60
Figure 19 WAM Modeling Process 60
Figure 20 Primary Modules within NIM Model 62
Figure 21 Relationships of the NIM Network Entities 63
Figure 22 Commodity Groupings for Brandon Road Lock –Navigation Investment Model (NIM) 68
Figure 23 Dry Cargo Barge Groupings for Brandon Road Lock –Navigation Investment Model (NIM) 68
Figure 24 Tanker Barge Groupings for Brandon Road Lock –Navigation Investment Model (NIM) 68
Figure 25 Towboat Groupings–Navigation Investment Model (NIM) 69
Figure 26 Bureau of Labor Statistics Producer Price InÞ Indices by Mode and Haul Type 70
Figure 27 Most Likely Transportation Savings by Year by Alternative 78
Figure 28 Normal Operations Tonnage-Transit Curves by Alternative 78
Figure 29 Most Likely Equilibrium Traffic by Year by GLMRIS-BR Alternative 80
Figure 30 Most Likely Transportation Savings by Year by Alternative Without Plant Closures 81

ATTACHMENTS

ATTACHMENT D1 – CAPACITY ANALYSIS

ATTACHMENT D2 – WATERWAY TRAFFIC DEMAND PROJECTIONS

D.1 Introduction

The purpose of this Economic Appendix is to describe the methods and results of each economic analysis completed in support of the GLMRIS-BR. The economic analyses can be broadly characterized as estimating the following:

(1) economic consequences of Silver carp and Bighead carp establishment in Lake Erie;
(2) economic impacts on navigation given the implementation of ANS controls (alternative plans) in the vicinity of at Brandon Road Lock and Dam (BRLD); and
(3) total cost (present value) and average annual costs for each GLMRIS-BR alternative.

The purpose of these economic evaluations is to support the formation of a defensible Agency decision for the Great Lakes and Mississippi River Interbasin Study at Brandon Road (GLMRIS-BR). Each of these evaluations is briefly described below.

All quantitative economic evaluations were completed in accordance with USACE policies and evaluation procedures as defined by the *Economic and Environmental Principles & Guidelines for Water and Related Land Resources Implementation Studies* (P&G). All values are presented in this report reflect the Fiscal Year 2017 discount rate of 2.175 percent and 2016 price levels, unless otherwise noted.

Economic Consequences of Silver and Bighead Carp Establishment in Lake Erie. The GLMRIS-BR evaluates structural and nonstructural options and technologies that could be implement at the BRLD site to prevent the upstream transfer of ANS from the MRB into the GLB to the maximum extent possible, while minimizing impacts to existing waterway uses and users. Alternative plans were developed in accordance with several plan formulation criteria, one of which is that the alternatives will include effective ANS control measures that address the following three modes of aquatic transport: swimming, passive drift, and hull fouling.

Specifically, GLMRIS-BR addresses three ANS of high or medium risk (as determined by the 2014 GLMRIS Report) that are threatening to enter the GL Basin via the CSSC: Silver Carp, Bighead Carp (herein, collectively referred to Asian carp or AC), and *Apocorophium lacustre* (herein referred to as *A. lacustre*). The risk assessment for the Asian carp considered the Silver Carp and Bighead Carp together in a single analysis due to their similarities. A separate risk assessment was completed for *A. lacustre*.

A qualitative multiplicative model approach to determine the overall risk of a given ANS involved an evaluation of the following 1) a quantitative probability of the ANS establishing in the Great Lakes Basin via the CAWS and (2) a qualitative and quantitative evaluation of the consequences of that establishment on ecological, economic, and social/political resources. Therefore, the risk of ANS establishment in the GL Basin is determined as:

Risk of adverse impacts occurring as a result of the establishment of ANS **X** in GL Basin	=	**Consequences** of ANS **X** becoming established in GL Basin (the *effects* to GL Basin of exposure to ANS **X**)	×	**Probability** of ANS **X** becoming established in GL Basin (GL Basin becomes *exposed* to ANS **X**)

For this assessment, because the consequences are qualitative and quantitative evaluations, calculating a "**risk** of adverse impacts occurring as a result of the establishment of ANS **X** in GL Basin" was not possible. Rather, the risk equation outlines the what was considered and evaluated in the Study. For a discussion of the quantitative probability assessment, refer to chapter 6 of the main report and Appendix C. For a discussion of the qualitative and quantitative ecological, economic and social/political consequences, refer to chapter 5 of the main report.

The ‘Economic Consequences of Silver and Bighead Carp Establishment in Lake Erie’ section of this Economic Appendix provides information regarding the analysis completed to estimate the economic consequences. The best-available ecological and economic information was utilized to estimate the economic consequences of ANS establishment in the GL Basin. This economic consequence assessment solely addresses Asian carp, because the GLMRIS Study concluded *A. lacustre* would have minimal economic and sociopolitical impact on the Great Lakes Basin.

The Great Lakes and their tributaries have numerous, economically important commercial and recreational purposes, such as fishing activities, shoreline real estate, boating, beach going, and many others. Estimating the economic consequences of Asian carp establishment on each of these uses requires knowledge of how the ecosystem would change, and in turn affect the use of each water body. However, predicted ecosystem changes following Asian carp establishment were only available for Lake Erie’s fishery and the data consisted of estimated changes in fish biomass based on food web modeling by the National Oceanic and Atmospheric Administration’s (NOAA). Biomass refers to the mass of a species in kilograms per hectare of Lake Erie. The estimated changes in the biomass of recreationally and commercially important species were then utilized to estimate economic impacts to recreational fishing, charter fishing, and commercial fishing. The consequences evaluations for each of these activities in Lake Erie are presented as changes to the national and regional economic development (NED and RED) accounts, consistent with USACE evaluation procedures outlined in the P&G.

It is important to note two limitations associated with the food web modelling output and the fisheries economic analysis. First, there was considerable uncertainty associated with the modeled fish biomass changes due to uncertainty in the assumptions and inputs used in the food web model. Because these biomass estimates were inputs into the economic analysis, there is also considerable uncertainty associated with the results of the economic consequences analysis. Second, there are numerous uses and users of the GLB that are economically important to the nation and the Great Lakes region. Because the economic consequences of Asian carp could only be quantified for commercial, charter, and recreational fishing in Lake Erie, the GLMRIS-BR analysis quantitatively addresses only a small subset of the total economic consequences that could be realized throughout the basin.

Impact of GLMRIS-BR Alternatives on Navigation. Each GLMRIS-BR alternative includes ANS controls to reduce the *probability* that ANS will transfer and establish in the GLB. However, many of these ANS controls would adversely affect the uses and users of BRLD, which is part of the Chicago Area Waterway System (CAWS) and is heavily utilized for commercial cargo navigation with few non-cargo navigation users (e.g., recreation and government vessels).

The economic analysis estimated the impact of GLMRIS-BR alternatives on commercial navigation. These impacts are presented as changes to the NED and RED accounts. Because some alternatives result in the diversion of shipments from the waterway to alternate land routes, a safety analysis was completed to describe the potential effects of shippers making use of truck or rail to transport their goods instead of the waterway. Rather than the NED or RED account, this analysis addresses the other social effects (OSE) account presented in the P&G. Overland modes typically have higher fatality, injury, and property damage rates when compared to the inland towing industry. The safety analysis estimates these externalized costs due to traffic diversions.

Non-cargo navigation users of BRL are a small percentage, but present nonetheless. Rather than a quantitative economic evaluation of impacts to these users, this appendix provides a qualitative description of the potential impacts to these users given the implementation of GLMRIS-BR alternatives.

Total Cost (Present Value) and Average Annual Cost of GLMRIS-BR Alternatives. Lastly, this economic appendix presents estimates of the total (present value) and average annual cost (AAC) for each

GLMRIS-BR alternative. The primary cost categories include: real estate acquisition; construction (including preconstruction engineering and design, and construction management); mitigation; monitoring and adaptive management; nonstructural measures; and operation, maintenance, repair, replacement, and rehabilitation.

D.2 Economic Consequences of Silver and Bighead Carp Establishment in Lake Erie

Estimating the economic consequences of Asian carp establishment requires knowledge of how the ecosystem would change due to Asian carp, and how these changes would affect the uses of each Great Lakes and its tributaries. The GLMRIS-BR economic analysis utilized the best-available ecological and economic information. Estimates of ecosystem changes due to Asian carp establishment were only available for Lake Erie's fishery and the estimates have significant uncertainty. NOAA estimated changes in Lake Erie fish biomass using an Ecopath with Ecosim model of the Lake Erie food web. A similar ecological assessment has not been completed for the remaining four Great Lakes and the tributaries of all Great Lakes. Thus, the existing ecological and economic information for Lake Erie afforded the GLMRIS-BR Study Team the opportunity to evaluate only a portion of the potential economic consequences of AC establishment. This information is useful for providing a preliminary, albeit uncertain, indication of the type of consequences that could be realized if Silver and Bighead carp established in the GLB. Further ecosystem modeling for the remaining Great Lakes and their tributaries, as well as extensive economic data collection effort, would be required to complete a comprehensive consequences analysis.

Using the NOAA model results, the potential economic consequences were estimated for Lake Erie's commercial, recreational, and charter fisheries, and are expressed as changes to people's well-being (NED account) and regional economy (RED account). This effort differs from the baseline economic assessments included in the GLMRIS Report (January 2014), which solely provided information about the existing use and economic value of five fishing activities in the GLB (commercial, recreation, charter, subsistence, and professional fishing tournaments). The GLMRIS Report *did not* include any estimates in changes to people's well-being (NED account) and regional economy (RED account) given the AC establishment in the GLB. The economic consequence assessment of AC establishment in Lake Erie presented in this Economic Appendix for the GLMRIS-BR does focus on such *changes*.

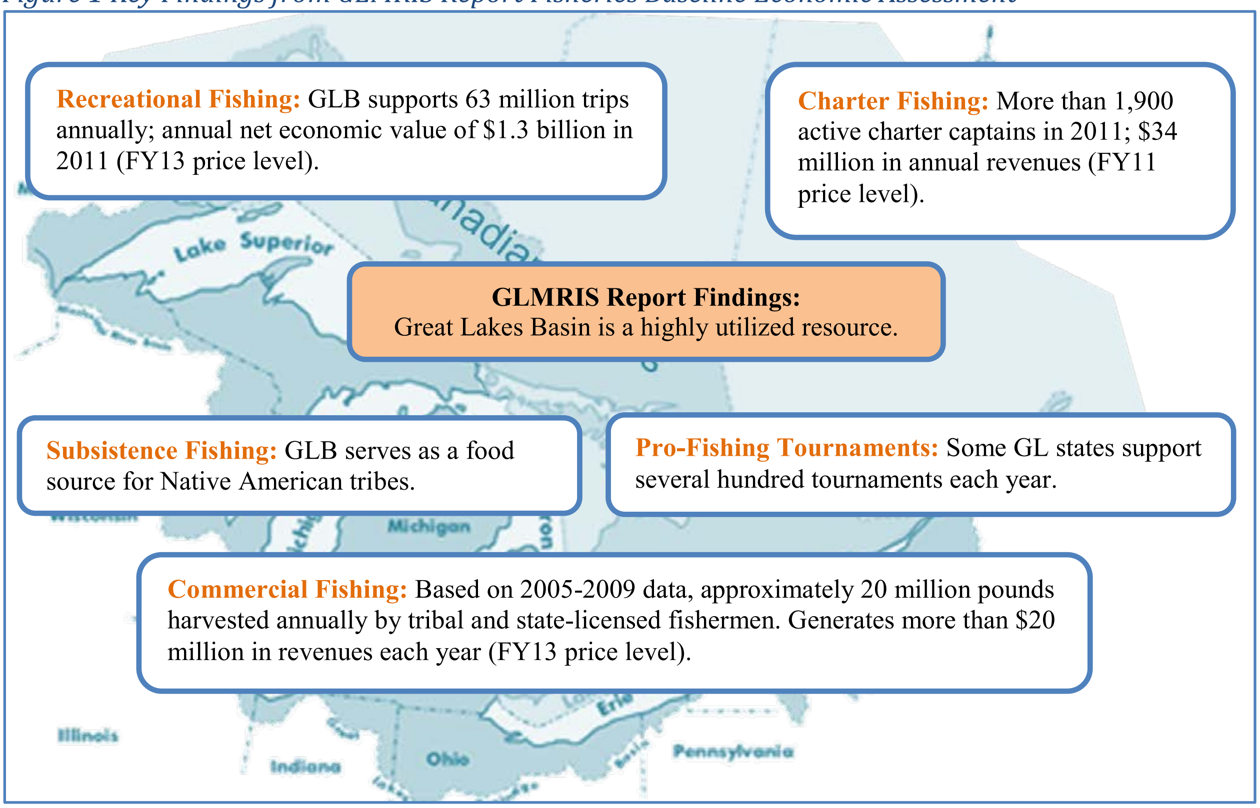
To highlight the differences between the aforementioned GLMRIS and GLMRIS-BR economic analyses, the following section provides a brief summary of the GLMRIS Report's baseline economic assessments of GLB fishing activities. This is followed by several sections that provide the framework, methods, and findings for the economic consequence assessment of AC establishment in Lake Erie completed in support of GLMRIS-BR.

D.2.1 Review of GLMRIS Report Findings: Baseline Economic Assessments of Fishing Activities in the Great Lakes Basin

As a way to highlight several important uses of the GLB that could be affected if ANS from the MRB were to transfer in and become established, the GLMRIS Report (January 2014) provided estimates of the current economic value of five key fishing activities in the U.S. waters of the GLB. Quantitative evaluations were completed for commercial, recreational, and charter fishing activities, while assessments of subsistence and professional fishing tournaments were qualitative in nature. This information *was not* intended to signify the total economic value of the GLB, nor do these values represent an estimate of economic activity that would be foregone given ANS establishment in the Basin. Rather, these findings serve as a few indicators of the economic importance of this basin and display some of the activities that could experience changes given the establishment of ANS.

Key findings from the GLMRIS Report's baseline economic assessments for five fishing activities in the U.S. waters of the GLB are presented in Figure 1 and the subsequent text.

*Figure 1 Key Findings from GLMRIS Report Fisheries Baseline Economic Assessment**



**Values presented in this figure reflect those presented in the GLMRIS Report (January 2014) and solely accounts for activities within the U.S. waters of the Great Lakes Basin.*

Baseline Economic Value of Commercial Fishing in the GLB (GLMRIS Report). USACE estimated the average harvest level and dockside value of commercial fish harvests in the U.S. waters of the GLB using the most recent 5 years of data available (2005 through 2009) at the time of the analysis. Harvest levels and dockside values were obtained from state agencies such as Departments of Natural Resources. These 'baseline' average annual values were estimated to be: 20 million pounds with an associated dockside value of about $22 million (FY13 price level).

Baseline Economic Value of Recreational Fishing in the GLB (GLMRIS Report). Cornell University, in coordination with USACE, estimated a baseline economic value of recreational fishing in the U.S. waters of the GLB. Based on fishing license sales data provided by the states, it was estimated that 6.6 million anglers lived and fished in the 12-state study area in 2011. These anglers spent an estimated 62.9 million days fishing in those portions of the GLB below barriers (e.g., dams) impassable to fish. The average net value per angler day, estimated from Cornell University's recreational fishing model, was $19.52 (FY13 price level). The aggregate net value of recreational fishing in those portions of the GLB below barriers impassable to fish is estimated to be $1.228 billion for calendar year 2011 (FY13 price level).

Charter Fishing in the Great Lakes Basin (GLMRIS Report). The Ohio State University Sea Grant Extension Office, in coordination with USACE, estimated a baseline economic value of charter fishing in the U.S. waters of the GLB. In 2011, there were an estimated 1,904 active licensed charter captains in the Great Lakes. Of these, approximately 1,700 captains operated as an independent small business, while another estimated 200 were non-boat owning captains. Together they generated between $34.4 million and $37.8 million in annual sales and salary (FY11 price level).

Subsistence Fishing in the Great Lakes Basin (GLMRIS Report). Argonne National Laboratory, in coordination USACE, conducted a study to identify and described tribal fishing activities in the GLB. A total of 16 tribes engage in subsistence fishing within the MRB and GLB under one of four treaties, mostly in the western GLB. Subsistence harvesting is an important part of tribal cultural heritage that has value that extends beyond economics, and is an important element in maintaining the sovereign status of the tribes. The annual value of subsistence fishing activities to an individual subsistence household would be between $15,000 and $16,500 (FY11 price levels).

While a small proportion of tribal members engage in subsistence fishing, the subsistence harvest is shared according to traditional priorities throughout the communities. Non-treaty tribes engage in less subsistence fishing, especially those with reservations close to urban areas where water bodies are more likely to be polluted, and tribal members are more likely to be employed off of the reservation. The main target species for subsistence fishers are walleye, whitefish, yellow perch, and trout; lake sturgeon is culturally important.

Professional Fishing Tournaments in the Great Lakes Basin (GLMRIS Report). USACE conducted a study to identify and described professional fishing tournaments in the GLB. Each tournament is regulated by its own set of rules, which generally vary in specificity or strictness depending on the seriousness or size of the tournament. General elements covered by tournament rules include entry fees, tournament dates and times, fishing boundaries, team structures, boat size and equipment descriptions, catch limits, fish weighing or measuring procedures, and point calculation and winner determination. Tournaments are held for the purpose of competing and winning prizes, or as fundraisers for charitable organizations. Formats for tournaments include one-day or weekend catch-and-release events, derby style events which span an entire season, or tournament trails where anglers compete in a series of weekend tournaments and obtain cumulative points to determine an overall winner. The availability of information on tournament fishing varies by state. On the Great Lakes, it is estimated that states such as Wisconsin or Minnesota host 450 to 700 fishing tournaments per year. It is estimated that there are fewer tournaments in states such as Illinois or Indiana. Based on a cursory analysis of fishing tournaments, bass fishing events seem to be particularly popular in all water-bodies researched.

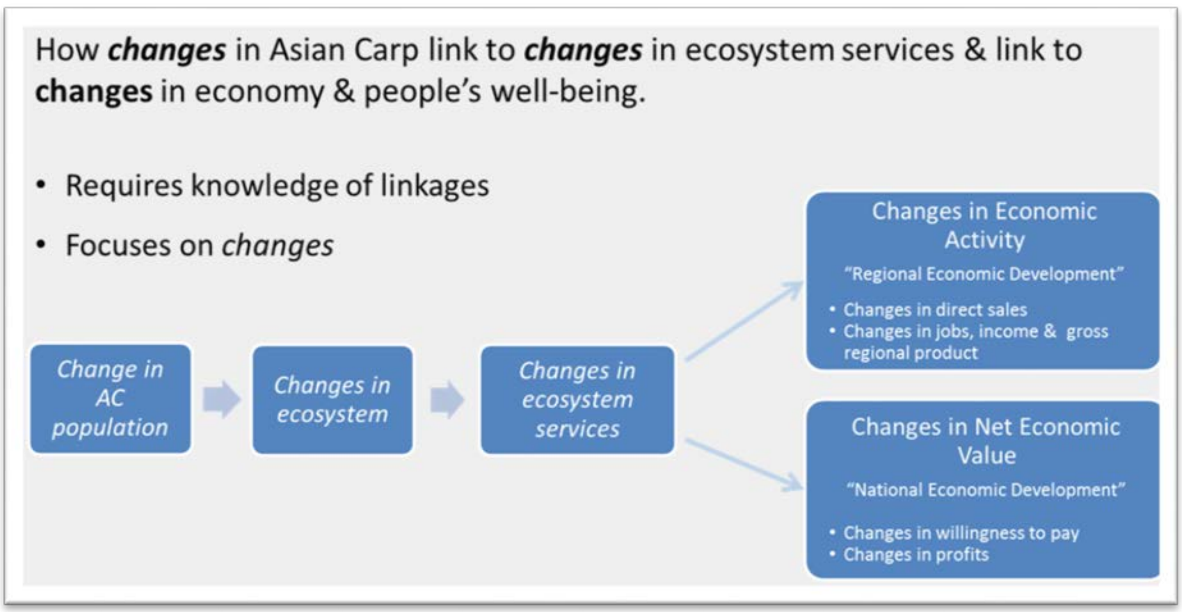
Collectively, the GLMRIS Report's fisheries baseline economic assessments provided useful information about the economic importance of the GLB. However, the consequence assessment completed in support of GLMRIS-BR is intended to describe some economic values that could change given the establishment of Asian carp in Lake Erie. The following section highlights how these two types of analyses differ.

D.2.2 Total Values Versus Changes in Values

The GLMRIS Report was able to provide useful information on the *total* amounts of some key activities in the Great Lakes. Information on the total levels of these activities provides vital evidence on their importance. What is most useful to planners and decision makers facing investment decisions is information on how any activity *changes* when AC become established.

Figure 2 illustrates some of the important concepts that are considered when estimating these changes. On the far left of the diagram a change in AC populations is assumed (e.g., from zero to establishment level) in a given water body. The next step in the linkage would be to understand how this change in AC would affect the ecosystem in which the AC become established. Often such knowledge requires previous experiences with AC establishment or sophisticated ecosystem models. Next, any changes in the ecosystem need to be linked to changes in the suite of ecosystem services provided by the GLB, and more specifically, how these ecosystem services change in response AC establishment. Finally, changes in ecosystem services can be mapped into changes to the regional economy (as considered by the RED account) and changes to people's well-being (NED account).

Figure 2. Illustration of Linkages between Asian Carp Establishment and Economic Outcomes



D.2.3 New Environment in the Great Lakes Basin With AC Establishment

Figure 2 AC establishment and changes in AC populations can alter the ecosystem, change ecosystem services to people, and thus affect economic activity and value. Connecting AC to these economic effects requires substantial information on the myriad ways that AC could affect the ecosystem and ecosystem services. Since AC have not established in the Great Lakes, scientific understanding of these linkages is limited and characterized by high uncertainty. Nevertheless, some possible ways that AC could affect people can be outlined even though a full understanding of all potential effects is not possible.

Some effects of AC in the Great Lakes can be inferred from the effects of AC invasions in other systems. In some systems where Asian carp have invaded, they represent a large part of the biomass of those systems and have had large adverse effects on some parts of the food web such as some types of zooplankton and some plankton eating fishes. It is also possible that besides altering the biomass of other species, an AC invasion could alter their size distributions and length-weight relationships (e.g., resulting in many smaller fish rather than fewer larger fish). It is also well established that AC behave differently than other fish, particularly in their jumping behavior – the noise of boats can cause them to jump in the air putting boaters at risk of injury.

There are many unknown or less understood possibilities associated with AC establishment in the GLB. Because of the changes AC induce in the food web, they might have unforeseen impacts on nutrient levels which in turn affect water quality. Effects on water quality could then have impacts on a range of human uses such as fishing, beach going and other shoreline recreation, boating, and the ways that people use properties on or near affected waterbodies.

D.2.4 Economic Activities Potentially Affected by Asian Carp Establishment in the Great Lakes Basin

In light of the uncertainty and range of possible environmental and aesthetic changes associated with AC in the GLB (as described in the previous section), there is a range of possible ways that human uses and the economy could be affected by AC. An illustrative listing of these is provided in Figure 3. The table rows represent a variety of existing uses that have the potential to be affected by AC while the columns show the Great Lakes and their tributaries. Connecting waters such as Lake St. Clair could also be affected. As previously stated, AC could potentially alter the abundance, size distributions and length-weight relationships of other fish species in the GLB. As such, key commercial activities potentially affected by AC include commercial fishing by state-licensed, tribal, and charter fishing operations. Other aspects of the fisheries that may be affected by AC include recreational angling on the Great Lakes and tributaries, fishing tournaments and subsistence fishing.

Non-fishing activities potentially affected by AC include recreational boating, other shoreline activities, and uses of coastal and riparian properties. Although some Great Lakes fishing occurs from private boats, potentially half of all Great Lakes boating does not involve fishing. Boating could be affected through equipment damage and personal injuries from jumping fish and through losses in enjoyment of boating due to jumping fish and other impacts of AC. AC have the potential to affect the significant amount of non-fishing shoreline recreational activities including swimming and beach going. For instance, participation in these activities could be altered if AC become prevalent in the recreational areas of interest and reduce their aesthetic appeal if the potential for contact with AC is undesirable.

Coastal and riparian properties and their values could be affected if the willingness of people to live near these waterbodies was altered in any way by AC. For example, these property values could be altered due to the changes in the availability or quality of recreational activities such as fishing, swimming and boating, as well as unforeseen adverse effects on water quality.

D.2.4.1 Description of What Can be Quantified

As discussed above, there is a broad range of uses and activities that would be potentially affected by establishment of AC in the Great Lakes Basin. In Figure 3, many of these are listed for each Great Lake and their tributaries. A economic consequence analysis requires some scientific studies or credible information linking AC to changes in these ecosystem services. This ecological information is lacking for four of the five Great Lakes and all of the more than 5,000 Great Lake tributaries, some of which may be especially susceptible to AC establishment (USFWS 2016). In Lake Erie, the GLMRIS-BR study team is able to make some estimates for three of the 14 activities potentially affected by AC.

The required information was obtained from the National Oceanic and Atmospheric Administration, Great Lakes Environmental Research Laboratory (NOAA-GLERL), which published a study modeled how the biomass of fish species in Lake Erie could change with the introduction of AC (Zhang et al, 2016). Herein, the model is referred to as the NOAA ecological model or the NOAA model. The model did not incorporate the tributaries of Lake Erie and therefore economic impacts to tributary fisheries were not estimated. The NOAA Lake Erie Food Web model used Ecopath with Ecosim (Christensen and Walters, 2004) to model the food web of Lake Erie with and without the introduction of AC. Inputs to the model were obtained from expert judgements and the available ecological datasets. The model output was then utilized by the GLMRIS-BR Economics Team to quantify how AC might affect biomass of fish, which in turn would affect recreational fishing, charter fishing, and commercial fishing.

The NED and RED analyses convert expected changes in biomass and harvests in these fisheries into changes in economic values to people and changes in economic impacts to the economy.

*Figure 3 Several Uses of Great Lakes and Tributaries that could be affected if Asian Carp Establish**

Lake Michigan	Lake Superior	Lake Huron	Lake Erie	Lake Ontario
Commercial Fishing	Commercial Fishing	Commercial Fishing	**Commercial Fishing****	Commercial Fishing
Recreational Fishing	Recreational Fishing	Recreational Fishing	**Recreational Fishing****	Recreational Fishing
Recreational Boating	Recreational Boating	Recreational Boating	Recreational Boating	Recreational Boating
Charter Fishing	Charter Fishing	Charter Fishing	**Charter Fishing****	Charter Fishing
Pro-fishing tournaments	Pro-fishing tournaments	Pro-fishing tournaments	Pro-fishing tournaments	Pro-fishing tournaments
Subsistence Fishing	Subsistence Fishing	Subsistence Fishing	Subsistence Fishing	Subsistence Fishing
Beach Going	Beach Going	Beach Going	Beach Going	Beach Going
Property Values	Property Values	Property Values	Property Values	Property Values
Lake Michigan Tributaries	**Lake Superior Tributaries**	**Lake Huron Tributaries**	**Lake Erie Tributaries**	**Lake Ontario Tributaries**
Recreational Fishing	Recreational Fishing	Recreational Fishing	Recreational Fishing	Recreational Fishing
Recreational Boating	Recreational Boating	Recreational Boating	Recreational Boating	Recreational Boating
Charter Fishing	Charter Fishing	Charter Fishing	Charter Fishing	Charter Fishing
Pro-fishing tournaments	Pro-fishing tournaments	Pro-fishing tournaments	Pro-fishing tournaments	Pro-fishing tournaments
Subsistence Fishing	Subsistence Fishing	Subsistence Fishing	Subsistence Fishing	Subsistence Fishing
Property Values	Property Values	Property Values	Property Values	Property Values

** Not a comprehensive list, and for simplicity omits connecting waters such as Lake St. Clair.*
*** The three fishing activities on Lake Erie for which changes are quantified by way of NED and RED analyses.*

Figure 4 Key Species for Fishing in Each Great Lake

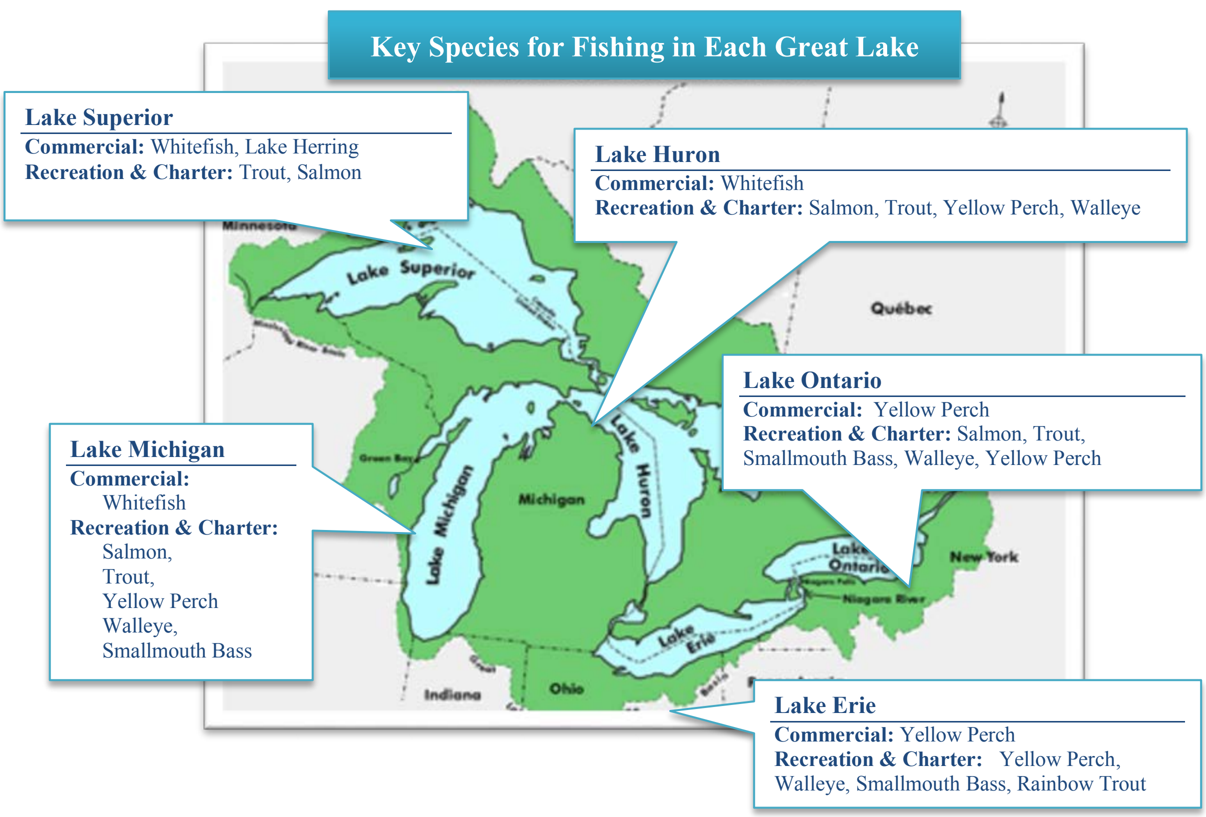


Figure 4 shows the species of key economic interest to the commercial, recreational and charter fisheries in each Great Lake. For commercial fisheries, any species that constitutes more than 10% of the harvest value is listed, and the key commercial species are either whitefish or yellow perch, depending on the lake. For recreational and charter, the key species groups are somewhat similar across lakes, with the various coldwater salmon and trout species (and in some places walleye) being key targets in deeper waters and on runs up tributaries, and with yellow perch, walleye and smallmouth bass being key targets in shallower areas such as near-shore zones and bays.

In all the lakes other than Lake Erie, the various salmon and trout species attract most of the recreational and charter fishing effort. Since key economic species, as well as their relative importance, varies across lakes, and since Lake Erie is different from the other lakes, any ecological and economic models for Lake Erie fisheries may not be applicable to the other lakes.

D.2.4.2 Summary of Key Species & Lake Erie NOAA Model

The recently developed ecological model of the Lake Erie food web (Zhang et al. 2016) is used to assess how species in Lake Erie are affected by AC. The NOAA model includes over 45 separate model categories in the food web to represent plankton, benthos and fishes. For some key fish species like yellow perch and walleye, separate categories are modeled for young fish and for adults. The introduction of AC can have effects on multiple species or species groups, including zooplankton, phytoplankton and different life stages of walleye, salmon, whitefish, and smallmouth bass. The model was run under multiple scenarios developed by NOAA modelers to reflect different assumptions about the diet of Asian carp, their plankton consumption efficiency, and the vulnerability of Asian carp to predation. Using the biomass output from the model, the percent difference in biomass of the species group between baseline conditions (no Asian carp) and under each AC establishment scenario was calculated. These scenarios are presented in Table 1.

Table 1 NOAA Model Scenarios Utilized for Economic Consequence Assessment of Asian Carp Establishment in Lake Erie

NOAA Model Scenarios[1/]	Scenarios Descriptions
Scenario 1	Low plankton vulnerability to consumption by Asian carp (i.e. lower Asian carp feeding efficiency); High Asian carp P/B (1.08); Salmonid predation on Asian carp assumed to occur; Asian carp do not feed on fish larvae
Scenario 2	High plankton vulnerability to consumption by Asian carp (i.e. higher Asian carp feeding efficiency); High Asian carp P/B (1.08); Salmonid predation on Asian carp assumed to occur; Asian carp do not feed on fish larvae
Scenario 3	Low plankton vulnerability to consumption by Asian carp (i.e. lower Asian carp feeding efficiency); Low Asian carp P/B (0.6); Salmonid predation on Asian carp assumed to occur; Asian carp do not feed on fish larvae
Scenario 4	High plankton vulnerability to consumption by Asian carp (i.e. higher Asian carp feeding efficiency); Low Asian carp P/B (0.6); Salmonid predation on Asian carp; Asian carp do not feed on fish larvae
Scenario 5	Low plankton vulnerability to consumption by Asian carp (i.e. lower Asian carp feeding efficiency); Low Asian carp P/B (0.6); No salmonid predation on Asian carp; Asian carp do not feed on fish larvae
Scenario 6	High plankton vulnerability to consumption by Asian carp (i.e. higher Asian carp feeding efficiency); Low Asian carp P/B (0.6); No Salmonid predation on Asian carp; Asian carp do not feed on fish larvae
Scenario 7	High plankton vulnerability to consumption by Asian carp (i.e. higher Asian carp feeding efficiency); High Asian carp P/B (1.08); Salmonid predation on Asian carp assumed to occur; Asian carp feed on fish larvae
Scenario 7 + 1SD	To characterize uncertainty for scenario 7, each species average biomass was increased by one standard deviation, derived from the NOAA model's uncertainty simulations.
Scenario 7 - 1SD	To characterize uncertainty for scenario 7, each species average biomass was decreased by one standard deviation, derived from the NOAA model's uncertainty simulations.

[1/] See Main Report for detailed description of the NOAA model and each scenario.

The results of the NOAA model indicate that the introduction of AC in Lake Erie adversely affect some species groups under all scenarios examined. Table 2 shows the percentage change in biomass associated with three species groups (shiners, burbot and white perch) under the various modeling scenarios considered in the NOAA model. In scenarios 2, 4, 6 and 7 the NOAA model suggests these species are expected to experience substantial declines in abundance.

*Table 2. Percentage Change in Biomass for Lake Erie Species Groups Adversely Affected by Asian Carp (for Scenarios Considered in NOAA Model)**

NOAA Model Scenario	**Biomass Change (%)**		
	Emerald & Spottail Shiners	Burbot	White Perch
Scenario 1	-1%	0%	-2%
Scenario 2	-68%	-27%	-45%
Scenario 3	-2%	-1%	-2%
Scenario 4	-52%	-21%	-39%
Scenario 5	-2%	-1%	-2%
Scenario 6	-52%	-21%	-39%
Scenario 7	-9%	-14%	-21%
Scenario 7 + 1SD	11%	-2%	21%
Scenario 7 - 1SD	-29%	-26%	-63%
*SD indicates standard deviation.			

Although the species shown in Table 2 are adversely affected by AC, these are not key target species for the Lake Erie commercial, charter and recreational fisheries. While there are other species that some recreational anglers target in Lake Erie, the key species for recreational fishing effort are walleye (48% of effort), yellow perch (29%) rainbow trout (steelhead, 20%) and to a lesser extent smallmouth bass (3%). For charter trips, the effort is mainly for walleye (79%), with some effort for yellow perch (18%) and minor amounts of effort for steelhead (rainbow trout) and smallmouth bass. In the Lake Erie commercial fishery, there are 20 species of fish that are caught that have some dockside value from 2009 to 2013. However, about two-thirds of the harvest value is for yellow perch and no other species accounts for more than 8% of the harvest value.

Table 3 presents the NOAA model's percentage changes in biomass for key recreational and charter species in Lake Erie. The table shows that for the key species of economic value, the impacts of AC are varied. In some of the scenarios where a species group like shiners were substantially negatively affected by AC (e.g. scenarios 2, 4 and 6), species such as adult yellow perch and adult walleye are positively affected – their abundance is expected to increase with AC because of changes in the food web predicted within the NOAA model. Note that in these same scenarios, another key recreational species, rainbow trout, is expected to decrease. The ultimate outcome of the economic analyses is driven by the net effect of changes in biomass predicted by the NOAA model for the key economic species, rather than for all possible species. These results illustrate the complex trade-offs than can potentially occur between species within the ecological model, and it highlights how the assumptions used within the model can differentially alter outcomes for key economic species.

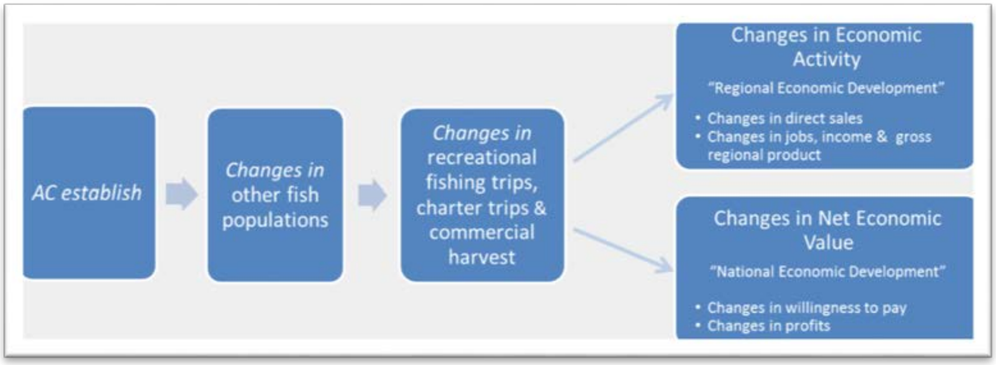
*Table 3 Percentage Changes in Biomass for Key Recreational and Charter Species in Lake Erie (based on NOAA model)**

NOAA Model Scenario*	**Biomass Change (%)**			
	Yellow Perch	Walleye	Smallmouth Bass	Rainbow Trout (Steelhead)
Scenario 1	1%	2%	0%	0%
Scenario 2	17%	12%	13%	-20%
Scenario 3	1%	2%	0%	0%
Scenario 4	11%	8%	7%	-15%
Scenario 5	1%	2%	0%	-1%
Scenario 6	11%	8%	7%	-19%
Scenario 7	-13%	-13%	22%	-2%
Scenario 7 + 1SD**	13%	1%	36%	14%
Scenario 7 - 1SD**	-38%	-27%	8%	-18%

*See Table 1 for scenario descriptions.
**SD indicates standard deviation.

In Figure 5, changes in AC populations in Lake Erie are linked to changes in other fish populations in Lake Erie using the NOAA ecological model. Given the changes in fish populations, existing data and studies are used to estimate changes in recreational and charter fishing trips and to changes in commercial fish harvests. These changes are then the inputs into the NED analysis of changes in well-being and the RED analysis of changes in economic activity.

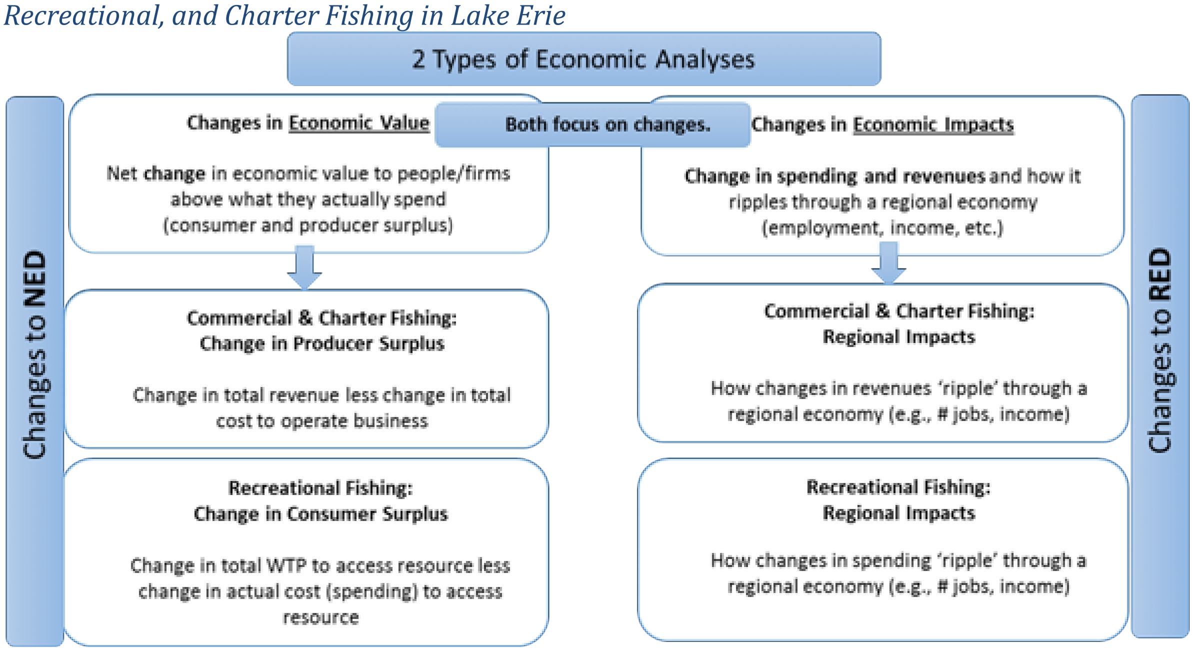
Figure 5 Linking AC Establishment to Changes the Fishery and to the Resulting Changes in NED and RED



D.2.4.3 Overview of Differences between NED and RED

This economic consequences analysis discusses two distinct economic concepts that relate to changes in the fishery due to AC. USACE refers to the economic concepts as NED, national economic development, and RED, regional economic development. More generally in economics, changes in NED are referred to as changes in "economic value" or changes in "economic welfare," commonly referred to as well-being (Freeman et al, 2014) and changes in RED are referred to as changes in "economic impacts". Economic values measure changes in people's and businesses' well-being net of their costs (Freeman et al. 2014). Economic impacts measure changes in regional economic activity such as economic output (e.g., sales), incomes, and jobs (Watson et al., 2007). Notably, RED and NED are typically not directly comparable, and should not simply be added together since they measure different concepts. Following the USACE P&G, this economic consequence analysis provides information on both NED and RED. The differences between changes to the NED and RED accounts are further illustrated in Figure 6, as they apply to commercial, recreational, and charter fishing. These concepts and applications are explored further in the following several sections.

Figure 6 Economic Consequences – Overview of Changes to NED and RED Accounts for Commercial, Recreational, and Charter Fishing in Lake Erie



D.2.5 National Economic Development (NED) Analysis: Economic Consequences of AC Establishment in Lake Erie

D.2.5.1 Overview of NED Approach

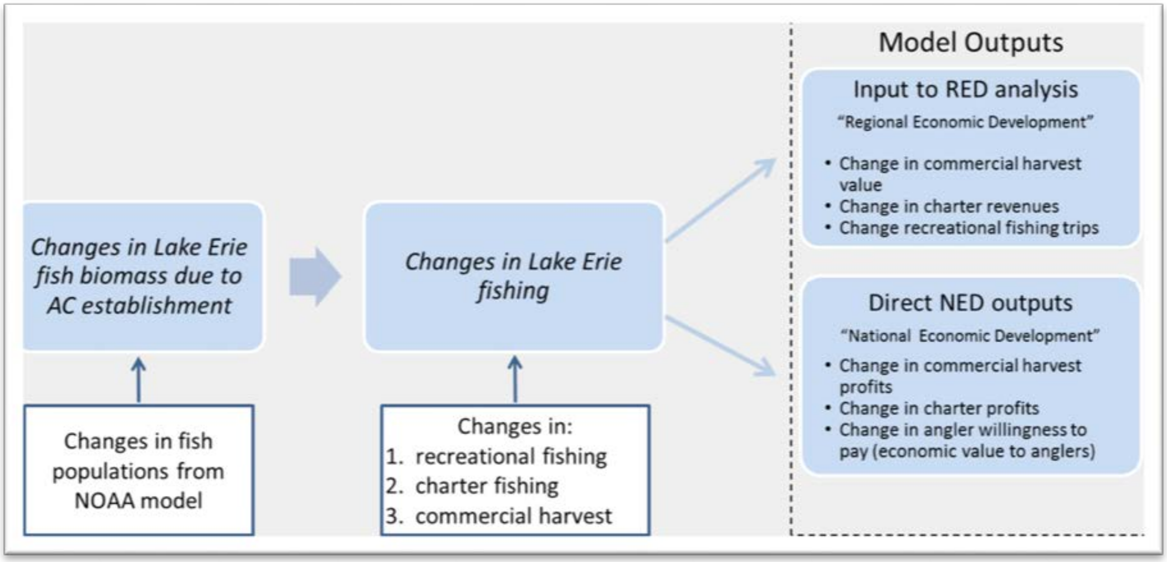
The theory underlying this NED approach is that under different assumptions, establishment of AC will affect existing key commercial, recreational (including charter) fisheries in the GLB. These biomass changes could have a direct bearing on commercial fishing harvests and recreational fishing days, which in turn affects the net economic value of commercial, charter and recreational fishing in the GLB. To measure the changes in these economic values, the approach follows standard theory of benefit-cost analyses and microeconomics and measures the changes in producer surplus (profits) and consumer surplus (net benefits) of commercial, charter and recreational fishing in the Great Lakes (Freeman et al., 2014). Here, changes in producer surplus are measured by estimating the changes in profits (revenues less costs) to commercial fishing and charter fishing operations.

Consumer surplus is the amount a consumer is *willing to pay* for a good or service *in addition to* what they have to pay. For recreational fishing, this is measured by the area under a demand curve for recreational fishing that relates the time and money costs of travel to fishing sites to the number of fishing trips anglers take (Haab and McConnell, 2002). In addition, these same recreation demands can be related to the quality of fishing as measured by fish catch rates. Then when catch rates change, these demand curves shift and provide estimates of how trips respond to fishing quality and how consumer surplus changes (Melstrom and Lupi, 2013; Kotchen et al., 2006). Data needed to estimate changes in recreational and charter fishing days given changes in fish biomass include values for fishing days and other key parameters; these data were derived from other studies and existing Lake Erie data. This approach is referred to as 'benefits transfer' (Johnston et al, 2015).

As discussed above, the NED approach takes as an input for each scenario the change in fish biomass for many different species and species groups as estimated by the NOAA model (Zhang et al. 2016). Other inputs include fishing trip data from state and federal data sources, historical commercial harvest dockside values from state and federal sources, consumer surplus values for recreational fishing trips from the literature, and response of fishing trips to changes in biomass from the literature. The approach produces final outputs for the NED analysis as well as inputs to the RED analysis, as outlined in Figure 7.

For commercial fishing, the NED analysis output is the change in profits from commercial fishing and the RED analysis input is the sum of the expected change in value of the catch by species, valued at the dock-side (producer prices). For charter boat fishing, the NED output is the total expected change in the profits from sales for charter boat fishing services and the RED input is the change in the value of the sales. Finally, the NED output data for recreation fishing is the consumer surplus value to recreational anglers, and the RED input is the change in the number of recreational fishing trips.

Figure 7 Economic Consequences of Asian Carp Establishment in Lake Erie – Inputs and Outputs of Fisheries NED Model (and Inputs for Fisheries RED Model)



D.2.5.2 NED Analysis – Commercial Fishing

For commercial fishing, two outputs were needed from the NED analysis: (1) changes in commercial fishing revenues for the RED analysis (as measured by changes in dockside values) and (2) changes in commercial fishing profits for the NED analysis (as measured by commercial fishing revenues minus costs).

Data on harvests and value for Lake Erie commercial fishing is summarized in Table 4, and were taken from NOAA data collected by respective states and aggregated for the lake (NOAA 2015). The data do not reflect Canadian harvests. Dockside value is the sales price of the harvest amount at the dock prior to any further sales or processing. A five-year average (2009-2013) was used for the harvests and dockside values, which were adjusted by the producer price index (PPI) for the fishing sector published by the Bureau of Labor Statistics (BLS).

The final column of Table 4 indicates species from the NOAA data that were grouped to match with the NOAA ecological model. These matches were reviewed with the NOAA model developers (personal correspondence). For example, minnows and goldfish are separate categories in the harvest data but are matched to the "shiners" group in the NOAA ecological model (Zhang et al. 2016).

Similarly, bigmouth buffalo and quillback are matched with whiter sucker in the suckers group, while brown bullhead is matched with catfish. In these cases, the harvest values across species that are grouped were summed to get a group's harvest value and then this rose and fell as the group biomass was affected by an AC scenario.

A very small adjustment was made to the total harvest value to net out some harvest values for two minor species with low harvests and values that do not appear in the NOAA ecological model (i.e., gar and bowfin).

Table 4 Lake Erie Commercial Fishery Harvest (Pounds) and Dockside Value (Dollars) by Species – Five-Year Average (2009-2013)

Species	Baseline Harvest Level (lbs) (5-Yr. Average: 2009-2013)	Baseline Dockside Value ($) (5-Yr. Average: 2009-2013)	NOAA Model Group for Each Species[1/]
Bigmouth Buffalo	461,183	$212,937	Suckers
Brown Bullhead	73,152	$24,672	Catfish
Common Carp	523,457	$129,598	
Freshwater Drum	627,509	$132,869	
White Bass	584,719	$441,959	
Yellow Perch	1,547,630	$3,415,374	
Burbot	1,123	$1,583	
Channel Catfish	544,189	$199,126	Catfish
Rainbow Smelt	328	$338	
Rockbass	245	$0	
Smallmouth Bass	53	$0	
Suckers	38,371	$6,053	Suckers
Walleye	684	$2,442	
Gizzard Shad	67,035	$13,444	
Goldfish	129,526	$95,976	Shiners
Quillback	257,264	$65,290	Suckers
Lake Whitefish	131,916	$144,049	
Lake Trout	71	$0	
Sunfish And Bass	312	$0	
Gar	10	$3	Unmatched
Bowfin	383	$191	Unmatched
Minnows	17,650	$59,779	Shiners
White Perch	670,319	$297,611	
White Sucker	992	$837	Suckers
Total	**5,678,121**	**$5,244,133**	
Adjusted Total [2/]		**$5,243,938**	

[1/] *If blank, the species was assigned to the NOAA Lake Erie model group of the same name.*
[2/] *Adjusted to net out gar and bowfin, which were not matched to the NOAA Lake Erie model groups.*

Harvests were assumed to respond in direct proportion to changes in biomass (Figure 6). Other studies have made this assumption (e.g., Kotchen et al 2006), which may be less reasonable for large changes in biomass. The assumption is widely used as a commercial fishing relationship that can be represented by $H=aSE$. That is, harvest, H, equals a catchability coefficient, a, times stock levels, S, times the effort, E, aimed at catching fish. Here, a change in stock by a factor f, holding catchability and effort constant, leads to a change in harvest of $H*f$. For large changes in the fishery, effort and possibly catchability may also change, so that the resulting harvest is no longer proportional to the stock change. Similarly, cost structures could change affecting profits. However, data are not available to account for such nonlinear changes, though for most scenarios the biomass changes are modest.

Finally, changes in harvest could result in changes in prices paid by consumers of fish, which would alter their well-being. If harvest changes are small and have no impact on fish supplies available to consumers, then any change in consumer well-being would be minimal. The present study lacks the information needed to evaluate the impacts of harvest changes on the well-being of fish consumers. Results of the commercial fishing NED analysis are presented in Table 5. The final column of Table 5 presents the estimated change in commercial fishing profits, which is derived by taking 9.5% of the dockside values based on the percentage of profit before taxes for Finfish Fishing operations under 500 million from the 2015-16 annual statement studies dataset (RMA 2016).

Table 5 Results of NED Analysis for Commercial Fishing in Lake Erie – Based on Biomass Changes Estimated by the NOAA Model (Consequences of Asian Carp Establishment)

	Total Change in Annual Harvest Value[1/]	Total Change in Annual Profits
Scenario 1	$38,300	$3,600
Scenario 2	$282,300	$26,800
Scenario 3	$16,900	$1,600
Scenario 4	$139,100	$13,200
Scenario 5	$17,100	$1,600
Scenario 6	$139,300	$13,200
Scenario 7	-$468,100	-$44,500
Scenario 7 + 1SD	$716,100	$68,000
Scenario 7 - 1SD	-$1,652,300	-$157,000

[1/]All scenarios relative to the "No AC" baseline scenario, and profits represent the revenues of commercial fishing operations less their costs. Dollar values are at 2016 price level and rounded to nearest hundred.

D.2.5.3 NED Analysis – Recreational Fishing

For recreational fishing, two outputs were needed: (1) changes in fishing days as an input to the RED analysis and (2) changes in consumer surplus to anglers for the NED analysis. These results were derived for each scenario. This process required linking changes in biomass for each species to changes in fishing days and the net economic value of those days to anglers. This was done by first relating catch rates to fish biomasses in the ecological model. To capture how catch rates respond to changes in biomass (see Figure 2), as in the commercial fishery analysis, catch rates were assumed to respond in direct proportion to changes in biomass. Other studies have made this assumption (e.g., Kotchen et al 2006), which may be less reasonable for large changes in biomass.

Next, changes in catch rates per species were used to derive changes in fishing effort per species, which was scaled to the whole lake using data on number of fishing days. Species-specific elasticities, which provide the percentage change in fishing days for a percentage change in catch rates, are derived from the Cornell GLMRIS study for warm-water species (Poe et al, 2012), and from Kotchen et al (2006) and Lupi and Hoehn (2001) for cold-water species. With the elasticities, the changes in catch rates were converted into changes in days of effort for each species and summed to get a total change in fishing days. Total trips to Lake Erie are taken from the 2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (NSFHWAR) which reports 8,451,000 trips in 2010; this is the most recent year for which this U.S. Census Bureau-collected data is available. This number lies above the number of trips imputed from creel fishing studies of effort hours but below that of the Cornell survey data.

Changes in the total number of trips were then valued by applying a benefits-transfer estimate of the consumer surplus anglers receive from a day spent recreational fishing. The value per day was derived from the Melstrom and Lupi (2013) study of Great Lakes fishing trips. This information is published in a peer-reviewed journal article and accounts for the same types of Great Lakes recreational fishing considered in this study. It was adjusted to 2016 dollars prior to being inputted into the model using the consumer price index (CPI) (BLS calculator, 2016). Table 6 summarizes the results for the Lake Erie recreational fishery for each of the AC scenarios considered.

Table 6 Results of NED Analysis for Recreational Fishing in Lake Erie – Based on Biomass Changes Estimated by the NOAA Model (Consequences of Asian Carp Establishment)

NOAA Model Scenario	Change in Annual Number of Recreational Fishing Trips[1/]	Change in Annual Recreation Value to Anglers
Scenario 1	26,300	$800,000
Scenario 2	83,900	$2,600,000
Scenario 3	18,000	$600,000
Scenario 4	40,500	$1,300,000
Scenario 5	16,100	$500,000
Scenario 6	18,600	$600,000
Scenario 7	-198,100	-$6,200,000
Scenario 7 + 1SD	197,300	$6,200,000
Scenario 7 - 1SD	-593,500	-$18,500,000
[1/]All scenarios relative to the "No AC" baseline scenario, and profits represent the revenues of commercial fishing operations less their costs. Dollar values are at 2016 price level and rounded to nearest hundred.		

D.2.5.4 NED Analysis – Charter Fishing

For charter fishing, the NED analysis produced two outputs: (1) changes in charter fishing revenues for the RED analysis and (2) changes in charter fishing profits for the NED analysis. To derive changes in revenues and profits, an estimate of how charter outings change in response to biomass changes was needed. The key species for Lake Erie charter fishing are walleye, yellow perch and rainbow trout (steelhead) along with some fishing for smallmouth bass. The distribution of charter fishing effort across species is derived from the peer-reviewed study by Lucente et al. (2012), which is then applied to all states. Changes in outings for each of these species were assumed to change in the same way as described above for changes in recreational fishing days for these species. That is, the proportional changes in charter outings for a proportional change in species biomass is the same for each species in the charter fishery as in the recreational fishery, though the net changes differ because the charter fishery effort across species differs from the recreational fishery.

To derive the baseline number of charter outings, data from state creel and fishery reports was used. For Michigan, the state creel data was used to get the number of charter outings, the number of charter trips (since there are usually more than one person per outing), the total charter effort (in hours), and the fishing hours per charter. For Ohio, their Lake Erie fishery reports gave the total effort hours for charter fishing, but did not give the number of charter outings. The outings were imputed for Ohio by applying the data from Michigan for hours per charter outing. For New York and Pennsylvania, similar charter data was lacking, so data was imputed by using the Michigan creel report's relationship between charter effort hours and recreational hours. These hours were converted to outings using the Michigan data on hours per charter outing. This process yielded a total estimated number of charter fishing outings for U.S. waters of Lake Erie that was then used to derive the changes in outings for each of the scenarios.

Changes in outings were converted into changes in revenues using the revenue per charter outing from Lucente et al. (2012), which was adjusted to 2016 dollars using the CPI (BLS calculator, 2016) prior to being input into the model. Changes in charter profits were then derived from the changes in charter outings. Lucente et al. (2012) suggest that the average Lake Erie charter outing in Ohio loses money (i.e., costs exceed revenues). Perpetual losses in the long run would not be economically sustainable, and it could be an artifact of the year the Lucente data was collected. Instead of using zero for the profits, this study applies an estimate of the percentage of revenues that are profits as derived from fishing industry data. Thus, 9.5% is used as it was for commercial fishing, and the figure comes from the percentage of profit before taxes for Finfish Fishing operations under 500 million from the 2015-16 annual statement studies dataset (RMA 2016). Table 7 summarizes the results for the Lake Erie charter fishery for each of the AC scenarios considered.

Table 7 Results of NED Analysis for Charter Fishing in Lake Erie – Based on Biomass Changes Estimated by the NOAA Model (Consequences of Asian Carp Establishment)

NOAA Model Scenario	Change in Annual Revenue [1/]	Change in Annual Profits
Scenario 1	$45,600	$4,300
Scenario 2	$306,000	$29,100
Scenario 3	$35,700	$3,400
Scenario 4	$203,500	$19,300
Scenario 5	$35,500	$3,400
Scenario 6	$201,900	$19,200
Scenario 7	-$304,500	-$28,900
Scenario 7 + 1SD	$97,100	$9,200
Scenario 7 - 1SD	-$706,000	-$67,100

[1/]All scenarios relative to the 'no AC' baseline scenario. Profits represent the revenues of charter fishing operations less their costs. Dollar values are at 2016 price level and rounded to nearest hundred.

D.2.5.5 Summary of NED Analysis

Table 8 presents a summary of the NED values for the economic consequences analysis. In scenarios 1 to 7, NED losses to the three types of fishing only occur in scenario 7 which assumes AC feed on resident fish larvae. Under this scenario, there are predicted declines in the yellow perch, walleye, and to some extent rainbow trout. In scenarios 1 to 6, the NED results reflect gains to anglers and to charter and commercial operators because the ecological models predict increases in yellow perch, Walleye and in some cases smallmouth bass. In scenarios 1 to 6 it is also the case that the ecological model sometimes predicted declines in rainbow trout, but these are not a part of the commercial fishery and compared to other species, in Lake Erie's charter and recreational fisheries rainbow trout do not attract a large enough share of the fishing effort for their losses to offset the predicted gains in the other species.

There is significant variability in the results of the NED analysis both within and between scenarios. The variability within a scenario is illustrated by the standard deviation of Scenario 7 (Table 8) and shows the potential for larger economic gains or larger losses depending on the range of standard deviations in predicted biomass changes from the ecological model. The high variability in the estimated fish biomass results from uncertainty associated with the inputs used in the NOAA model. The high variability between scenarios shows the importance of the different scenario assumptions, such as the growth rate of AC and whether AC consume fish larvae.

As the results for all the scenarios evaluated illustrate, the predicted economic consequences depend critically on the predictions of the ecological model. Fundamentally, the economic results track the ecological predictions to the key economic species in the lake. When biomass for most of the key economic species goes *up*, the economic consequences of AC are estimated to be *positive*. Conversely, when biomass for most of the key economic species goes *down*, the economic consequences of AC are estimated to be *negative*. Moreover, even for scenarios where the biomass of a key economic species such as rainbow trout is predicted to go down, when the corresponding effects on other key species such as walleye and yellow perch are positive, then the net effect on the economic consequence was positive. The reason is that, in Lake Erie, perch and walleye are relatively more economically important than rainbow trout.

It is important to note that the relative importance of key economic species changes across lakes. For example, in Lake Michigan coldwater species (e.g., whitefish, salmon and trout) are relatively more important to recreational and commercial fisheries than in Lake Erie. Thus, even if the uncertainty could be ignored, it would be incorrect to simply assume the ecological and economic implications at other Great Lakes mirror those examined for Lake Erie.

Another caveat of the results presented here is that the full range of possible effects on the fishery and possible dynamic feedback to fish behavior could not be accounted. The ecological models predicted changes in fish biomass and assumptions were required to translate these into changes in the economic consequences. For example, the method we used does not provide information about how numbers of adult fish change, even though any possible changes in the size of adult fish could affect harvest success, alter desirability as game fish or alter prices of commercial fish. In addition, changes in biomass could lead to changes in cost structures for both commercial and recreational fishing, e.g., harvest costs might increase with higher AC densities and lower target species density. Quantifying these types of effects would require better ecological and economic information, which is not available at this time.

Finally, despite the uncertainty over the implications of AC establishment for the Lake Erie fishery, at least for fisheries in Lake Erie there was an ecological model upon which to base the consequences assessment. Due to the lack of critical ecological and economic information, all other possible effects of AC in Lake Erie, such as implications for boating, other coastal recreation, and nearby property owners, were not quantified. *For the same reason, no effects were quantified for all the other lakes and for all tributaries.*

Table 8 Summary of Results of NED Analysis for Commerical, Recreational, and Charter Fishing in Lake Erie – Based on Biomass Changes Estimated in NOAA's Lake Erie Model (Consequences of Asian Carp Establishment) /1

NOAA Model Scenario	Change in Commercial Fishing Profits[2/]	Change in Recreational Fishing Value to Anglers[1/]	Change in Charter Fishing Profits[1/]
Scenario 1	$3,600	$821,400	$4,300
Scenario 2	$26,800	$2,619,600	$29,100
Scenario 3	$1,600	$562,300	$3,400
Scenario 4	$13,200	$1,263,400	$19,300
Scenario 5	$1,600	$503,100	$3,400
Scenario 6	$13,200	$581,200	$19,200
Scenario 7	-$44,500	-$6,186,100	-$28,900
Scenario 7 + 1SD	$68,000	$6,161,600	$9,200
Scenario 7 - 1SD	-$157,000	-$18,533,800	-$67,100

[1/] Sufficient information allowed for consequences to Lake Erie commercial, recreational and charter fishing to be assessed. Due to lack of critical information, consequences on the other Great Lakes and their tributaries fishing and all other possible effects of AC on the Great Lakes Basin was not quantified.
[2/] All scenarios relative to the 'no AC' baseline scenario. Profits represent the revenues of charter fishing operations less their costs. Dollar values are at 2016 price level and rounded to nearest hundred.

D.2.6 Regional Economic Development (RED) Analysis: Economic Consequences of AC Establishment in Lake Erie

D.2.6.1 RED Approach Overview

This regional economic development (RED) analysis provides an estimate of potential changes in regional economic activity of eight Great Lakes states should AC establish in Lake Erie. As described in the GLMRIS-BR fisheries NED consequence analysis, the establishment of AC in the GLB could change the availability of fishing resources in the invaded waters, therefore altering the direct revenues and expenditures associated with the region's commercial, recreational, and charter fishing activities. This RED analysis explores how estimated changes in direct revenues and expenditures reverberate to the larger economy in terms of sales, employment, earnings and gross regional product – a subnational measure of gross domestic product. This tendency for a direct change in economic activity to give rise to secondary changes in transactions has been called a multiplier effect and has been well documented in the economics literature (Coughlin and Mandelbaum, 1991). The Civil Works Regional Economic System (RECONS) model, developed by the USACE Institute for Water Resources, was utilized to complete this RED analysis. RECONS is the only USACE certified RED model for agency-wide use (Institute for Water Resources, 2016) and is founded on same well-established economic impact modeling methods used by academic economists. Such models, often called input-output (IO) models, are used to estimate how changes in monetary transactions of one sector affect those of other sectors.

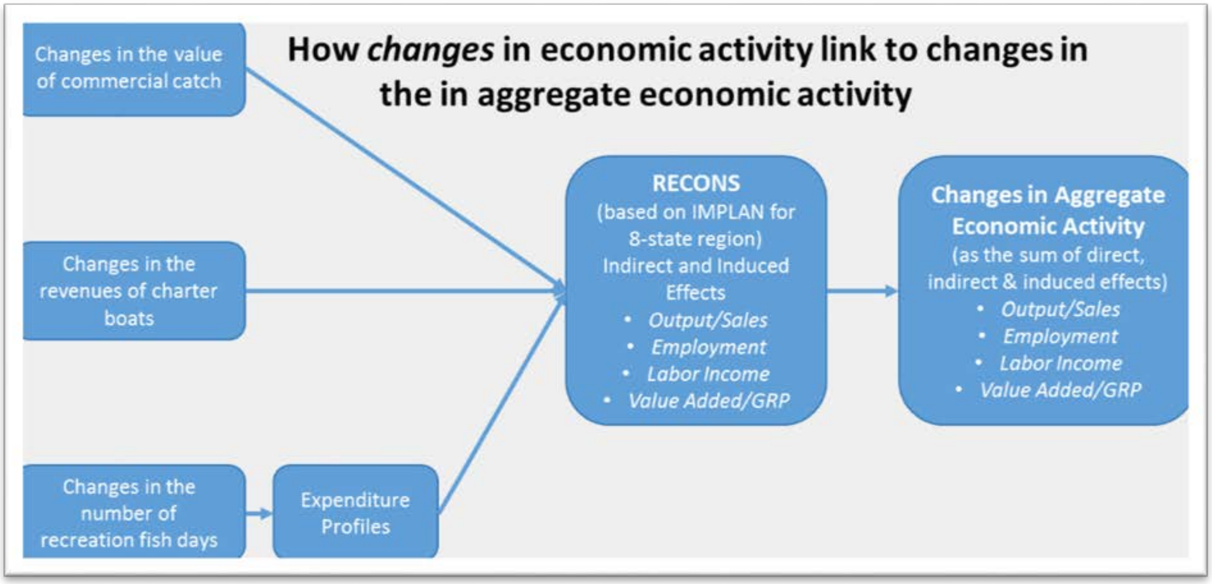
In accordance with the P&G, the geographic region used for this RED analysis encompasses the regions that could experience significant income and employment effects due to changes in monetary transactions associated with GL commercial, charter, and recreational fishing activities. As such, the region of analysis is specified as the eight states that make up the GL region of the United States. This includes all the counties that make up Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin. This expanse is designed to capture the relevant geographic extent of direct and secondary transactions associated with GL commercial, charter, and recreational fishing activities.

A total of seven non-baseline scenarios corresponding to seven different assumptions are modeled for commercial and charter fishing industries and the set of industries that will be directly impacted by changes in recreational fishing expenditures. As species have specific values in commercial and recreation fishing, it is important to tie impacts to the changes in underlying species that drive economic activity. Hence, all economic impacts are tied to expected changes in GL biomass by species. The NOAA Food Web model produced seven scenarios describing changes in the biomass of Lake Erie fisheries given AC establishment, as described by the previous discussion of the fisheries NED analysis. The outcomes of these scenarios show the expected change in Lake Erie biomass by key species. Such changes are then conjectured to induce changes in commercial fishing sales, charter boat trips and recreational fishing trips to Lake Erie in predictable ways. In estimating impacts, changes in biomass of key Lake Erie species, will impact the revenues of commercial and charter fishing operations, and influence recreational fishing expenditures through changes in recreational fishing.

The NED analysis involved the estimates of changes in commercial harvest revenues; changes in charter revenues; and changes in recreational fishing trips. Such impacts give rise to larger changes in aggregate economic activities as shown in Figure 8. Changes in commercial catch will have a direct impact on dockside revenues of commercial fishing in proportion to the change in commercially viable biomass. Similarly, biomass availability has a proportional impact on revenues of charter boat operators. Finally, recreational fishing trips are assumed to be proportionately related to changes in recreational fish species, where fishing trips give rise to recreational fishing expenditures. As opposed to the NED analysis, the

RED analysis only measures the change in private exchange of money and does not include changes in non-priced social benefits.

Figure 8 Flowchart of Regional Economic Development (RED) Analysis – Economic Consequences of Asian Carp Establishment in Lake Erie



Estimated changes in the NED value of commercial catch and changes in the revenues of charter boats are directly imputed into the RECONS model using their respective industry classifications. However, the changes in the number of recreation fish days must be transformed into expected changes in transactions for corresponding goods and services by anglers, based on their typical fishing trip day expenditures. This requires transforming each recreational fishing day into recreation trip expenditures using a representative expenditure profile.

The RECONS model uses changes in direct transactions as inputs to modeling changes in aggregate economic activities. Direct changes in expenditures represent direct infusion or removal of economic transactions to the local economy. In this case, the local economy is the eight states making up the GL region. This region is modeled as a single region. The changes in direct expenditures will give rise to secondary transactions. Secondary transactions can be broken out into indirect expenditures and induced expenditures. Indirect expenditures are the business-to-business transactions initiated by direct changes in expenditures. Induced expenditures arise from changes in institutional incomes, including household earnings through changes in wages. These secondary expenditures continue to recirculate throughout the economy through subsequent transactions, giving rise to changes in aggregate economic activity that exceeds the value of the changes in direct expenditures.

While the RECONS model tracks transactions by dollar value, it also translates these values into employment, labor income and gross regional product terms, based on fixed ratios. The use of fixed ratios calculated from regional economic statistics reported by the U.S. Bureau of Economic Analysis (2016) is a standard procedure in IO modeling.

D.2.6.2 RED Analysis – Great Lakes States' Commercial Fishing Industry

The regional economic impacts of AC establishment in Lake Erie on the commercial fishing industry in the GL region begins with the corresponding estimates of changes in revenues earned (dockside values), as estimated in the NED analysis. That is, they account for all activities required to supply commercial catches, but do not account for post-catch value-added activities for bringing the catch to market for final consumption. For each scenario, changes in direct commercial harvest values from the NED analysis were imputed into the RECONS model as changes in output (sales) in the "Commercial Fishing Production" sector. Standard multipliers from the RECONS model were applied to estimate changes in aggregate economic activity by scenario, and are reported in sales (output), employment, labor income and gross regional product (value added).

Table 9 Regional Economic Impacts of Asian Carp Establishment in Lake Erie on the Commercial Fishing Industry in Great Lakes Region

NOAA Model Scenario	Direct Sales	Total Impact on Commercial Fishing Industry in GL States[1/] (Direct and Secondary Effects)			
		Sales	Employment	Labor Income	Gross Regional Product
Scenario 1	$38,300	$70,200	1	$24,100	$33,900
Scenario 2	$282,300	$516,700	9	$177,400	$249,700
Scenario 3	$16,900	$31,000	1	$10,600	$15,000
Scenario 4	$139,100	$254,500	4	$87,400	$123,000
Scenario 5	$17,100	$31,200	1	$10,700	$15,100
Scenario 6	$139,300	$255,100	4	$87,600	$123,200
Scenario 7	-$468,100	-$856,900	-15	-$294,200	-$414,000
Scenario 7 + 1SD	$716,100	$1,310,700	23	$450,000	$633,300
Scenario 7 - 1SD	-$1,652,300	-$3,024,500	-52	-$1,038,500	-$1,461,400

[1/]Source: IMPLAN and GLMRIS Fisheries RED Model (RECONS modification).
Great Lake States include the following: IL, IN, MI, MN, NY, OH, PA, and WI. Direct effects account for changes to directly affected industries. Secondary effects include indirect and induced effects (changes to supporting industries and household/consumer spending associated with the labor income changes for workers in affected industries). Dollar values rounded to nearest hundred and reflect 2016 price levels.

D.2.6.3 RED Analysis – Great Lakes States' Charter Fishing Industry

Similar to commercial fishing, the regional economic impacts of AC establishment in Lake Erie on the charter fishing industry in the GL region begins with the corresponding estimates of changes in revenues earned by the charter boat for fishing industry, as estimated in the NED analysis. Changes in gross revenues are applied to the RECONS model through the appropriate industry sector "Scenic and sightseeing transportation and support activities for transportation." Standard multipliers from the RECONS model were applied to estimate changes in aggregate economic activity by scenario, and are reported in sales (output), employment, labor income and gross regional product (value added).

Table 10. Regional Economic Impacts of AC Establishment in Lake Erie on the Charter Fishing Industry in Great Lakes Region

NOAA Model Scenario	Direct Sales	Total Impact on Charter Fishing Industry in GL States[1/] (Direct and Secondary Effects)			
		Sales	Employment	Labor Income	Gross Regional Product
Scenario 1	$45,600	$97,100	1	$44,900	$58,800
Scenario 2	$306,000	$651,300	6	$301,100	$394,400
Scenario 3	$35,700	$76,100	1	$35,200	$46,100
Scenario 4	$203,500	$433,200	4	$200,300	$262,300
Scenario 5	$35,500	$75,500	1	$34,900	$45,700
Scenario 6	$201,900	$429,800	4	$198,700	$260,200
Scenario 7	-$130,900	-$278,600	-2	-$128,800	-$168,700
Scenario 7 + 1SD	$1,469,300	$3,127,100	27	$1,445,900	$1,893,500
Scenario 7 - 1SD	-$1,731,100	-$3,684,300	-32	-$1,703,500	-$2,230,900

[1/]Source: IMPLAN and GLMRIS Fisheries RED Model (RECONS modification)
Great Lake States include the following: IL, IN, MI, MN, NY, OH, PA, and WI. Direct effects account for changes to directly affected industries. Secondary effects include indirect and induced effects (changes to supporting industries and household/consumer spending associated with the labor income changes for workers in affected industries). Dollar values rounded to nearest hundred and reflect 2016 price levels.

D.2.6.4 RED Analysis – Great Lakes States' Recreational Fishing Industry

Finally, impacts to the recreational fishing industry arise from changes in the number of fishing trips and corresponding expenditures. Impacts of angler expenditures are linked to changes in recreational fishing trips due to reductions in biomass of targeted species, including Yellow Perch, Walleye, Smallmouth Bass, and Steelhead. Changes in angler expenditures per fishing trip drive economic impact estimates, where expenditures by category are applied based on a recent survey of expenditures by GL anglers (Ready et al., 2012). The survey of fishing trip expenditures was undertaken for the twelve-state region of New York, Pennsylvania, Ohio, Indiana, Michigan, Illinois, Wisconsin, Minnesota, Iowa, Missouri, Kentucky, and West Virginia. The spending profile for Great Lakes anglers is shown Table 11**.** Because this RED analysis evaluates charter fishing impacts independently of recreational fishing impacts, the 'Fishing Charters or Guides' spending category was removed. The unavoidable consequence of this is that revenues to fishing guides are also eliminated in the estimates, where such revenues were not captured in charter fish impact estimates. The 2012 estimates of expenditures per trip were adjusted to 2016 price levels using the applicable consumer price index (2016 from 2012) for the Midwest (Bureau of Labor Statistics, 2016).

Table 11 Great Lakes Anglers: Spending per Trip per Day ($)

Spending Category	2012 Trip Expenditure[1/]	Midwest Price Index[2/] (Annual 2016-2012)	CPI (2016/2012)	2016 Trip Expenditure
Bait and Tackle	$17.32	Recreation commodities	0.953	$16.51
Restaurants or Bars	$23.33	Food away from home	1.085	$25.32
Grocery Stores	$13.34	Food and beverages	1.054	$14.05
Lodging	$24.66	Rent of shelter	1.066	$26.29
Gas Stations	$31.16	Gasoline (all types)	0.669	$20.85
Marinas or Yacht Clubs	$21.07	All items	1.016	$21.41
Fishing Charters or Guides	$34.68	Recreation services	1.052	$0.00
Other	$3.58	All items	1.016	$3.64
Total Spending per Trip per Day	$169.14			$128.07

[1/]Source: Ready, Poe et al. 2012
[2/]Source: Bureau of Labor Statistics, 2016 price level.

Recreational expenditures include those for both goods and services. It is customary to treat the retail purchases of goods differently than services when modeling economic impacts. In this, the total value of retail expenditures on goods should not count toward the local economic impact if the actual goods purchased were not created locally. For example, if an angler spends $50 on fishing lures, and the fishing lures were manufactured overseas and sold to local retailers at the point of delivery for $40, then the local economic direct impact is only $10, or the total revenues, net of the cost of goods sold. That is, only the margins earned locally should contribute to local economic impact estimates. Hence, as shown in Table 12, retail sector expenditures for bait and tackle, grocery stores, gas stations and others are set to margins. To exemplify, the value of 0.404 on Bait and Tackle indicates that the local sectors generated $0.404 per dollar spent on bait and tackle. Margins used were provided by IMPLAN and collected from the Annual Retail Trade Report provided by the U.S. Census Bureau (2016).

Table 12 Great Lakes Anglers: Direct Expenditures per Fishing Trip ($)

Spending Category	2016 Trip Expenditure	Gross Margins	2016 Direct Expenditures
Bait and Tackle	$16.51	0.404	$6.67
Restaurants or Bars	$25.32	1.000	$25.32
Grocery Stores	$14.05	0.284	$3.99
Lodging	$26.29	1.000	$26.29
Gas Stations	$20.85	0.111	$2.31
Marinas or Yacht Clubs	$21.41	1.000	$21.41
Fishing Charters or Guides[1/]	$0.00	1.000	$0.00
Other	$3.64	0.448	$1.63
Total Spending per Trip per Day	$128.07		$87.63

[1/]Removed to avoid double counting.

Table 13 Regional Economic Impacts of Asian Carp Establishment in Lake Erie on the Recreational Fishing Industry in the Great Lakes Region

	Direct Sales	Total Impact on Recreational Fishing Industry in GL States[1/] (Direct and Secondary Effects)			
		Sales	Employment	Labor Income	Gross Regional Product
Scenario 1	$2,304,600	$4,401,100	50	$1,641,400	$2,750,800
Scenario 2	$7,349,900	$14,036,100	159	$5,234,900	$8,772,800
Scenario 3	$1,577,600	$3,012,700	34	$1,123,600	$1,883,000
Scenario 4	$3,544,600	$6,769,200	77	$2,524,600	$4,230,900
Scenario 5	$1,411,500	$2,695,600	31	$1,005,300	$1,684,800
Scenario 6	$1,630,600	$3,113,900	35	$1,161,400	$1,946,300
Scenario 7	-$17,356,800	-$33,146,300	-376	-$12,362,200	-$20,717,100
Scenario 7 + 1SD	$17,287,900	$33,014,800	374	$12,313,100	$20,634,900
Scenario 7 - 1SD	-$52,001,400	-$99,307,300	-1126	-$37,037,400	-$62,068,900

[1/]Source: IMPLAN and GLMRIS Fisheries RED Model (RECONS modification).
Great Lake States include the following: IL, IN, MI, MN, NY, OH, PA, and WI. Direct effects account for changes to directly affected industries. Secondary effects include indirect and induced effects (changes to supporting industries and household/consumer spending associated with the labor income changes for workers in affected industries). Dollar values rounded to nearest hundred and reflect 2016 price levels.

D.2.6.5 Regional Economic Impact Summary and Conclusions

Table 14 presents a summary of the RED values for the economic consequences analysis. For the first six Ecopath with Ecosim model scenarios, results suggest that introduction of AC may actually increase commercially viable biomass. While invasive, the AC population is expected to transition to be a core component of the GL's biomass over time. Through this interaction, the biomass of some species in Lake Erie will increase while others will decrease. Thus, when assuming the AC do not feed on the larvae of resident fish, the model suggests that in most cases the species that are most relevant for commercial and recreation fishing increase in adult populations. This increase in desired biomass would, in turn, result in an increase in commercial catch and an increase in angler participation in hiring charter boats for recreation fishing and other recreation fishing. Other anglers are also expected to increase visits for fishing, and in turn, increase fish-recreation expenditures. Hence, the expected changes in aggregate economic activity is expected to be positive, yet mostly negligible.

Unlike the first six scenarios, Scenario 7 assumes that AC feed on resident fish larvae, resulting in large declines in commercial and recreational fish biomass. This would adversely affect commercial revenues, revenues for charter boat fishing and expenditures from recreational fishing trips. Scenario 7 also afforded the opportunity to gauge the precision of impact estimates by measuring the dispersion of point estimates. Hence, in addition to estimating the expected change in biomass, a measure of uncertainty in predictions was also measured and reported as the expected biomass plus and minus one standard deviation; the range encompassing plus and minus one standard deviation of an unbiased prediction asserts that there exist at least a 68 percent chance that the actual outcome will be within that range. In this, the wide variation in expected changes in aggregate economic activities suggest a high degree of uncertainty in the results.

Table 14 Summary of Results – Regional Economic Impacts of AC Establishment in Lake Erie on Commercial, Recreational, and Charter Fishing Industries in Great Lakes States

NOAA Model Scenario	Changes in Employment and Income[1/] (Direct and Secondary Effects)					
	GL Commercial Fishing Industry		GL Recreational Fishing Industry		GL Charter Fishing Industry	
	Employment	Income	Employment	Income	Employment	Income
Scenario 1	1	$24,100	50	$1,641,400	1	$44,900
Scenario 2	9	$177,400	159	$5,234,900	6	$301,100
Scenario 3	1	$10,600	34	$1,123,600	1	$35,200
Scenario 4	4	$87,400	77	$2,524,600	4	$200,300
Scenario 5	1	$10,700	31	$1,005,300	1	$34,900
Scenario 6	4	$87,600	35	$1,161,400	4	$198,700
Scenario 7	-15	-$294,200	-376	-$12,362,200	-2	-$128,800
Scenario 7 + 1SD	23	$450,000	374	$12,313,100	27	$1,445,900
Scenario 7 - 1SD	-52	-$1,038,500	-1,126	-$37,037,400	-32	-$1,703,500

[1/]Source: GLMRIS Fisheries RED Model (RECONS modification).
Great Lake States include the following: IL, IN, MI, MN, NY, OH, PA, and WI. Direct effects account for changes to directly affected industries. Secondary effects include indirect and induced effects (changes to supporting industries and household/consumer spending associated with the labor income changes for workers in affected industries). Dollar values rounded to nearest hundred and reflect 2016 price levels.

D.2.7 Summary and Conclusions

The results of the economic consequences analysis provide a strong indication of the uncertainty of the economic consequences should AC become established in Lake Erie and some indication of the potential magnitudes of changes to the NED and RED accounts for commercial, recreational, and charter fishing. If we assume that AC do not feed on resident larvae, the expected economic changes to fishing-related activities ranges from negligible to positive based on food web modeling. However, should AC feed on resident larvae, the impacts are a bit more pronounced and negative. The extent of the impact on fishing-related activities is quite uncertain, as the predicted impact on lake biomass are highly variable.

Measuring the potential effects of AC establishment in the GLB poses significant challenges related to both the lack of ecological impact estimates for most of the GLB and the uncertainty of the ecological impact estimates that are available. To minimize conjectures, this study limited consideration to geographies and activities for which data and science provides an objective opportunity for estimates. Considerations in this analysis are limited to changes in people's well-being and the regional economy given AC effects on commercial, charter, and recreational fisheries. Other potential sources of impacts that could not be quantified include recreational water uses, lake-side commerce and tourism, and property values of those residents who choose to locate near or on the lake. Additionally, impact assessments were limited to AC establishment in Lake Erie, as current food web modeling of AC has only been applied to this lake. Therefore, it is critical to recognize that the full-spectrum of potential sources of AC related economic consequences have not been explored.

D.3 Impacts to Navigation Due to GLMRIS-BR Alternatives

While the GLMRIS Report (January 2014) identified multiple control points that could be used to prevent the transfer of ANS between the MRB and GLB. Brandon Road Lock and Dam (BRLD) was recognized as the only control point that could address upstream transfer of MRB ANS through all Chicago Area Waterway System (CAWS) pathways. As illustrated in Figure 9, the BRLD is located south (downstream) of the confluence of the Des Plaines River and the Chicago Sanitary and Ship Canal (CSSC). The purpose of this study is to evaluate structural and nonstructural options and technologies near the Brandon Road Lock and Dam site to prevent the upstream transfer of ANS from the Mississippi River Basin into the Great Lakes Basin, while minimizing impacts on existing waterways uses and users.

Each GLMRIS-BR alternative includes ANS controls to reduce the *probability* that ANS transfer and establish in the GLB. However, many of these ANS controls would adversely affect the uses and users of BRL, which is part of the CAWS and is heavily utilized for commercial cargo navigation with few non-cargo navigation users (e.g., recreation and government vessels). Four economic analyses were completed to describe and quantify how navigation users would be would be adversely affected by the alternative plans considered in the GLMRIS-BR. These analyses include a commercial cargo navigation analysis NED analysis; a commercial cargo navigation analysis RED analysis; safety analysis; and non-cargo navigation analysis. The purpose of each of these analyses are summarized below.

Commercial Cargo Navigation NED Analysis (Section D.3.3). The impacts on commercial cargo navigation are included as an NED cost of the alternatives and were included as project costs in the CE/ICA analysis. The estimated impacts on navigation account for all project phases, to include: construction, and the operation, maintenance, repair, rehabilitation, and replacement (OMRR&R) of ANS controls.

The USACE P&G defines the basic economic benefit of a navigation project to be the *reduction* in the value of resources required to transport commodities. Thus, national economic development (NED) benefits represent "*... increases in the net value of the national output of goods and services, expressed in monetary units ...*" Rather than benefits, the navigation economic analysis completed in support of GLMRIS-BR found that project alternatives result in either no change or a decreased output in goods and services (NED costs). These *NED costs* are composed primarily of *increases in transportation costs*. Increases in transportation costs are the result of the following: (1) reductions in efficiency of existing waterway movements; (2) shifts of waterway and overland traffic to less efficient modes and routes; and (3) shifts of waterway and overland traffic to less efficient origin-destination combinations.

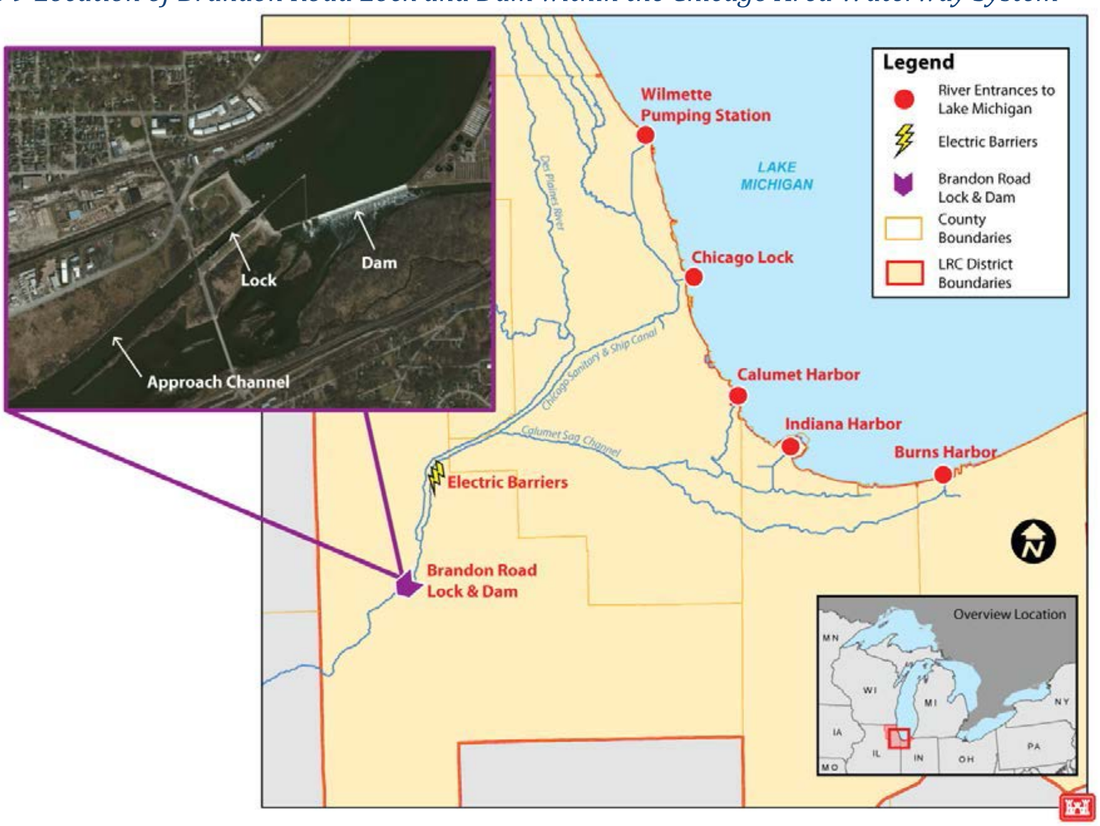
Commercial Cargo Navigation RED Analysis (Section D.3.4). Some of the GLMRIS-BR alternatives could also impose changes on the regional economy, referred to in the P&G as the regional economic development (RED) account. Specifically, the P&G states the "The regional economic development (RED) account registers changes in the distribution of regional economic activity that result from each alternative plan… The regions used for RED analysis are those regions in which the plan will have particularly significant income and employment effects." As such, this RED analysis focused on economic changes that could be incurred by the Chicago Combined Statistical Area (CSA) due to proposed changes at BRLD. This is not to suggest that other regional economies would not be impacted.

However, this RED analysis focused on industries in the Chicago CSA that utilize BRLD, and would be impacted if its modification hindered their access to markets. This includes both local firms that ship goods through BRLD and those that receive shipments through the lock and dam. For this analysis, expected changes to transportation costs are linked to changes in total sales. This is to suggest that if shipping costs were to increase for those industries using the lock and dam to deliver or receive goods and commodities, then the selling price of those goods will be impacted. Should selling prices increase, the impacted firms will face a reduction in competitive advantage relative to other firms not impacted by the increased cost in shipping. It is from this basis that economic impacts are estimated. While this is not a comprehensive regional economic impact evaluation, the RED analysis was completed in order to display how the Chicago CSA region could sustain economic impacts due to implementation of a GLMRIS-BR alternative plan.

Safety Analysis (Section D.3.5). For the alternatives under consideration in the vicinity of BRLD, a safety analysis was conducted to assess the externalized costs associated with traffic diverting from a route that includes barge transportation, to a least-costly all overland land route. The GLMRIS-BR navigation economic analysis also accounts for the following: 1) diverted traffic due to anticipated plant closures during construction, and 2) lost traffic during scheduled maintenance events. Since overland modes typically have higher fatality, injury, and property damage rates when compared to the inland towing industry, these traffic diversions give rise to these externalized costs.

Non-Cargo Navigation Analysis (Section D.3.6). Non-cargo users include passenger boats and ferries, federal and non-federal government vessels, and recreation vessels. While present, non-cargo users of BRLD are few in number but present nonetheless. As such, a qualitative assessment was completed in order to characterize how each alternative plan would impose new challenges for non-cargo navigation users of BRLD. This discussion considers all project phases, to include: construction, and the operation, maintenance, repair, rehabilitation, and replacement (OMRR&R) of ANS controls. Therefore, an economic analysis was not completed to quantify the effects of alternative plans on these users.

Figure 9 Location of Brandon Road Lock and Dam within the Chicago Area Waterway System



D.3.1 Overview of GLMRIS-BR Alternative Plans & ANS Control Measures Used to Inform the Navigation Economic Analyses

In support of GLMRIS-BR, several alternative plans were developed in order to address this need to prevent the upstream transfer of ANS from the MRB into the GLB to the maximum extent possible. Alternative plans represent combinations of measures that collectively meet study goals and objectives within the defined study constraints, which are described in Chapter 3 of the main report. Plans were developed by combining one or more of the following ANS control measures: nonstructural measures, complex noise, water jets, engineered channel, electric barrier, flushing lock, boat launches, and mooring cells. These measures are combinable. A lock closure measure is also considered, but is only included a single 'Lock Closure' Alternative. The final array of GLMRIS-BR alternatives include:

1. No New Federal Action Alternative (No Action);
2. Nonstructural Alternative;
3. Technology Alternative – Electric Barrier;
4. Technology Alternative – Complex Noise;
5. Technology Alternative – Complex Noise with Electric Barrier; and
6. Lock Closure.

Table 15 displays the final array of alternatives considered in the GLMRIS-BR, along with the ANS control measures that they include.

Table 15 ANS Control Measures Included in GLMRIS-BR Alternative Plans

GLMRIS-BR Alternative	ANS Control Measures/Features									
	Sustained Current Activities	Nonstructural	Boat Launches	Flushing Lock	Engineered Channel	Water Jets	Complex Noise	Electric Barrier	Mooring Cells	Lock Closure
No New Federal Action	×									
Nonstructural Alternative	×	×	×							
Technology Alternative – Electric Barrier	×	×	×	×	×	×		×	×	
Technology Alternative – Complex Noise	×	×	×	×	×	×	×			
Technology Alternative – Complex Noise with Electric Barrier	×	×	×	×	×	×	×	×	×	
Lock Closure	×	×	×							×

The BRL is part of the CAWS, and is heavily utilized for commercial cargo navigation, and also supports a small amount of non-cargo navigation users (e.g., recreational and government vessels). Each plan, aside from the 'No New Federal Action' plan includes nonstructural and/or structural measures. Some of the GLMRIS-BR alternatives, if implemented, could require navigation users of BRL to accommodate changes to their operations during each project phase, including: construction, and the operation, maintenance, repair, rehabilitation, and replacement (OMRR&R).

Impacts to navigation vary for the range of project alternatives. The No New Federal Action and Nonstructural alternatives allow navigation to continue without further impacts. For the purpose of the navigation economic analysis, the following four technology alternatives were considered: Technology Alternative – Electric Barrier; Technology Alternative – Complex Noise; Technology Alternative – Complex Noise with Intermittent Electric Barrier; and Technology Alternative – Complex Noise with Continuous Electric Barrier. The technology alternatives with complex noise and an electric barrier were analyzed separately in order to estimate for the potential range of impacts on navigation given different operating parameters (continuous and intermittent). The technology alternatives do allow navigation to continue through BRL, but include ANS control measures that impose impacts due to their construction and OMRR&R. The Lock Closure alternative is the only alternative that results in the permanent discontinuation of use of BRLD for navigation.

To evaluate the effects of the GLMRIS-BR alternatives on navigation users of BRLD, the potential impacts of the construction (implementation), operation, and periods of maintenance, repair, rehabilitation and/or replacement (MRR&R) of each measure in each alternative was estimated. A review of each ANS control measure is presented in the upcoming section.

D.3.1.1 Review of ANS Control Measures and Considerations for Navigation at Brandon Road Lock and Dam

Each plan, aside from the 'No New Federal Action' plan includes a combination of nonstructural and/or structural ANS control measures. Some of these ANS control measures, if implemented, would be expected impact navigation because of one or more of the following:

(1) Construction of Structural ANS Control Measures – The construction of ANS control measures for some of the alternatives would require temporary, scheduled lock closures. During these construction periods, the BRL would be unavailable. Based on best-available engineering information at the time of the economic analysis, the expected duration and frequency of these construction closures for each ANS control measure is presented in Table 16. This information was used to inform the estimates of the impacts to navigation (NED costs).

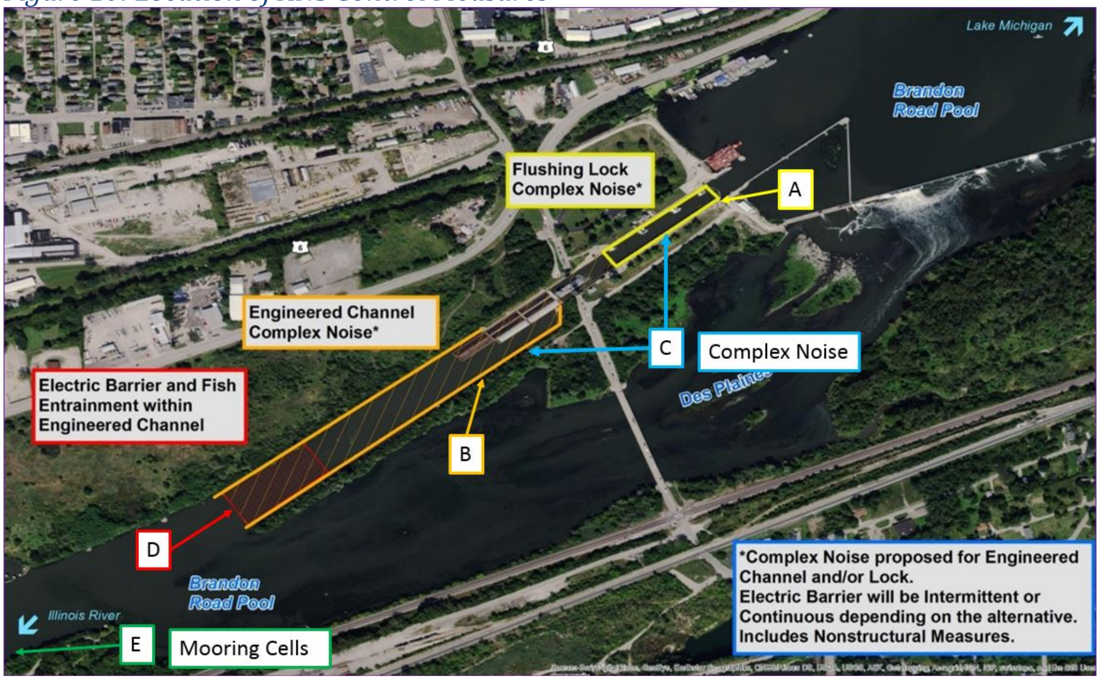
(2) Modified Lock Operations Due to Nonstructural & Structural ANS Control Measures – Once constructed, some ANS control measures would require changes to the use of BRL. Based on best-available engineering information at the time of the economic analysis, a summary of the estimated changes to the standard operation of BR Lock are displayed in Table 17. This information was used to inform the estimates of the impacts to navigation (NED costs).

(3) Maintenance, Repair, Rehabilitation, and/or Replacement of Structural ANS Control Measures – Once constructed, some ANS control measures would require temporary, scheduled lock closures in order to maintain these features. During these periods, the BRL would be unavailable. Based on best-available engineering information at the time of the economic analysis, the expected duration and frequency of these maintenance closures for each ANS control measure is presented in Table 18. This information was used to inform the estimates of the impacts to navigation (NED costs).

The following structural ANS control measures are included in one or more of the technology alternatives: (1) flushing lock; (2) engineered channel; (3) complex noise; (4) electric barrier; (5) fish entrainment (water jets), (6) mooring cells, and (7) boat launches (not depicted in figure below). Figure 10 displays an aerial view of BRLD with outlines of the proposed measure locations. The letters and colored indicators serve as references for the following discussion of the measures. For a detailed description of each measure, please see Chapter 6 of the main report.

The details of these measures are discussed below in terms of assumptions made regarding their impacts on navigation. Assumptions regarding operating parameters were developed with the intention of being protective of life safety. If an alternative is implemented, USACE and USCG would test and evaluate measures included in the alternative to address site-specific operating considerations that cannot be addressed until after construction. Additional engineering and economic analysis, safety testing, and coordination with navigation stakeholders and the USCG would be completed during the PED phase to better inform these assumptions and estimates.

Figure 10: Location of ANS Control Measures



Nonstructural Measures

Nonstructural measures above those expected to occur in the No New Federal Action alternative are included as a part of all alternatives. Nonstructural controls do not require the construction of a permanent feature in the waterway and can generally be implemented fairly quickly. Examples include but are not limited to electrofishing and netting. These additional nonstructural measures are not anticipated to have any effects on navigation at BRLD.

Flushing Lock (See Location 'A' in Figure 10).

The flushing lock (Figure 6-9) would be designed to exchange water from the upper pool prior to a lockage, thereby removing floating ANS from the lock. The flushing lock would not control the passage of swimming or hitchhiking species. The operation for the flushing lock assumed that vessels would be staged downstream on the right descending bank when water from the upper pool (Brandon Road Pool) is diverted through the lock's modified filling and emptying culverts and through open downstream miter gates.

Navigation Considerations During Construction of Flushing Lock. Construction of the flushing lock would occur at the beginning of the construction period and take approximately 40 days to completely construct. Construction entails reengineering the filling and emptying ports to successfully facilitate the flushing process. These 40 days of construction require a complete, scheduled lock closure.

Navigation Considerations for Operation of Flushing Lock. Operations of the flushing lock entail performing a flushing operation whenever an upbound (moving north from the Dresden Island pool into the Brandon Road pool) vessel approaches the lock. Additionally the second iteration of a consecutive downbound operation, whether it be the second of a multi cut tow or a downbound tow right after another downbound tow, will require a flushing operation. The frequency of this operation is subject to further refinement through physical modeling and dependent upon the availability of water in the Brandon Road pool sufficient to perform the operation, but this analysis assumes every upbound operation and the second consecutive downbound operation is subject to the flushing operation.

The reconfiguration of the filling and emptying ports is beneficial for the lockage process as it is expected to allow the lock to be filled and emptied more quickly and efficiently. This reduction in chambering time slightly reduces the magnitude of the impact from the overall flushing process. The assumed flushing process requires that vessels approaching the lock wishing to pass from the Dresden Island pool to the Brandon Road pool will approach the lock as usual, tie off to the long wall on the right-descending bank, and wait for the lock chamber to flush. Once the flushing process has completed, the vessel will untie from the wall and enter the chamber to process normally.

Navigation Considerations for MRR&R of Flushing Lock. The flushing lock is not expected to require additional MRR&R.

Engineered Channel (See Location 'B' in Figure 10)

An engineered channel is a concrete channel structure installed within the downstream approach channel to Brandon Road Lock highlighted in orange in Figure 10. The engineered channel serves to increase the effectiveness of some ANS controls, reduce control impacts and serves as a platform to add new technologies in the future, if deemed appropriate.

Navigation Considerations during Construction of the Engineered Channel. The engineered channel is the main construction item of the technology alternatives evaluated in this analysis. The construction begins concurrently with the flushing lock and takes approximately 909 days to complete. Concurrent with the 960-hour (40 day) closure for flushing lock implementation, construction crews will be constructing the section of the engineered channel closest to the lock chamber to minimize the impact to navigation once the lock reopens. After this 960-hour (40 day) closure, the lock will be unavailable 12 hours per day for the next 30 days, or 360-hours, so that construction crews can complete the engineered channel near the lock to the point that the remainder of the construction can be completed with minimal navigation impacts. Given the intermittent nature of the closure and its proximity to the 960-hour (40 day) closure, traffic is not rescheduled for this event.

Navigation Considerations for Operation of the Engineered Channel. Post implementation of the engineered channel, there are no operational changes identified from operating the engineered channel in and of itself.

Navigation Considerations for MRR&R of the Engineered Channel. The engineered channel is not expected to require additional MRR&R.

Complex Noise (See Location 'B' in Figure 10)

Complex noise is underwater sound generated to deter ANS fish species from entering the Brandon Road Lock approach channel. However, this measure would not control the passage of floating ANS or ANS that are known to be hitchhikers. The speaker system requires work within the lock chamber and engineered channel.

Navigation Considerations During Construction of Complex Noise System. Construction of the complex noise system is assumed to be the final construction activity for alternatives where complex noise is the alternative's only fish deterrent. For alternatives including the speaker system, installation is expected to take approximately 45 calendar days to complete. During this implementation phase, the lock will be closed for approximately 8 hours per day, 5 days a week. For partial closures, navigation is not assumed to reschedule shipments around the closures. For alternatives utilizing both complex noise and electric barrier as swimmer controls, implementation of these measures is anticipated to occur concurrently.

Navigation Considerations for Operation of Complex Noise System. The complex noise system, once implemented, is not anticipated to have an impact on navigation through Brandon Road Lock.

Navigation Considerations for MRR&R of Complex Noise System. The speakers will require periodic replacement, but this is not expected to impact navigation.

Electric Barrier (See Location 'D' in Figure 10)

An electric dispersal barrier creates an electric field that repels and stuns fish and would be placed at the downstream extent of the engineered channel.

Navigation Considerations during Construction of Electric Barrier. Implementation of the electric barrier requires work by divers to complete electrode and parasitic placement. This work requires the lock to be shut down for 8 hours per day, 5 days per week for a construction period of approximately 22 calendar days. In alternatives with both an electric barrier (D) and a complex noise system (C), the implementation of the measures are assumed to occur concurrently.

Navigation Considerations for Operation of Electric Barrier.
Two operating parameters were are considered for the electric barrier, intermittent and continuous operating parameters. See Chapter 6 of Main Report for more information regarding operating parameters.

Intermittently Operated Electric Barrier. For alternatives that include two swimmer controls, electric barrier and complex noise, the electric barrier was assumed to be turned off while vessels were approaching the downstream channel, while they were in the channel, and while they were in the lock. The second swimmer control would be available when the electric barrier was off. By shutting off the electric barrier in the presence of vessels, the navigation restrictions for a continuous electric barrier are assumed to be avoided, and navigation is assumed to not be appreciably altered.

Continuously Operated Electric Barrier. A continuously operated barrier is included in the alternative that has one swimmer control. As noted above, assumptions regarding operating parameters were developed with the intention of being protective of life safety. If an alternative is implemented, USACE and USCG would test and evaluate measures included in the alternative to address site-specific operating considerations that cannot be addressed until after construction. These assumptions may or may not be a more restrictive than what would actually be imposed.

Vessel operators will sometimes approach lock chambers with flotillas that do not fit inside the lock chamber as they are configured. Sometimes this requires tows to make multiple cuts to transit a lock, a process by which a portion of the flotilla is placed within the chamber, the rest backs away, and mechanical tow-haulage units or other tows will extract the preceding portion after it completes the process. This will be repeated until the entire tow has transited. In other scenarios, it may be more efficient for a flotilla to move in a tow that exceeds the locks length, counting the towboat, but not the locks width. In these instances, the towboat will disconnect from the rest of the flotilla after placing it in the chamber, and pull alongside to fill the remaining width, allowing the long tow to transit in a single cut.

These operations all require workers to be out on deck disassembling tows or reconfiguring them. These operations put workers at higher risk for falling overboard. To facilitate the evaluation of this measure within the context of the navigation analyses, it is assumed that these operations would no longer be allowed in the vicinity of the engineered channel or lock. The only time this restriction is assumed to be in place is in the immediate area of the lock and the engineered channel. Thus, for commercial cargo navigation, this limits tows transiting the lock to 550 feet by 110 feet, as discussed above in the reconfiguration restriction section.

It is assumed that the electric barrier would increase the time for upbound vessels to transit the lock due to the inability of tows to wait in the vicinity of the downstream channel, and for any precautions they made need to take to insure they transit the lock safely. The actual increase in time is unknown. However, to account for this unknown time increase for upbound tows making a long approach, a 10-minute increase was used as a proxy. Accounting for this additional time allowed for more accurate estimate of the navigation impacts.

Navigation Considerations for MRR&R of Electric Barrier. The electric barrier is projected to have a design life of approximately 25 years, therefore this analysis assumes the system will have to be rehabilitated every 25 years throughout the planning horizon. This rehabilitation is projected to require the same downtime period as the implementation, so the rehabilitation is considered to occur within 22 calendar days and require 8 hour per day closures, 5 days per week.

Fish Entrainment Mitigation (Water Jets) (See Location 'D' in Figure 10)

Water jets would be attached to the channel bottom and be used to remove or dislodge fish from up-bound tows to contend with vessel-induced motion that transports fish along with the vessel.

Navigation Considerations During Construction of Water Jets. Water jets are included in the construction of the engineered channel, and do not impose a unique set of restrictions during construction, and do not impose restrictions on navigation during their post-construction operation.

Navigation Considerations for Operation of Water Jets. The water jets are not anticipated to have an impact on navigation through Brandon Road Lock.

Navigation Considerations for MRR&R of Water Jets. The pumps for the water jets will require periodic replacement, but this is not expected to impact navigation.

Mooring Cells for Downstream Approach Channel (See Location E in Figure 10)

The addition of four mooring cells downstream of the lock is not a measure to address ANS, but is under consideration to facilitate the ease of navigation through the project and allow crews to make sure their tow is safe to transit the project.

Navigation Considerations During Construction of Mooring Cells. These mooring cells are projected for construction south of the lock away from the main approach area. They are not predicted to have any impact on navigation during construction.

Navigation Considerations for Operation of Mooring Cells. To capture the potential benefits of the mooring cells, the proxy time of 10 minutes that was assumed for upbound tows making a long approach due to the continuous electric barrier was removed in the model runs that included the new mooring area.

Navigation Considerations for MRR&R of Mooring Cells. The mooring cells will require a 1-time dredging event 25 years after they are constructed. This is not expected to impact navigation.

Boat Launches for Downstream Approach Channel (Not depicted in Figure 10)

The downstream launch into Dresden Island Pool would be built at one of two locations, depending on the alternative. For the Nonstructural Alternative, the launch would be constructed on the isthmus of land adjacent to the approach channel. A gravel road with secure gate access would lead from Brandon Road to a parking area, and a boat launch into the approach channel. For the technology alternatives, the boat launch would be built further downstream, just south of the approach channel outlet. The access road to the electric barrier and/or complex noise control buildings would extend to a parking and launch area.

Navigation Considerations During Construction of Boat Launches. Construction of the boat launches are not expected to have any impact on navigation.

Navigation Considerations for Operation of Boat Launches. The boat launches are not anticipated to have an impact on navigation through Brandon Road Lock.

Navigation Considerations for MRR&R of Boat Launches. The boat launches are not expected to require additional MRR&R.

Permanent Lock Closure

Permanent lock closure involves the removal of the upstream operational gates from the Brandon Road Lock and replaces them with a permanent concrete wall that ties into the existing concrete gate sill and existing lock walls to structurally separate the upper pool from the lower pool. Permanent lock closure is solely included in the Lock Closure alternative.

Table 16 Summary of Estimated Changes to Standard Brandon Road Lock Operations Due to Construction of ANS Controls (Description, Frequency, and Duration) [a, b, c]

Estimated Changes	**Construction Component**				
	Flushing Lock	Engineered Channel & Water Jets		Speaker Placement for Complex Noise	Electrode & Parasitic Placement for Electric Barrier
		Guide Wall	Walls & Floor		
Estimated Closure Duration	24 hours	12 hours (during daylight)	1 hour	8 hours	8 hours
Estimated Frequency	Daily	Daily	6 days/week (open Sundays)	5 days/week	5 days/week
Number of Calendar Days Change Would be in Effect	40 days	30 days	800 days	45 days	22 days
Alternative					
No New Federal Action					
Nonstructural Alternative					
Technology Alternative –Electric Barrier	×	×			×
Technology Alternative – Complex Noise	×	×		×	
Technology Alternative – Complex Noise with Electric Barrier	×	×		×	×
Lock Closure					

[a] All changes to standard BRL operations were estimated based on the current level of design with the goal of minimizing impacts to navigation. During the PED phase, additional design and a value engineering (VE) study will be conducted with the goal of reducing the duration of construction impacts on navigation. Opportunities to schedule BRL construction (and required closures) at same times as other Illinois Waterway (IWRR) Lock schedule operation and maintenance lock (O&M) would be explored to minimize system IWW impacts to navigation.
[b] Construction methods were planned so 165-foot channel width always available. This is assumed to allow for navigation to transit without restrictions on tow configurations.
[c] For Technology Alternative – Complex Noise with Electric Barrier, changes to standard BRL operations due to construction of ANS controls would be the same regardless of how the electric barrier is operated post-construction (intermittently or continuously).

Table 17 Summary of Assumed Changes to Standard Brandon Road Lock Operations Due to Operation of ANS Controls [a, b, c, d]

	ANS Control Measures	
	Flushing Lock	Continuous Electric Barrier
Assumed Changes	▪ Estimated time to flush lock is 15 minutes. ▪ All upbound traffic assumed to be tied off downstream of lock chamber during flushing. ▪ All upbound lockages would require flushing. ▪ For downbound lockages, any consecutive lockages in that direction would be flushed.	▪ New Restricted Navigation Area (RNA) in Downstream Approach Channel of Brandon Road Lock. ▪ Entire tow assumed to be outside RNA in order for someone to be on deck. ▪ Assume no tow reconfigurations or tie-offs permitted in RNA. ▪ Tows transiting RNA assumed be restricted to a maximum length of 500 feet. ▪ All reconfigurations or refleeting assumed to occur at one of the following: (1) new downstream mooring area or (2) location further downstream of BR Lock.
Alternative		
No New Federal Action		
Nonstructural Alternative		
Technology Alternative –Electric Barrier	×	×
Technology Alternative – Complex Noise	×	
Technology Alternative – Complex Noise with Electric Barrier	×	**
Lock Closure		

[a] All assumed changes to standard BRL operations were based on best-available engineering information at the time of the navigation economic analysis. Based on the best available information, the operation of the following ANS controls are not expected to impact navigation: nonstructural, engineered channel, water jets, complex noise, or intermittent electric barrier.

[b] Every year, there would be a 1 in 3 chance of a single 5-day closure to accommodate potential ANS emergency response procedures. For No New Action Plan, these closures fall within the emergency response procedures for the exiting EB in Romeoville, IL.

[c] The actual operating parameters of the electric barrier and of vessels through this area assuming an electric barrier is operating during vessel transit cannot be established until after construction, operation and testing of the system. Operating assumptions were developed with the intention of being protective of life safety.

[d] During PED, a scaled physical model of the flushing lock would be used to optimize the operating parameters to maximize flushing effectiveness while minimizing navigation impacts.

** For Technology Alternative – Complex Noise with Electric Barrier, changes to standard BRL operations due to the electric barrier would vary depending on whether it is operated continuously or intermittently. For the purposes of the navigation economic analysis, intermittent operation assumes that the electric barrier would be turned off when vessels are in the lock or approach channels. However, continuous operation of the electric barrier would impose the changes described in this table.

Table 18 Estimated Changes to Standard Brandon Road Lock Operations Due to Maintenance, Repair, Rehabilitation, and/or Replacement (MRR&R) of ANS Controls [a, b, c]

Estimated	MRR&R Activities for ANS Controls
	Electric Barrier
Estimated Closure Duration (To Occur 25 years after Implementation)	8 hours
Estimated Frequency	5 days/week
Number of Calendar Days Change Would be in Effect	60 days
Alternative	
No New Federal action	
Nonstructural Alternative	
Technology Alternative – Continuous Electric Barrier	
Technology Alternative – Complex Noise	
Technology Alternative – Complex Noise with Electric Barrier	**
Lock Closure	

[a] Changes to standard BRL operations were estimated using best-available engineering information at the time of the navigation economic analysis. The following ANS controls are not expected to require additional MRR&R that would impact navigation: nonstructural, engineered channel, water jets, complex noise, or the flushing lock.

[b] A major rehabilitation of BRL is assumed to occur in year 2030, with an estimated closure duration of approximately 30 days. This would occur with or without implementation of a GLMRIS-BR project, and is therefore included in both the with-project and without-project conditions.

** For Technology Alternative – Complex Noise with Electric Barrier, changes to standard BRL operations due to MRR&R of an electric barrier would be the same regardless of how the electric barrier is operated post-construction (intermittently or continuously).

D.3.2 Historical Overview of Brandon Road Tonnage, Lock Size, and Tow Configurations

D.3.2.1 Tonnage

The Chicago River, Des Plaines River, CSSC, and the Cal-Sag Channel are the primary navigation channels that make up the Chicago portion of the IWW also known as the CAWS. Brandon Road is an integral part of the IWW, and along with the other locks on the system allows the Chicago area to receive and transport bulk commodities across a broad area of the country. Commercial waterway navigation provides the most cost-effective mode of transit for commodities required by several industries. The movement of these goods via the waterway contributes to both the regional and national economies. The extent of these historical traffic flows can be seen in Figure 11.

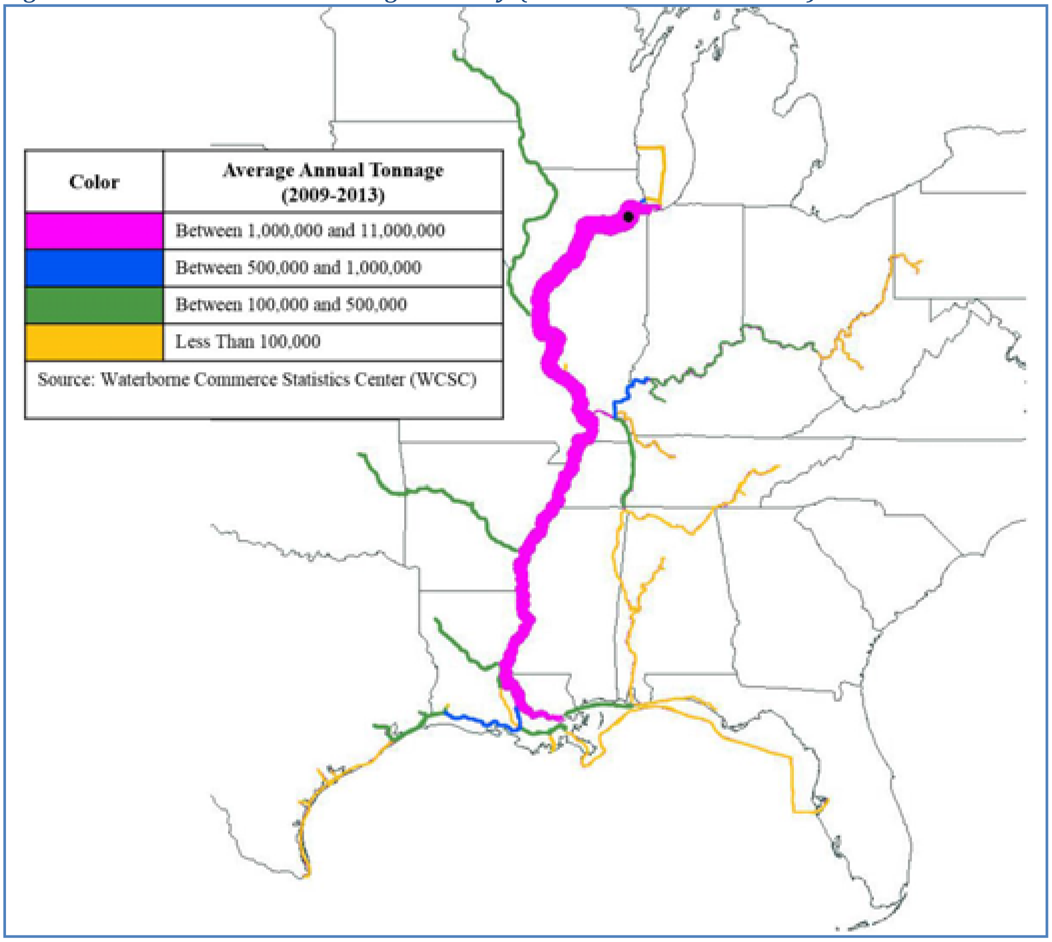
Commercial waterway traffic in the Chicago region reflects the interactions of economic drivers and commercial needs within a unique, multi-modal freight environment. This multi-modal nexus includes a complex rail network, and the convergence of several Interstate highways that form one of the nation's greatest concentrations of industrial activity. Throughout its history, the CAWS has facilitated the transport of commodities for iron and steel industry, and the petroleum industry (amongst others) that have been vital to the regional and national economies.

Although growth in each of these industries has fluctuated throughout the historical operation of the locks and dams on the system, they both directly and indirectly support economic activity. Specifically, the petroleum refineries situated on the IWW are key to ensuring low energy prices (e.g. diesel, gas). Waterway traffic supports a broad array of the petroleum industry's supply chain by transporting raw, intermediate, and residual commodities that are necessary for the refining process. Examples include the movement of crude petroleum, refined petroleum products and oils, petroleum coke (used in the production of power at electric utilities) and asphalt (used for road construction).

Brandon Road Lock also supports the construction industry by allowing low-cost transport of aggregates that are necessary in the production of ready mix concrete. Aggregates traffic moving through BRL are dominated by sand and gravel, and limestone, with smaller quantities of gypsum and other materials. In contrast to iron and steel, which are moved across the country, aggregate traffic typically stays in the CAWS region and supports construction activities in the Chicago area. Sand and gravel traffic mostly originates in quarries along the CAWS or Illinois Waterway and moves to area aggregate yards for distribution to construction sites. Natural sands dredged from the river ensure a consistent blend that is needed for the production of concrete.

Low-cost transport of steel and scrap products also support construction activities, and with the continued evolution of the electric arc furnace, the automotive industry as well. These iron and steel products include iron and steel scrap, pig iron, iron and steel plates, ferroalloys, iron ore, iron and steel bars and rods, primary iron and steel products, and iron and steel pipe and ingots. Iron and steel traffic moving through Brandon Road serves the raw material input needs of steel mills in the Chicago area and elsewhere, as well as the intermediate iron and steel product needs of downstream steel manufacturers both in the Chicago area and other markets, especially along the Lower Mississippi and Gulf Coast.

Figure 11 Brandon Road Tonnage Density (2012-2014 WCSC Data)



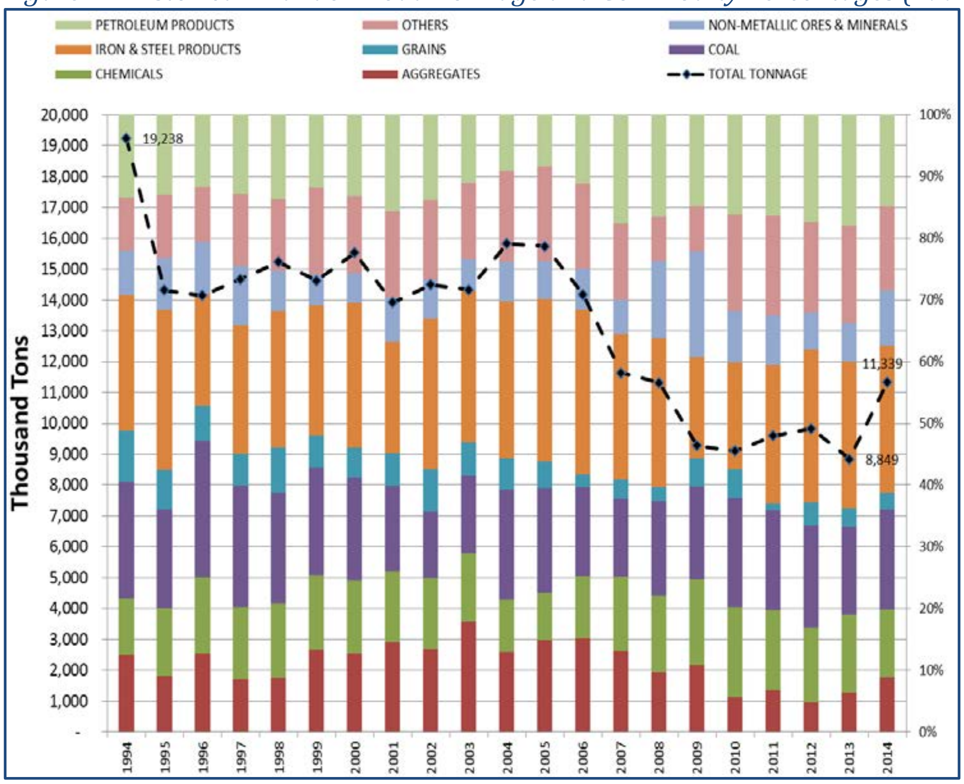
Brandon Road supports an array of commercial traffic and commodities. A summary of the historical traffic can be seen in Table 19 and Figure 12. A detailed write-up of the forecasted demand for traffic moving through Brandon Road at the individual commodity-level can be found in *Attachment 2 – Waterway Traffic Demand Projections*.

Table 19 Brandon Road Lock Tonnage (Thousands) 1994-2014

Year	Aggregates	Chemicals	Coal	Crude Petroleum	Grains	Steel Products	Metallic Ores & Minerals	Others	Petroleum Products	**Total**
1994	2,401	1,759	3,631	**	1,594	4,221	1,396	1,657	2,579	19,238
1995	1,300	1,577	2,265	35	919	3,700	1,199	1,463	1,855	14,313
1996	1,795	1,741	3,138	**	795	2,575	1,190	1,254	1,653	14,141
1997	1,255	1,719	2,874	**	762	3,074	1,418	1,691	1,887	14,680
1998	1,332	1,839	2,736		1,113	3,360	992	1,776	2,080	15,228
1999	1,943	1,784	2,533		775	3,085	720	2,062	1,730	14,632
2000	1,973	1,840	2,592		753	3,635	751	1,929	2,053	15,526
2001	2,022	1,601	1,929	**	738	2,510	993	1,944	2,188	13,925
2002	1,945	1,668	1,553	**	1,007	3,516	927	1,877	1,994	14,487
2003	2,564	1,594	1,792		768	3,525	725	1,776	1,585	14,329
2004	2,048	1,352	2,820	**	798	4,016	1,033	2,318	1,441	15,826
2005	2,345	1,216	2,667		674	4,148	960	2,416	1,318	15,744

Year	Aggregates	Chemicals	Coal	Crude Petroleum	Grains	Steel Products	Metallic Ores & Minerals	Others	Petroleum Products	**Total**
2006	2,155	1,431	2,041		293	3,789	939	1,952	1,584	14,184
2007	1,516	1,417	1,459		365	2,744	647	1,439	2,056	11,643
2008	1,097	1,399	1,729		258	2,742	1,408	818	1,862	11,313
2009	1,004	1,283	1,405	**	415	1,533	1,577	692	1,369	9,278
2010	521	1,318	1,615	**	427	1,578	751	1,423	1,476	9,109
2011	651	1,241	1,554		109	2,153	764	1,549	1,577	9,598
2012	461	1,164	1,582	233	365	2,379	565	1,411	1,670	9,830
2013	554	1,085	1,224	237	259	2,041	542	1,361	1,546	8,849
2014	1,006	1,245	1,832	**	310	2,700	1,012	1,563	1,671	11,339
Average (1994-2014)	**1,518**	**1,489**	**2,141**	**168**	**643**	**3,001**	**977**	**1,637**	**1,770**	**13,201**
Source: Waterborne Commerce Statistics Center (WCSC).										

Figure 12 Historical Brandon Road Tonnage and Commodity Percentages (1994-2014)



D.3.2.2 Lock Size and Historic Tow Configurations

Figure 13 displays an example of a tow configuration of eight 200-foot by 35-foot barges in transit on the inland marine transportation system. However, Brandon Road's current 600' by 110' chamber can accommodate eight barges per tow - assuming an average barge size of 200' by 35' - in a single lockage process known as a "cut." Figure 14 displays the necessary tow configuration required to accommodate a standard flotilla of eight barges (200' by 35') into a 600' by 110' chamber. The 200' by 35' barges are the standard size used on the inland marine transportation system. Additional barges would require multiple lockages to fully transit the project; however combinations of smaller barges may be able to accommodate more per cut.

Figure 13 Example Tow Configuration of Eight 200-Foot by 35-Foot Barges In Transit on the Inland Marine Transportation System (700 Feet by 105 Feet)

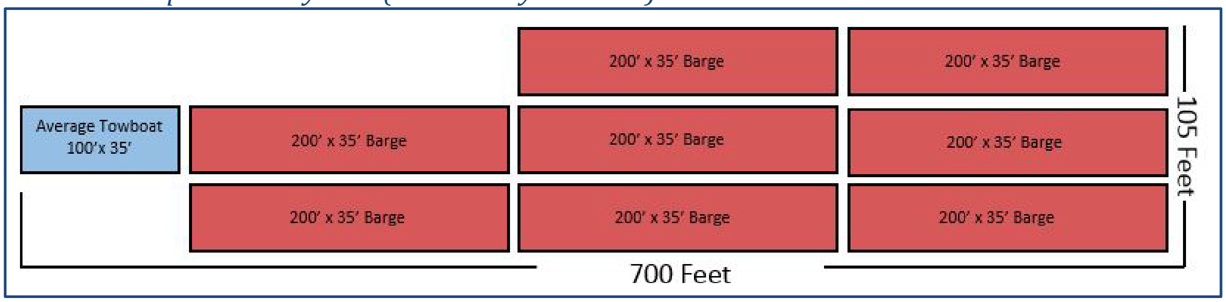


Figure 14 Tow Configuration to Accommodate Standard Flotilla of Eight 200-Foot by 35-Foot Barges into the Brandon Road Lock Chamber (600 Feet by 110 Feet)

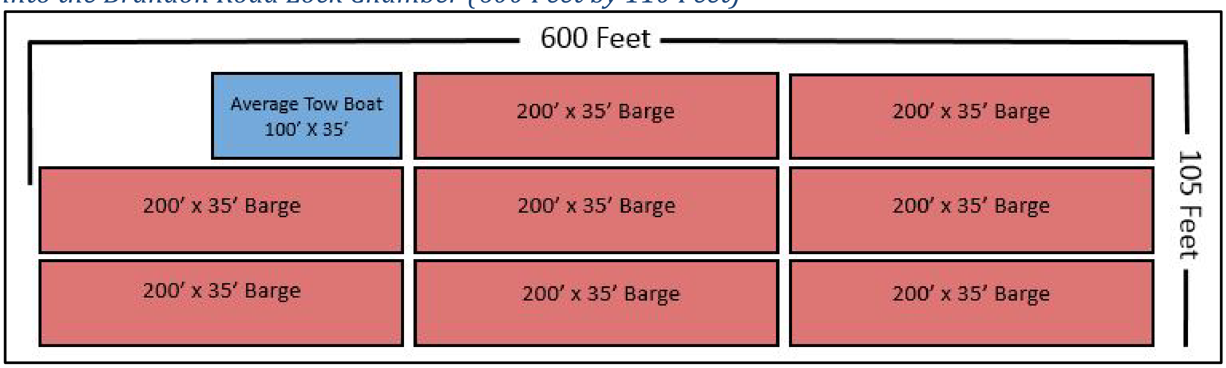


Table 20 shows the average number of barges per tow between years 2009 and 2014 was about 4.37; the highest annual average among those years was 4.61 barges per tow in 2009. Since the lock is able to accommodate eight barges per tow, an average of 4.61 means the average tow can lock through without having to split apart for separate cuts. Furthermore, the range of barges per tow is relatively low. Table 21 shows that, on average, tows transiting Brandon Road Lock consist of 8 barges or less 90% of the time for the years 2009 through 2014.

Table 20 Barges per Tow at Brandon Road Lock (Years 2009-2014) [a]

Year	Loaded Barges	Empty Barges	Total	Tow Count	Average Number of Barges per Tow
2009	6,359	4,283	10,642	2,310	4.61
2010	6,078	3,609	9,687	2,367	4.09
2011	6,449	4,112	10,561	2,551	4.14
2012	6,641	3,757	10,398	2,484	4.19
2013	6,193	3,870	10,063	2,369	4.25
2014	7,552	4,239	11,791	2,387	4.94
				Average:	**4.37**

[a] Source: Lock Performance Monitoring System (LPMS).

Table 21 shows that approximately 8% of tows are required to cut multiple times based upon number of barges; however the data in Table 22 suggests that some tows likely consist of smaller than average barges which require fewer cuts. The channel-width restriction imposed by the CSSC of 70 feet prevents tows from configuring more than two barges wide.

Table 21 Number of Barges per Tow (Percent of Occurrences) at Brandon Road Lock (Years 2009-2014)[a]

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	21
2009	0	13	20	12	11	6	17	4	7	5	1	1	3	0	0	1	0
2010	0	13	22	15	14	7	17	3	5	2	1	0	1	0	0	1	0
2011	0	14	22	11	14	7	18	3	5	2	1	1	1	0	0	0	0
2012	0	12	23	11	12	7	20	3	8	1	0	0	1	0	0	0	0
2013	0	16	22	13	10	4	17	3	6	2	1	1	2	1	0	1	0
2014	0	11	22	2	8	4	17	3	7	5	2	2	4	1	1	2	0
2009-2014 Average [b]	0	13	22	11	12	6	18	3	6	3	1	1	2	0	0	1	0
Average Percent of Occurrences (1-8 barges per tow):																	**90%**
Average Percent of Occurrences (9-21 or barges per tow):																	**8%**

[a] Source: Lock Performance Monitoring System (LPMS).
[b] Annual totals may not sum to 100 percent due to rounding.

Table 22 Cut Percentage for Commercial Cargo Lockages at Brandon Road (Years 2009-2014) [a]

	2009	2010	2011	2012	2013	2014	Average
Commercial Cargo Lockages	2,310	2,367	2,551	2,484	2,369	2,387	2,411
Single Cuts	2,147	2,279	2,411	2,430	2,183	2,107	2,260
Double Cuts	163	87	140	54	186	280	152
>2 Cuts	-	1	-	-	-	-	0.17
% Single Cuts	92.94%	96.28%	94.51%	97.83%	92.15%	88.27%	93.66%
% Double Cuts	7.06%	3.68%	5.49%	2.17%	7.85%	11.73%	6.33%
%>2 Cuts	0.00%	0.04%	0.00%	0.00%	0.00%	0.00%	0.01%

[a] Source: Lock Performance Monitoring System (LPMS).

D.3.3 Impacts to Commercial Cargo Navigation due to GLMRIS-BR Alternatives: Methods and Results of NED Evaluation

D.3.3.1 Methods

Normally, fewer resources are required to move bulk commodities via waterways (waterborne transportation) than on land (i.e., via truck and rail). In these instances, the difference between the costs of moving commodities on land and the cost of moving them on a waterway is called 'transportation cost savings'. The NED benefits of navigation projects are the increases in transportation costs savings (increased efficiency of using the waterway to transport commodities).

However, the navigation economic analysis completed in support of GLMRIS-BR found that several of the alternatives include measures that would *reduce the efficiency* of moving commodities on the waterway, consequently *increasing transportation costs*. Therefore, the GLMRIS-BR project alternatives are expected to result in navigation NED costs rather than NED benefits. In other words, there would be an overall reduction in *transportation cost savings*. Project alternatives that impose greater impacts on navigation are those that yield greater navigation NED costs.

The following discussion provides a detailed review of the methods utilized to estimate the impacts to navigation (NED costs) for each GLMRIS-BR alternative.

D.3.3.1.1 Consideration of System Analysis

The inland waterway system is a network of locks 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. lock) 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 inland navigation system equilibrium is a substantial computational problem given the mix of commodity flows, each transiting different locks and each having their own set of economic properties.

The primary goal of a system analysis in a traditional navigation study is to determine if improving or expanding a lock chamber (and increasing its capacity) might simply pass this alleviated congestion upsteam or downsteam to the next project. As an example, expanding a lock chamber to 1200 feet from 600 feet when examined in isolation from neighboring projects might show very high benefits. However, when analyzed as a system, neighboring 600 foot projects might reduce these benefits if tows would still be forced to reconfigure (or cut) immediately upstream or downsteam at the next lock. Therefore, the recommended plan with the highest net benefits might be one that involves expanding or improving multiple projects. For GLMRIS-BR, this level of complexity was deemed unnecessary, since the alternatives under consideration near BRL are not improvements but rather detrimental to future waterway traffic levels. It could be argued that reducing the traffic levels through Brandon Road might relieve congestion at the neighboring projects who share the same traffic. However, the economics team determined that the utilization levels (tonnage-transit) of those locks were not high enough to warrant the calculation of this minor benefit. In other words, the average transit time at those projects would not significantly decrease through time due to changes at Brandon Road.

D.3.3.1.2 Framework for GLMRIS-BR Navigation Analysis (NED)

The inland waterway transportation system is a mature transportation system and as a result, the investment options are focused on operational measures. The alternative plans considered in GLMRIS-BR were not formulated to improve the waterway transportation system. Rather, the Study evaluates structural and nonstructural options and technologies near the Lock to prevent the upstream transfer of ANS from the MRB into the GLB to the maximum extent possible, while minimizing impacts to existing waterways uses and users. Therefore, the objective of this navigation economic analysis is not to determine the value of the waterway transportation system, but to identify the changes in value of waterway transportation system given the implementation of the alternative plans considered in GLMRIS-BR.

The structural options and technologies considered for implementation near BRLD could impose performance issues for lock users. Navigation performance issues can arise as traffic levels increase (congestion) and/or the operating policies at the lock change. At locks 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. Increased lock transit times, whether caused by traffic growth congestion or a lock outage, increases transportation costs for shipments transiting the lock, increasing trip cycles and ultimately requiring more equipment to move the same annual volume of traffic.

D.3.3.1.2.1 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. The need does not exist to estimate the total benefits the nation would lose if a waterway system no longer existed. Given this focused objective, a spatially-detailed, partial-equilibrium model is sufficient. In a partial-equilibrium analysis, the determination of the equilibrium price-quantity of a good is simplified by just considering the price of that good and assuming that the prices of all other goods remain constant. In other words, the prices of all substitutes and complements (as well as consumer income levels) are constant.

As previously noted, the primary guidance for this framework is described in P&G. 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.*" To accomplish this incremental cost 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 costs associated with each respective future. The temporal aggregation of these cash flows necessitates discounting to complete the analysis.

Incremental costs in the GLMRIS Brandon Road navigation analysis are calculated by comparing the total transportation savings that are afforded while sustaining current operations to prevent further intrusion of ANS species (WOPC) compared to new proposed action plans (WPC). For GLMRIS-BR, the WOPC is referred to as the No New Federal Action plan. The incremental costs differences between each operating condition can be further classified into the following categories:

- Cost-increases for commodity movements having the same origin, destination and waterway routing that realize cost increases because of a project alternative. This increase in cost represents an NED loss because resources will be constrained from productive use elsewhere in the economy. Examples for inland navigation are increases in costs incurred from trip delays (e.g. increases in lock congestion), increases in costs associated with the use of smaller, sub-optimal tows, and increases in costs due to inefficient use of barges.
- Shift-of-mode costs for commodity movements having the same origin and destination that incur a cost increase by shifting from their current water routing to an overland mode. In this case, lost transportation savings are the difference in costs of transport between the WOPC (where the unconstrained waterway system is used) and the WPC (when rails, trucks or different waterways or ports are used). The economic cost to the national economy is the loss of resources from having to use a more costly mode or point of transport.

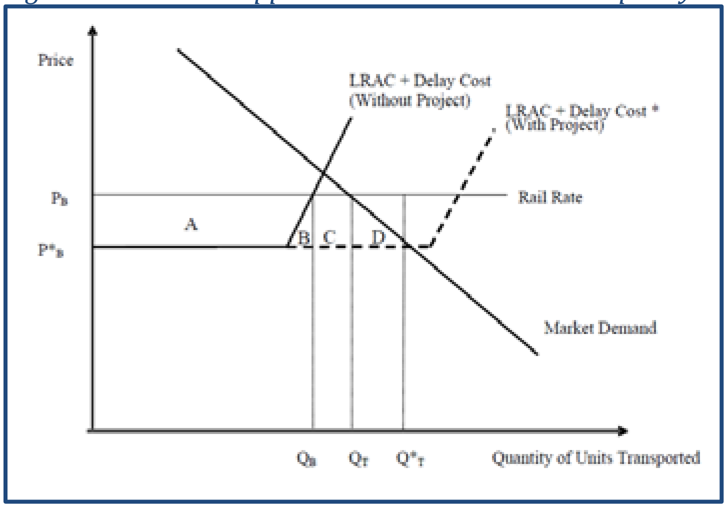
The economic analysis of waterway investments focuses on the evaluation and comparison of the costs and benefits of the existing waterway system with two basic alternative measures: 1) decreased capacity (increased transit times and thereby increased delay costs) and 2) reduced demand.

For the GLMRIS-BR analysis, the features and operating policies of the technology alternatives reduce lock capacity and increase transportation costs by decreasing tow-sizes and increasing the number of trip vessels. Similarly, lock closure increases transportation costs by forcing cargo to move by an overland mode. The non-structural alternative is not expected to increase average transit times, and therefore shares the same capacity curves as the No New Federal Action alternative.

The P&G provides general guidance for doing cost assessments and incremental cost analysis, but it does not overly restrict or dictate how the assessments should be done. As discussed in IWR Report 09-R-2, National Economic Development Procedures Manual (June 2009), transportation savings are the principal inland navigation benefit category and the other categories reflect the different ways that costs can give rise to non-marginal changes in the use of inland navigation. The Report also describes calculation of transportation costs, shift-of-mode, and new movement benefits through the hypothetical project example shown in Figure 15. This example depicts the calculation of benefits to shippers from expanding locks along a specific origin-destination route as a means to alleviate barge traffic congestion and associated passage delays at the locks. The vertical axis represents the unit prices (rates) for transport, and the horizontal axis shows the total quantity of commodity units transported in response to different rates.

The downward sloping line shows shippers' total market (derived) demand function for transporting a specific commodity from a given origin to a given destination. The slope of the demand function, or Market Demand for all available transportation methods, represents the response of the quantity of the commodity transported to changes in transportation rates. For simplicity, it is assumed that this market is served by only two transport modes (barge and rail), and there is no qualitative difference between the services they provide.

Figure 15 Cost to Shippers Due to Reduced Lock Capacity



In the Figure 15 example, it is assumed that, because of the open access nature of the barge industry, competition forces barge rates to the level of the long-term average costs (LRAC) of providing barge transportation. Further, the example assumes that the long-run average cost function for barge transportation is horizontal over some initial range of shipments, reflecting constant marginal costs of moving that range of shipments by barge. However, the example also assumes that as the level of barge shipments increases beyond a certain point, increased barge traffic results in congestion and queuing delays at the locks on the system. The increasing waiting times for passage through the locks reflects diseconomies for barge transportation due to increasing factor input costs, which is represented in Figure 15 by the portion of the barge long-run average cost function that suddenly veers upwards and to the right. The difference between the horizontal and upward sloping sections of this function is the delay (congestion) cost.

For the GLMRIS-BR navigation analysis, technology alternatives can result in reduced lock capacity. For those alternatives, the WOPC would be represented by the dashed line, with total barge shipments equaling Q^*_T. In the WPC (solid line), the total quantity of units shipped is Q_T. Of this total, Q_B is shipped by barge at price P_B that approaches but remains slightly below the prevailing rail rate. Since barge rates are set equal to barge long-run average costs, the barge price for Q_B includes a lock delay cost that is imposed on all barge shippers. The remaining quantity transported ($Q_T – Q_B$) is carried by rail, since the prevailing rail rate is below the rate that barges would need to charge shippers to accommodate the increased delay cost if total barge shipments were to increase beyond Q_B. This is illustrated by the horizontal section of the with-project average cost function and the solid black line. This represents the new long-run average cost function for barge shipment with reduced lock capacity. The new average cost function eventually turns upward, reflecting that even without reduced lock capacity, delay costs can appear if barge shipments increase.

In a traditional navigation analysis, cost reduction benefits would equal to the sum of areas A and B in Figure 15 and are calculated by multiplying existing barge shipments (Q_B) by the difference between the without-project barge rate (P_B) and the estimated with-project barge rate (P^*_B). Shift of mode benefits are equal to area C, and are calculated by multiplying the quantity previously carried by rail ($Q_T – Q_B$) by the difference between the prevailing rail rate and the with-project barge rate. Finally, new movement benefits are equal to area D. In the context of the Brandon Road study, these P&G accounts are costs rather than benefits for the technology alternatives under consideration. Additionally, there are no new movement or induced benefits, since the project alternatives under consideration yield no change or a reduced lock capacity. However, it is important to note that reducing the lock capacity of the project and increasing the delay times may have a similar effect, and dissuade potential users of the system due to a perceived unreliability of the deliveries. As part of UT-CTR's research in 2011, the effect of perceived unreliability of the lock due to lock closure was mentioned by shippers as a potential issue when contracting the sale of their goods with their customer base. This was also mentioned in a shipper survey issued in 2016.

D.3.3.1.2.2 Life-Cycle Analysis.

Since the inland navigation investments analyzed have long lives (and regulation requires a Cost-Benefit Analysis (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.

To accomplish a life-cycle analysis, the Navigation Investment Model (NIM) is designed to estimate and analyze the benefits of incremental improvements (or detriments as in the case of this analysis) in a river system and then to compare the benefits against the costs. NIM operates within the supply and demand framework discussed, with inputs that describe the long-run average cost of water transportation (supply) and movement level demand for water transportation. NIM determines WOPC and WPC movement demand equilibrium and incremental benefits (or costs), however, the analysis of an investment within a system is much more complex than the simple commodity origin-destination route used as an example in the previous section (Figure 15). Additionally there are other considerations beyond equilibrium and surplus calculations that must be factored into the investment decision. The modeling requires a movement from the theoretical model to an empirical model that appropriately addresses the empirical question at hand and does so in a way that provides the most useful insights for decision-making, given modeling and resource constraints placed on the overall analysis. This section briefly describes the modeling framework used to apply the theoretical framework discussed previously.

D.3.3.1.2.3 Life-Cycle Analysis Accounting

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.

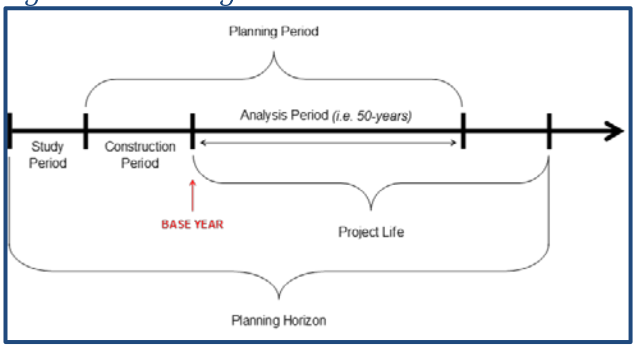
D.3.3.1.2.4 Planning Period (Period of Analysis)

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., construction period). Figure 16 displays the terminology that will be used in the remainder of this document.

Figure 16 Planning Period



The first possible budget year (and the beginning of the Planning Period) for the Brandon Road analysis is 2021. However, not all alternatives share the same construction period, or simply do not require construction, which makes specification of the base year for the analysis (or beginning of the Analysis Period) subjective. In comparison across alternatives the specification of the base year is not significant as long as the same discounting base year is specified for each alternative. In the GLMRIS-BR analysis each alternative was analyzed with a 2021 base year, which is the first implementation year for the lock closure alternative. The final year of the analysis period extends to 2070.

D.3.3.1.2.5 Compounding, Discounting, and Amortization

The life-cycle cash flows (whether costs, benefits, or disbenefits) 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 (or disbenefits, as is the case of this study) 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 appropriate rate can be a matter of debate; however, Congress has resolved the dilemma for water resource agencies. The rate used in evaluating water resource projects is set annually, by law (Section 80 of PL 93-251), using a prescribed formula based on the cost of government borrowing. The rate is published each year by Corps Headquarters as an Economic Guidance Memorandum (EGM). The FY 2017 project evaluation and formulation rate is 2.875%.

The estimated benefit (or disbenefits) 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.

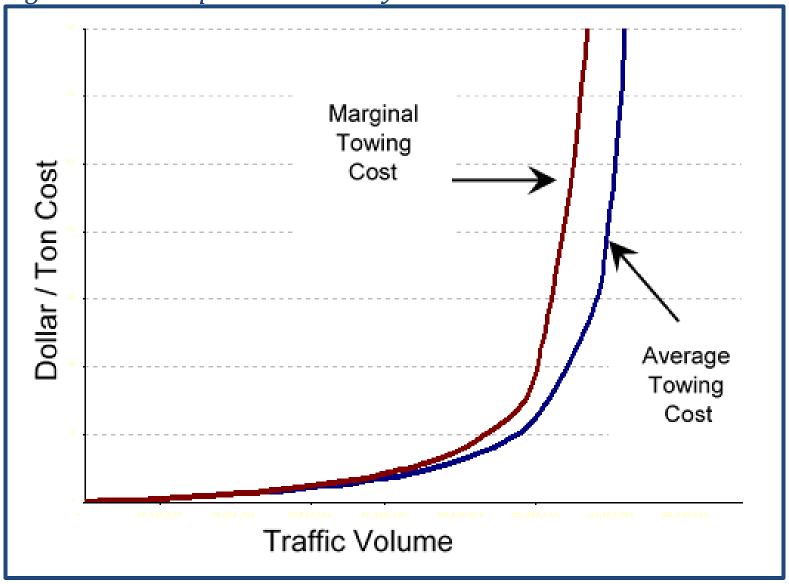
D.3.3.1.3 Waterway Equilibrium

To complete a life-cycle analysis of an incremental improvement to a river system, the WOPC and WPC movement demand equilibrium must first be determined. In typical NIM equilibrium execution, individual shippers (i.e. movements) are assumed to make decisions based on their observed cost of moving on the waterway system In the equilibrium process NIM calculates a conditional cost curve for each movement which represents, for every level of traffic, the shipper cost of shipping commodities via the water routing. The costs include only those costs borne by the waterway carrier (e.g., equipment, labor, fuel, and supplies), and not those borne by the Federal Government in the operation and maintenance of the waterway system. Two waterway conditional cost curves are depicted in Figure 17 - the average towing cost (ATC) curve and the marginal towing cost (MTC) curve. The ATC curve represents the average cost of shipping at different traffic levels. It rises because the average delay, and therefore the average cost, is higher at higher levels of traffic. The MTC curve represents the additional cost to the shipping industry of transporting an additional ton of cargo on the waterway. It increases at a faster rate than the ATC because the higher delays associated with higher levels of traffic are sustained by all shippers, not only the shipper who causes the delay. An additional tow entering the river system increases the delay costs for all tows sharing resources with the new tow (i.e. all tows transiting a shared lock).

D.3.3.1.4 Calculation of Transportation Surplus

As discussed in section the previous sections, the primary benefits of an inland navigation system are transportation cost reductions. Another way to view the incremental differences between project alternatives is to compare the WOPC and WPC transportation benefits (i.e. transportation savings). This method is used for the Brandon Road analysis to determine how increases in cost increases due to increased delay can affect the total savings offered by each alternative throughout the analysis period. In Figure 15 the transportation benefit is the area between the market demand curve and the LRAC (including delay cost) curve. There are however, two ways to define this market demand in NIM; inelastic and elastic. For the Brandon Road study, an inelastic demand is used, based on movement-level transportation rate information developed by the University of Tennessee Center for Transportation Research (UT-CTR).

Figure 17 Conceptual Waterway Movement Conditional Cost Curves



D.3.3.1.4.1 Inelastic Demand

For inelastic movement demand the transportation surplus (typically referred to as waterway transportation savings) is represented by a rectangle above the equilibrium waterway cost, under the inelastic willingness-to-pay (typically set at the least-costly all-overland rate), and between 0 and the equilibrium quantity. The transportation surplus is represented by Equation 1.

Equation 1. Transportation Surplus

$$TS_{inelastic} = (A - P^*) \times Q^* \quad (2)$$

where:

TS = transportation surplus

A = the inelastic willingness-to-pay $/ton (least-cost all-overland alternative rate $/ton)

P = is the equilibrium water transportation rate (cost adjusted base water rate in $/ton)*

Q = is the equilibrium quantity (tonnage)*

D.3.3.1.4.2 Incremental Cost Analysis

Ultimately, for Brandon Road, the total transportation savings for each project alternative are converted into average annual values. These average annual savings are then compared to one another to determine the total average annual incremental costs. These incremental costs are then input into the decision matrix for consideration of the tentatively selected plan (TSP).

D.3.3.1.5 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. The primary uncertainty assessment for the Brandon Road analysis was an alternative demand scenario analysis where the impacts of constructing the technology alternatives results in a series of plant closures.

D.3.3.1.6 Waterway Analysis Model & Navigation Investment Model

The goal of WAM for GLMRIS-BR is to estimate the impact that operational and/or structural changes at Brandon Road have on transit times due to a particular alternative. This change is measured by a series of tonnage-transit curves, which estimate how each alternative can affect average transit times at a particular level of tonnage. The primary inputs into the WAM model are operation data, data from the engineering team, and historical data on lock performance from the LPMS database.

Ultimately, the tonnage-transit curves from WAM are used as an input into the NIM model. Along with other inputs, the NIM model then performs a what-if analysis to determine the effect that changes in average transit time and other operating conditions under each alternative has on equilibrium traffic levels and transportation costs. Other major inputs into the NIM include an annual traffic demand forecast that projects the demand for barge transportation for each year of the analysis period. The model also uses movement willingness to pay information, which is defined by the transportation rate data and shipper response information. The model also defines the waterway network by using historical LPMS data, WCSC data, and data from the National Transportation Atlas Database (NTAD). The primary module of NIM used for the GLMRIS-BR analysis is the Waterway Supply & Demand Module (WSDM).

The results from NIM produce the total transportation savings by year under each alternative (With Project Condition). These savings are compared to the Without Project Condition to determine the effect that each alternative has on the total NED benefits afforded by the project. The following sections provide a description of the WAM and NIM models.

D.3.3.2 Waterway Analysis Model (WAM)

The WAM is a vessel-level discrete-event stochastic simulation model used to estimate lock performance (i.e., transit time) under a given operating condition, operating policy, defined fleet, and at a specified traffic level. WAM is capable of modeling single, or multiple, navigation projects each with multiple lock chambers.

The current shallow-draft version of WAM-SD-10-01 received HQ Planning Model corporate model certification 15 August 2011; however, it was a short duration certification given anticipation of a new project level vessel simulation model in development being stood up. The new model is still in development and the shallow-draft WAM was required for the Brandon Road analysis. A HQ Planning Model Certification approval for use in the GLMRIS-BR analysis was received 9 August 2016.

Being a stochastic simulation, the WAM model uses arrival and processing time distributions derived from historic LPMS data. For example, instead of a vessel of a set size arriving every 30 minutes, a large tow can arrive 2 minutes or 2 hours after a smaller tow or recreational vessel, all using values derived from historical distributions. Figure 18 shows a simplified representation of a standard WAM lockage. WAM modeling consists of four basic steps (Figure 18): (1) input preparation; (2) system simulation; (3) calibration and validation; and (4) output summarization.

The main input for the WAM is LPMS data, which is recorded at each lock and contains information on the characteristics and timing of each lockage operation. Data on chamber closures are also recorded in LPMS. Data on the flotilla processed includes vessel type, number of loaded and empty barges by size, and tonnages by commodity. Waterborne Commerce Statistics (WCS) Center data is used to supplement the LPMS and provides information on barge loading tonnages and commodities as reported by the shippers. Other input information sources include industry interviews, USACE operations information, and USACE engineering information as it relates to future lock performance, transit conditions, and planned outages. All of this information is fed into WAM during the model execution phase. Prior to production of tonnage-transit curves for input into NIM, base year results are validated against historical LPMS data to insure that WAM is producing reasonable and defendable results.

Figure 18 WAM Lockage Operation Times

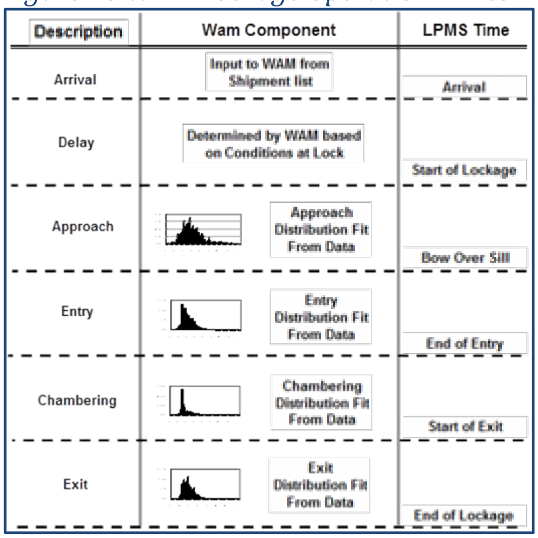
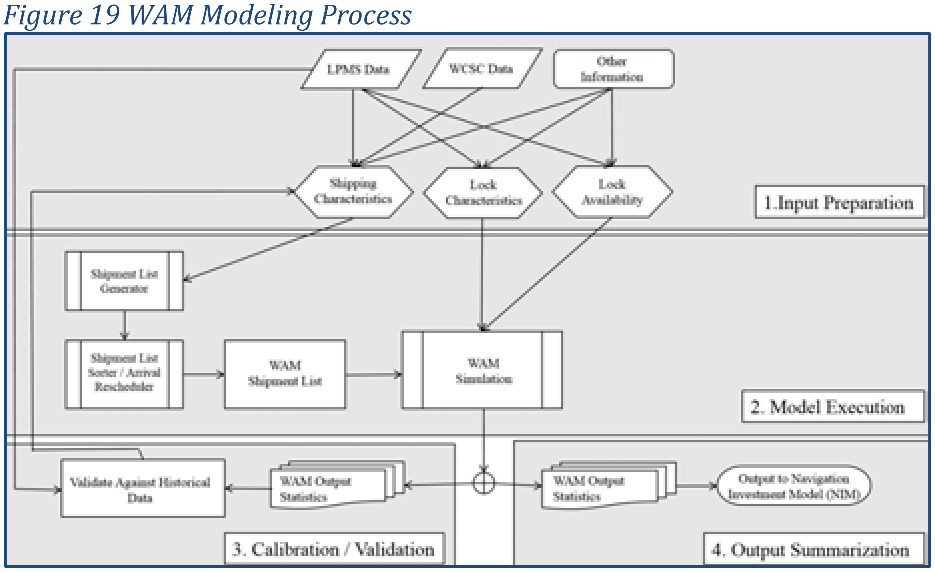


Figure 19 WAM Modeling Process



D.3.3.3 Navigation Investment Model (NIM)

NIM was built by Oak Ridge National Laboratory (ORNL) in collaboration with the USACE Planning Center of Expertise for Inland Navigation (PCIXN). NIM received its HQ Planning Model Corporate Certification 14 February 2012.

NIM is an annual model which can be described as a spatially-detailed partial-equilibrium waterway transportation cost and equilibrium model. While it is not really designed to estimate the total benefits of a river system, or the benefits the nation would lose if the river system no longer existed (something like a computable general equilibrium model would be needed), it is appropriate to estimate the benefits of incremental changes to river systems.

NIM is a behavioral model which serves two tasks: develop least-cost movement level shipping-plans and estimate equilibrium system traffic levels from a bottom-up movement level analysis. By using detailed data describing the waterways network, the equipment used for towing operations, and the commodity flow volume and pattern, NIM calculates the resources (i.e., number towboats, trip time, and fuel consumption) required to satisfy the demand on a least-cost basis for each movement in the system and how much of that movement demand can move in system equilibrium with a positive willingness-to-pay for barge transportation.

D.3.3.3.1 Model Development and Structure

Development of a model requires a number of design decisions and technology choices. NIM utilizes a relational database structure which allows flexibility in input and output structure, eliminating model code changes if analysis resolution (e.g. increasing the number of towboat classes considered) and / or assumptions change. Input, output, and execution data is stored in Microsoft Sequel (SQL) Server 2012 database in the PCXIN-RED Inland Navigation Database Warehouse (INDW). Data loading, model execution, and report generation is controlled through a desktop application. The model code is actually housed and executed on the PCXIN-RED application server.

Simulation models fall into two basic categories: event-based and period-based. In an event-based model, a set of events that the model is concerned with are defined, and time moves forward in jumps, as each event takes place. Period-based models divide time into discrete periods of known length (e.g. years). All calculations are made for a given period, and then time is advanced to the next period. Both types of approaches have their advantages and disadvantages. In general, period-based models are easier to formulate and contain simpler calculations, but the assumptions required about averaging of data may be limiting. NIM is classified as a period-based model running on yearly time increments.

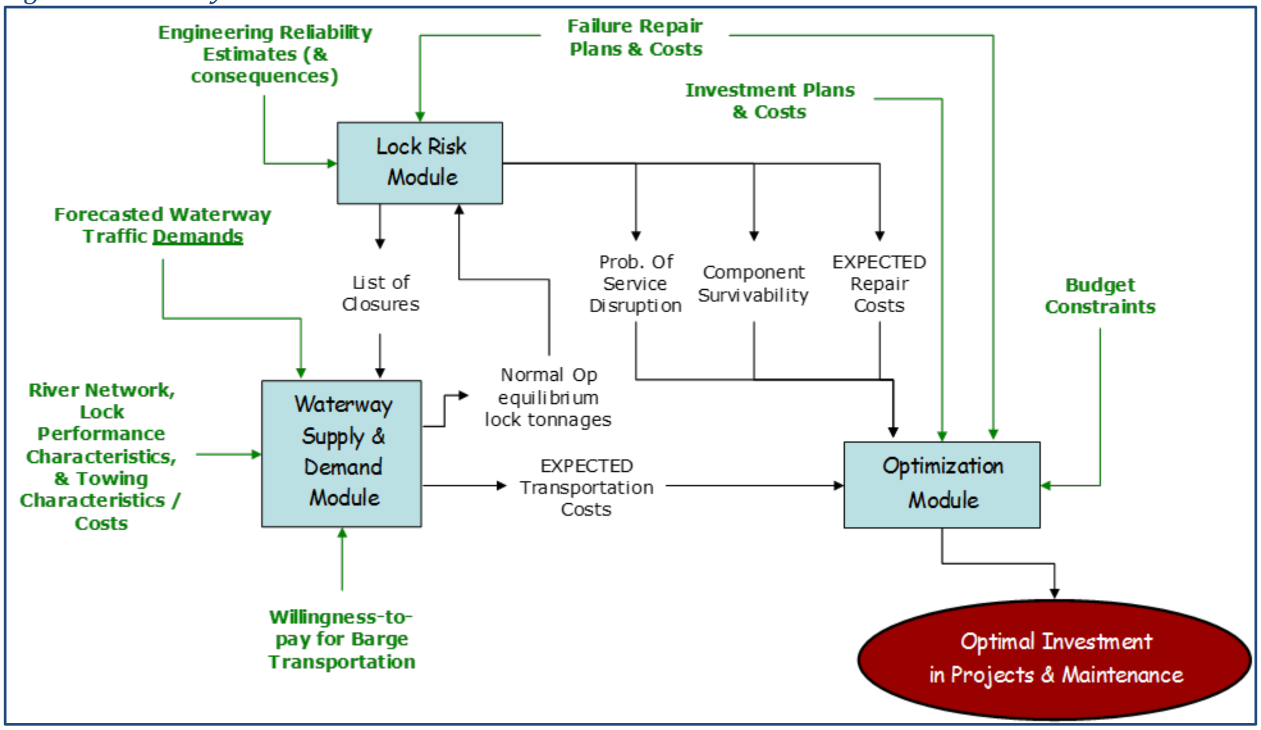
The NIM System is composed of three primary modules – the Lock Risk Model (LRM), the Waterway Supply and Demand Model (WSDM), and the Optimal Investment Module (Optimization). The general linkage of the model modules are shown in Figure 20.

The LRM Module forecasts structural performance by simulating component-level engineering reliability data (hazard functions and event-trees) to determine life-cycle repair costs and service disruptions. The LRM summarizes the probabilities of reliability driven service disruptions (typically lock closures) for each lock for each component for each year, which are then used by the WSDM and Optimization modules to estimate expected transportation impacts resulting from the service disruptions.

The WSDM Module estimates equilibrium waterway traffic levels and transportation costs given a traffic demand forecast, movement willingness-to-pay, and waterway system performance characteristics. NIM's major economic assumptions are embedded within WSDM.

The Optimization Module organizes and analyzes the investment life-cycle benefit and cost streams and recommends optimally timed investments (what and when).

Figure 20 Primary Modules within NIM Model



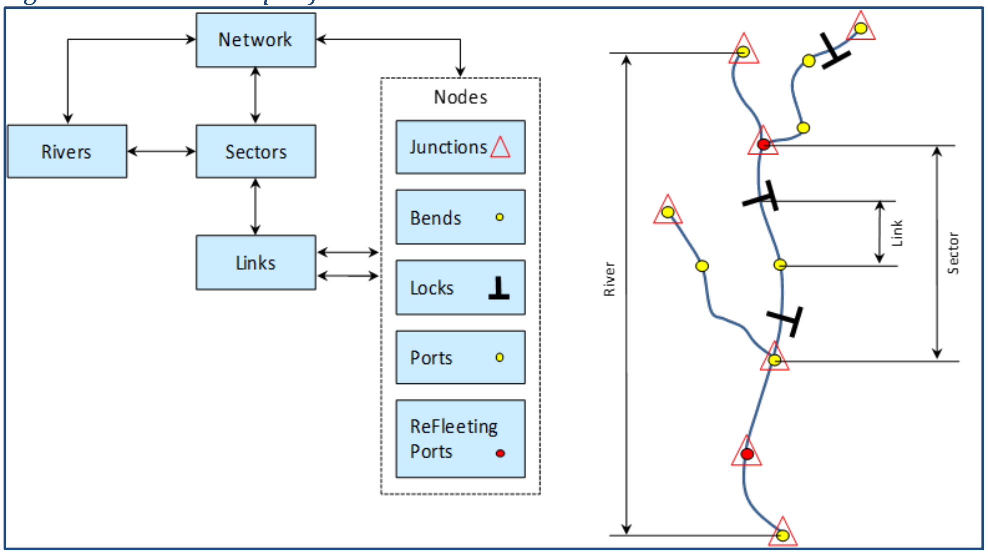
D.3.3.3.2 Spatial, Sectoral, and Temporal Simplifying Assumptions.

As noted, economic models vary in terms of sectoral, spatial, and temporal detail. Simplifying assumptions are made in empirical models because of data, time, computational, and resource limitations. The keys in making these simplifying assumptions are to clearly understand: (1) the theoretical model that serves as a starting point for the analysis; (2) how the simplifying assumptions deviate from the theoretical model; (3) the reasonableness of the assumptions as compared to what we know about real-world markets; and (4) the implications of the assumptions in terms of biasing and/or reducing the accuracy of the model's results (i.e. the estimation of WPC benefits). As a result, the fundamental sectoral assumption in the NIM model framework is to analyze inland navigation investments under a spatially-detailed barge transportation partial-equilibrium framework. The spatial and temporal detail level in NIM is data driven (i.e. user specified) as discussed in the sections below.

Spatial Detail. The spatial detail is defined by the model user through the waterway transportation network, and through the aggregation level of the commodity groups and barge types. In the model a commodity origin-destination route and barge type defines the shipment which demands barge transportation. Spatial detail does not come without a cost. Since each movement (commodity origin-destination barge type) must be equilibrated with every other movement, each increment of detail increases computational time exponentially.

The NIM link-node network specifies the topology of the inland waterway network and the characteristics of the locks, ports, bends and junctions for each river. In short, the NIM network provides the framework for much of the other NIM data (e.g., movement flows, lock performance characteristics, fees, etc.). Figure 21 provides a graphical view of the network data relationships. The network is defined based on a set of nodes and links between the nodes. Nodes can be locks, ports, bends or junctions. Locks and bends represent the points that cause delay based on traffic levels. A network (NIM can store multiple networks) is made up of one or more rivers. Each river is divided into sectors at junctions (e.g., the head and mouth of the river and points where tributaries enter the river). Each sector is then divided into links between nodes. A link is defined with an upstream and a downstream node, length, depth (minimum and average), current speed, and coefficients for calculating tow speed.

Figure 21 Relationships of the NIM Network Entities



For the GLMRIS-BR analysis, the 95 5-digit WCS commodity codes moving through Brandon Road were aggregated into 9 major commodity groups, the 607 docks were aggregated into 236 pick-up / drop-off port nodes, the 7,531 unique barges were aggregated into 8 barge types, and the 705 unique towboats were aggregated into 16 towboat classes. This resulted in 921 unique commodity origin-destination-route barge type movements in the model.

Temporal Detail. The model does not simulate individual waterway shipments (e.g., tow), but operates off a movement-level (an aggregation of shipments) cost in discrete annual time periods. As with the spatial detail, increased detail significantly increases the computation time and too much granularity can complicate, if not invalidate, the theoretical framework (e.g. trip times spanning multiple periods). A movement is defined as the annual volume of shipments for the commodity origin-destination barge type. There are 921 unique commodity origin-destination-route vessel type movements defined in the Brandon Road analysis, each of which are forecasted by year over the planning period.

Inter-Temporal Detail. Each time period in the model is independent of the other time periods, however, there is an inter-temporal effect interjected into the modeling process through user specification of infrastructure change and through any engineering reliability data included in the analysis.

Lock performance characteristics can be specified by the user to change through time. This allows for currently authorized projects to come online and change the waterway system transportation characteristics at the appropriate time. Additionally, the analysis of the WPC alternatives requires the investment to be timed and the characteristics of the waterway system transportation to be adjusted accordingly at the correct times.

Lock performance can also change through time probabilistically through reliability. In this respect, the expected benefits and costs calculated in a given year is dependent upon the results in the previous years. With increasing service disruption through time, expected equilibrium traffic levels can decline as expected capacity declines. If, however, the user desires to model declining demand from increased reliability risk, this must be done through the forecasted demand input (i.e., development of a forecasted demand scenario assuming risk aversion or facility closure from decreased shipment reliability).

Network and Movement Detail. Much of the model's spatial detail comes through the waterway transportation network definition. The transportation network not only defines the pick-up / drop-off nodes (236 of them in the Brandon Road analysis network) but it also defines constraint points in the system (bottlenecks). These constraint nodes can be any obstruction where vessel queuing can occur and congestion effects can be felt. While these constraint nodes can be areas such as bends or one-way channel sections, typically the only constraint nodes modeled are the navigation projects. For the Brandon Road analysis, only Brandon Road Lock and Dam is modeled as a constrained point.

To determine the impact of congestion effects on a movement's transportation costs (and ultimately the movement's equilibrium and transportation surplus), the movement's trip time needs to be estimated. Distances between each model node (both pickup / drop-off nodes and the constraint nodes) are defined through the input data. Additionally, data on current speeds, channel depths, and equipment drag are input and utilized by a speed function and combined with the trip distance to estimate line-haul trip time. Estimating the trip time at the constraint points is a different story and requires the utilization of the lock project tonnage-transit curves.

D.3.3.3.3 Lock Project Maintenance and Reliability

Capacity of the navigation system is a function of the availability of the lock projects. Service disruptions, both from a scheduled maintenance event or an unscheduled failure, can decrease the project capacity in that year, inhibit traffic flow, and increase waterway transportation costs. While NIM itself utilizes an annual period-based framework, impacts from these intermittent events are calculated.

For scheduled maintenance events, engineering and operation maintenance schedules are utilized. Often a new lock will require maintenance that is less frequent, of shorter duration, and/or less costly. Given that scheduled events are known to shippers, NIM assumes average trip time through the project given the reduced capacity is known and that the movement level equilibrium tonnage and transportation surplus is so estimated. Two major scheduled lock maintenance events occur during the Brandon Road project analysis period, which is discussed in further sections.

For unscheduled maintenance events, engineering and operation reliability data is utilized (i.e., probabilities of unsatisfactory performance and event or consequence trees). Given that unscheduled events are not known to shippers in advance, NIM assumes an equilibrium traffic level given known or scheduled maintenance and then adjusts the waterway movement trip cost given the increased average trip times through the project given the unscheduled event. This increase in waterway transportation cost is then weighted into the system statistics given the probability of occurrence in that year. Expected component-level reliability information is not utilized for GLMRIS-BR, since a lock reliability analysis is not the focal point or objective of this study.

D.3.3.3.4 Tonnage-Transit Curves

At the constraint points (i.e., lock projects), the transit times are characterized by a tonnage-transit curve. This tonnage-transit curve plots an average vessel (e.g., tow) transit time against annual tonnage at the lock project. The transit time not only includes the processing time to transfer to the next pool, but it also includes delay time from queuing resulting from the congestion effect. As utilization of the lock project increases, the delay exponentially increases once persistent queuing starts.

Given a traffic level at the project, the average transit time is pulled from the tonnage-transit curve and applied to each movement transiting the project. All projects transited are polled for transit times along each movement's route and added to the movement's line-haul time to determine the movement's total transportation time.

The tonnage-transit curves are externally derived (typically through vessel-level simulation) and input into the model. Additional detail on the tonnage-transit curve development can be found in Attachment 1 – Capacity Analysis.

D.3.3.3.5 Movement Shipping-Plans

Congestion in the waterway transportation system does not affect all movements equally. To determine the impact of congestion effects on a movement's transportation costs, the shipping costs and characteristics of that movement must be known. The shipment characteristics for tows are referred to as the "*shipping-plan*". A shipping-plan is needed for each of the 921 commodity origin-destination-route barge type movements in the model.

The tow shipping-plan drives the shipping cost and is stored in dollars per hour per ton. The tow shipping-plan includes specification of the shipment tow-size, the towboat class used, empty backhaul requirements, re-fleeting points, and tons per trip. Given the movement tonnage and the trip time, a movement cost can be calculated and then compared against the movement's willingness-to-pay for water transportation.

The shipping plans could be specified by the user and given to the model through input; however, this data is not readily available and difficult to compile for large systems and data sets. Instead, NIM is designed to develop a least-cost shipping-plan for each movement which is then calibrated against observed lock project level data. This NIM shipping-plan developer also allows for re-specification of shipping-plans under increased congestion and for what-if scenarios.

D.3.3.3.6 Movement Level Willingness-to-Pay for Water Transportation

Willingness-to-pay for water transportation is needed to determine the equilibrium traffic level and to calculate the waterway transportation deficit (cost) experienced under some of the project alternatives for the Brandon Road study. As discussed, the willingness-to-pay can be defined as either inelastic or elastic. For the Brandon Road analysis, all movements modeled were assigned an inelastic demand curve based on transportation rate information developed as part of research conducted by the UT-CTR in 2011.

D.3.3.3.7 Movement Closure Response

As previously discussed, impacts for scheduled events are calculated by NIM. As discussed scheduled events are known in the equilibrium process and then unscheduled event impacts are probabilistically added. In some situations; however, there is a need to account for specific responses to specific complete river closure events and NIM is coded with a closure-response option. For a specified river closure event or events, a selected percentage of selected movements is diverted from the equilibrium tonnage level. Then a specified cost is added to the remaining tonnage in the case of a scheduled event or a specified cost is added to the diverted tonnage in the case of an unscheduled event.

D.3.3.4 Application of NIM Model for GLMRIS-BR

As discussed, NIM is data driven and can be set up for analysis of any inland waterway system or sub-system. For the GLMRIS-BR analysis, NIM was setup to model movement flows through BRL. The average tonnage flows through this project (years 2012-2014) is shown in Figure 11. While BRL flows are quite disperse, traffic is predominately flowing between the Illinois River and the Gulf Coast via the Mississippi River.

D.3.3.4.1 NIM Inputs

NIM is a data-driven spatially-detailed annual planning-period transportation cost equilibrium model; the development and loading of up to 70 input data tables are required to perform an analysis. The major inputs include:

- Determination of the study area, study movement flows, and the definition of the waterway system transportation network.
    - WCS data accuracy.
    - Network links and nodes (including link shipping characteristics).
    - Commodity grouping.
    - Equipment grouping.
- WPC construction navigation impacts, and lock project maintenance and reliability assumptions for the WOPC and each WPC.
- Lock project tonnage-transit curves for the WOPC and each WPC.
- Waterway system traffic demand forecasts specified at a movement level.
- Willingness-to-pay for water transportation specified at a movement level.
- WPC construction navigation impacts, and lock project maintenance and reliability assumptions for the WOPC and each WPC.
- Lock project tonnage-transit curves for the WOPC and each WPC.
- Waterway system traffic demand forecasts specified at a movement level.
- Willingness-to-pay for water transportation specified at a movement level.

D.3.3.4.2 The Brandon Road Waterway Network Definition

The first step in defining a network in an inland navigation analysis is verification of the WCS data to make sure it is accurate enough for use. WCS data is very accurate in barge origin-to-destination information and barge loading; however, it does not identify how the barges are grouped into tows, and tonnage can be underreported. LPMS data is very accurate at counting barges (loaded, partially loaded, empty), but the tonnage in each barge is estimated by the lock operators. As such, a target tonnage was developed that utilizes the most reliable aspects of both databases. Using both sources, the average barge loading in WCS was multiplied by the counts of barges in LPMS by each major commodity group. For example, coal and coke barges might load at 1,623 tons according to WCS. LPMS might have recorded 842 loaded coke and coal barges having transited the lock. The resulting target tonnage for this group would be 1,366,566 tons.

As shown in Table 23, WCS data discrepancies were found when comparing WCS data to LPMS data at Brandon Road. As a result the team utilized the target value of tonnage to serve as the base year in the analysis before applying any forecasted projections. This target was developed by major commodity group, since loading rates can vary depending the type of commodity being transported. The results of each tonnage value by major commodity group are shown in Table 24.

Table 23 Waterborne Commerce Data Verification for Brandon Road Lock Tonnage (Years 2012-2014)

Year	Target Tons [a]	LPMS Actual	WCS Actual
2014	12,923,133	12,588,435	11,455,030
2013	10,338,088	10,427,098	8,848,073
2012	11,232,183	11,089,065	9,803,265
[a] Developed using loaded rate from Waterborne Commerce Statistics (WCS) tons per trip and the number of loaded barges from the Lock Performance Monitoring System (LPMS).			

Table 24 Target Tonnage Escalation Factor by Commodity Group for Brandon Road Lock (Average Tonnage for Years 2012-2014)

Commodity Group	2012-2014 Average Tons (WCS) [a]	Target Escalation Factor	2012-2014 Average Tons (Target)
Coal and Coke	1,536,660	1.127663246	1,732,835
Petroleum Products	1,628,866	0.99839697	1,626,255
Crude Petroleum	195,405	2.147527023	419,638
Aggregates	673,692	2.091956298	1,409,335
Grain	311,514	1.272299162	396,339
Chemicals	1,164,585	1.145900432	1,334,498
Ores and Minerals	706,085	1.057879081	746,952
Iron and Steel	2,373,569	0.998912172	2,370,987
All Others	1,445,079	1.010990352	1,460,961
[a] Developed using loaded rate from Waterborne Commerce Statistics (WCS)			

As shown in Figure 11, the BRL WCS dock-to-dock flows are quite disperse. To simplify modeling, in NIM docks are aggregated into ports which are generally defined as a pick-up / drop-off centroid between the waterway features (e.g., a lock and dam navigation pool, or between river junctions, or between a lock project and a river junction). While the extremities of the network could be trimmed back with little impact to an incremental WOPC and WPC analysis, it is often easier to let the dock aggregate to its nearest port and let the network spatially expand to its full extent. This allows for a more accurate mileage and trip time calculations for movements extending to the extremities of the network. Regardless, the network utilized for the Brandon Road analysis extends to all rivers visited by BRL traffic flows.

For the GLMRIS-BR analysis, two additional pick-up and drop-off nodes are also included in the model; a port directly below the project at the site of the new proposed mooring area, and a port 7 miles downstream at the current re-fleeting area. These ports were included to allow the model to emulate the increased tripping effect caused by a continuously operating electric barrier and were assigned to specific network definitions associated with the electric barrier alternative. In alternatives that include a continuously operating electric barrier, vessels are restricted from cutting, and are also confined to a 550' length restriction. This would force vessel operators to prepare their tow configurations to traverse the project 7-miles below the project, which is the closest existing area available for use. This not only has a significant impact on average vessel transit-time as calculated by the WAM model (See Attachment 1 - Capacity Analysis), but also would force barge operators to utilize more towboats to move the same amount of tonnage, greatly increasing trip costs. As part of reducing the costs incurred by this increased tripping effect, the team has embedded a new mooring area downstream of Brandon Road into the alternatives with an electric barrier.

The waterway network also includes specification of the fuel tax and fuel tax waterways as defined by the Inland Waterways Revenue Act of 1978, the Water Resources Development Act of 1986, and the Achieving a Better Life Experience (ABLE) Act of 2014. Since fuel tax waterways are defined at the Sector level Junctions must also be placed between fuel tax and non-fuel tax waterway reaches.

Additionally, the waterway network is defined by the movement commodity grouping, link level shipping characteristics, and equipment characteristics and costs. Prior to analyzing forecasted traffic demands and determining the equilibrium tonnage level for each movement in the system, NIM must estimate a shipping-plan and cost for each defined movement. This is accomplished by determination of the movement least-cost waterway shipping-plan given the waterway link constraints. As such, the shipping-plans are calibrated and the model is validated.

As previously indicated, the GLMRIS-BR analysis groups the 95 5-digit WCS commodity codes moving through Brandon Road into 9 major commodity groups, the 607 docks were aggregated into 236 pick-up and drop-off port nodes, the 7,531 unique barges were aggregated into 8 barge types, and the 705 unique towboats were aggregated into 16 towboat classes. This resulted in 921 unique commodity origin-destination-route barge type movements in the model. These groups and the composition of the traffic can be seen in Figure 22 through Figure 25 below.

Figure 22 Commodity Groupings for Brandon Road Lock –Navigation Investment Model (NIM)

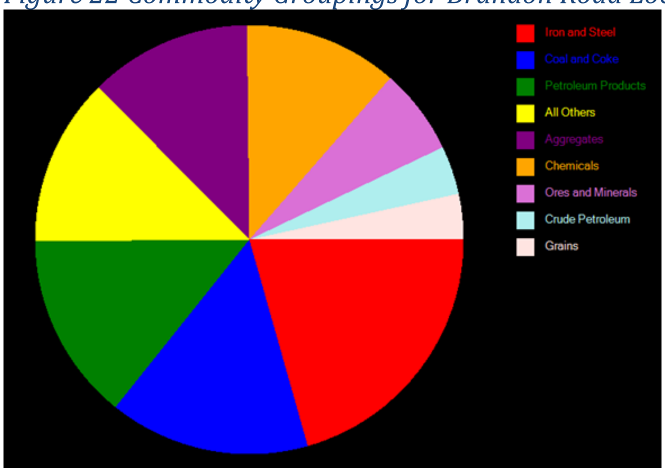


Figure 23 Dry Cargo Barge Groupings for Brandon Road Lock –Navigation Investment Model (NIM)

	vesselGroup	nickname	handlingClassCode	minLength	maxLength	minBreadth	maxBreadtl	minDraft	maxDraft	numVessel:	numTrips	estimatedCape
▸	Non-Self-Propelled, Dry Cargo		1	104.8	205.4	33.4	47.5	6.6	15	5,222	14,089	1842
	Non-Self-Propelled, Dry Cargo		3	104.8	205.4	33.4	47.5	8	14	1,256	1,783	2071
	Non-Self-Propelled, Dry Cargo		1	241.7	296.1	49.3	54.8	9	11	33	55	2108

Figure 24 Tanker Barge Groupings for Brandon Road Lock –Navigation Investment Model (NIM)

	vesselGroup	nickname	handlingClassCode	minLength	maxLength	minBreadth	maxBreadtl	minDraft	maxDraft	numVessel:	numTrips	estimatedCape
▸	Non-Self-Propelled, Tanker		3	118.5	206.7	47.8	55.5	8.6	12	42	309	2423
	Non-Self-Propelled, Tanker		2	143.4	215.9	31.2	44.7	9	12.5	63	95	1664
	Non-Self-Propelled, Tanker		3	143.4	215.9	31.2	44.7	8	17.3	584	1,751	1926
	Non-Self-Propelled, Tanker		2	231.5	359.4	25.2	54.9	9	12	9	10	3809
	Non-Self-Propelled, Tanker		3	231.5	359.4	25.2	54.9	8.9	13	322	1,762	4164

Figure 25 Towboat Groupings–Navigation Investment Model (NIM)

min horsepower	max horsepower	num vessels	num trips	avg horsepower	avg length	avg breadth	avg draft	avg idling fuel rate	avg op fuel rate down loaded	avg op fuel rate down empty	avg op fuel rate up loaded	avg op fuel rate up empty
90	600	11	75	432	46	17	5.0	4	8	8	10	9
680	860	13	315	755	53	21	6.9	5	13	13	17	15
900	1140	17	1,292	1,001	64	24	7.0	6	17	17	22	20
1200	1410	26	2,064	1,218	64	25	6.9	6	20	20	27	24
1495	1800	29	573	1,719	82	29	7.8	7	29	29	38	34
1860	2200	54	920	1,995	82	30	8.0	8	34	34	44	39
2400	2900	102	1,610	2,581	93	32	8.9	9	44	44	57	51
2970	3450	97	1,224	3,135	111	33	8.6	10	54	54	69	62
3600	4000	52	458	3,872	143	38	8.3	11	66	66	86	76
4200	4400	44	930	4,239	144	37	8.3	12	72	72	94	84
4500	5000	38	486	4,870	156	40	8.6	14	83	83	108	96
5200	5600	35	320	5,589	147	44	8.7	15	96	96	124	110
5750	6250	174	1,997	6,104	145	45	8.8	16	104	104	135	120
6800	7000	2	4	6,900	165	47	8.1	18	118	118	153	136
7200	8400	8	10	7,925	182	50	9.0	20	135	135	176	157
8800	9000	3	4	8,933	193	49	9.9	22	153	153	198	176

Tow equipment costs were based on IWR's Informa Economics FY2009 Shallow-Draft / Inland Vessel Operating Costs, dated 5 December 2010. These FY2009 costs were indexed up to the FY 2016 price level using the Bureau of Labor Statistics' Inland Waterways Towing Transportation Producer Price Index. Information from the report provides equations that allow the estimation of vessel costs, primarily by horsepower and also other vessel characteristics. These VOCs are developed and applied to WCS data at a vessel level to allow NIM the flexibility in aggregating VOCs for any given study.

D.3.3.4.3 Maintenance and Reliability Assumptions

Although the GLMRIS-BR analysis does not include a component level reliability analysis, the Lock Risk Module of NIM is used to estimate the effect of potential emergency ANS response actions on lock performance. For this analysis, it is assumed that the lock would experience a 5-day unscheduled closure to enact emergency ANS response. The likelihood of this 5-day unscheduled closure event is set to 33% for both the WOPC and WPC alternatives.

For scheduled repairs, it is assumed that the lock will undergo a major rehabilitation in FY2030, resulting in a 30-day closure. For technology alternatives with the electric barrier, a rehabilitation of the barrier will be required in 2050, resulting in 8-hour closures 5 days per week for 22 days.

Each of these closures result in a unique tonnage-transit curve that can have substantial effects on transportation costs in those years. These curves are further documented in *Attachment 1 - Capacity Analysis.*

D.3.3.4.4 Brandon Road Lock Tonnage-Transit Curves

Tonnage-transit curves are required for each lock project specified in the system, and in situations where chamber service disruption is modeled, a unique tonnage-transit curve is required for each service disruption event. For the existing and WOPC Brandon Road Lock and the proposed WPCs, a capacity analysis was performed as documented in Attachment 1 - Capacity Analysis.

D.3.3.4.5 Willingness-To-Pay (WTP) For Water Transportation

NIM equilibrates either system traffic levels from a movement level fixed quantity (inelastic) or price-responsive (elastic) assumption. For the GLMRIS-BR analysis, an inelastic movement level demand was assumed as defined by the movement-level transportation rates developed by the UT-CTR in support of the GLMRIS Report in 2011.

To develop the rates, the UT-CTR conducted a robust, population-level survey in 2011, which accounted for 99% of the CAWS traffic from 2007 through 2009. This GLMRIS Report survey included 90 interviews yielding data on 139 docks, which established a comprehensive understanding of how the CAWS functions within a larger transportation network and the cost of moving commodities on this system. This allowed the following information to be identified:

- ultimate origin and destination of waterborne commodity movements on the CAWS;
- how shippers, carriers, river terminal operators, and other affected users would respond to various unexpected lock closure periods; and
- how unscheduled lock closure periods would affect their operational, transportation, and logistics costs.

This information was necessary to identify changes to transportation benefits for the alternatives considered in the GLMRIS Report. The rates developed by UT-CTR were system-level in a sense that the study encompassed a broad mixture of regional traffic moving in the Chicago area.

To verify whether the 2011 GLMRIS Report surveys and data are still relevant for use in GLMRIS-BR, the PCXIN compared more recent origin-destination-commodity traffic flows to those identified in 2011. The team found that although the tonnage levels had changed, movements analyzed in 2011 still accounted for 99% of the traffic moving through Brandon Road from 2012 to 2014 (base year of traffic flows for GLMRIS-BR). Thus, rate information from the 2011 GLMRIS Report surveys was determined to be appropriate for use in this Study.

As such, transportation rates rates were updated to a current FY16 price level by using the Bureau of Labor Statistics (BLS) Producer Price Index (PPI). An appropriate index is assigned to each leg of each movement depending on the transportation mode that was identified by UT-CTR. Figure 26 displayed the index used for each mode and haul type.

Figure 26 Bureau of Labor Statistics Producer Price InÞ Indices by Mode and Haul Type

Series_ID	Mode_Type	Haul_Type	Industry	Product
PCU4832114832112	barge	long	Inland water freight transportation	Inland waterways towing transportation
PCU4841214841212	truck	long	General freight trucking, long-distance TL	General freight trucking, long-distance, truckload
PCU4841104841101	truck	short	General freight trucking, local	General freight trucking, local
PCU4831134831133	ocean barge	long	Coastal and Great Lakes freight transport	Coastal and intercoastal towing transportation
PCU4831134831132	ship	long	Coastal and Great Lakes freight transport	Great Lakes - St. Lawrence Seaway freight transportation
PCU4883204883209	other	NULL	Marine cargo handling	Other marine cargo handling
PCU482111482111	rail	long	Line-haul railroads	Line-haul railroads
PCU482---482---	rail	short	Rail transportation	Rail transportation
PCU3339223339228	conveyor	NULL	Conveyor and conveying equipment manufacturing	Bulk material handling conveyors & conveying systems
PCU4883204883209	load	NULL	Marine cargo handling	Other marine cargo handling
PCU4883204883209	unload	NULL	Marine cargo handling	Other marine cargo handling
PCU4883204883209	transfer	NULL	Marine cargo handling	Other marine cargo handling

D.3.3.4.6 Forecasted Movement Demands

Traffic demand forecasts from the GLMRIS Report were updated for the GLMRIS-BR analysis. Increased granularity of traffic forecasts reflect the following:

1) Forecasts at the individual commodity level, rather than only group levels;
2) Forecasts at the individual dock level, and;
3) Analyzing more specific growth indicators that may affect potential traffic. Fluctuations in traffic within the vicinity of Brandon Road have been most recently dictated by the fortunes of the

petroleum and iron & steel industries. These industries and their respective inputs/outputs are among the most volatile of bulk commodities. The industries as a whole have been experiencing rapid changes due to the advents hydraulic fracturing and horizontal drilling producing large influxes of shale and Canadian crude oil. The iron and steel industry faces its own unique challenges with changes in the competitiveness of the U.S. dollar and low-priced imports. Although there are several other bulk commodities moving on the CAWS, changes in the aforementioned industries were the central focus on the Brandon Road traffic demand forecasts. Other commodities were included but forecasted with less detail due to their milder and more predictable traffic flows. Additional information on the specifics of the traffic demand forecasts can be found in *Attachment 2 – Waterway Traffic Demand Projections.*

D.3.3.4.7 Demand Forecast Adjustments: Shipper Responses to Temporary Lock Closure during Construction

This extended closure period serves as a key account for plant closures demand for BRL are primarily For the Brandon Road analysis, adjustments are made to the forecasted traffic demands to account for plant closures. These plant closures are projected to occur in the first year of construction for the alternatives requiring construction, due to a 40-day closure event.

Changes in a waterway's availability and/or shipment reliability could result in usage changes. This arises due to users' inability to incur additional costs associated with usage changes or risk aversion to these changes. To account for such changes, adjustments must be made to the forecasted traffic demands. The three technology alternatives (Technology Alternative – Complex Noise; Technology Alternative – Electric Barrier; and Technology Alternative – Complex Noise with Electric Barrier) require a planned lock closure period of 40 days in the first year of project construction to account for construction of the flushing lock. This effort imposes the most stringent change to lock availability (temporary closure) as compared to the Technology Alternatives' other construction elements.

To account for demand changes during this period, information from the robust survey conducted by UT-CTR in 2011 in support of the GLMRIS Report was utilized. As previously mentioned, shippers surveyed still account for 99% for traffic moving through Brandon Road from 2012 to 2014. Shipper responses to lock closure gathered in 2011 by UT-CTR accounted for reactions to unexpected lock closure durations of 15, 30, 60, 90, and 180 days.

Typically, the reaction to a scheduled lock closure varies from those of an unscheduled closure. A scheduled lock closure allows shippers the ability to pre-ship and post-ship, mitigating against potential losses before a shipping plan is developed. However, several shippers indicated that closure of their facility could occur regardless of a known outage, due to limited capacity to move their goods via an overland mode in conjunction with limited on-site storage. As an example, a petro-chemical company might only have tank storage capacity to serve their production needs for 30 days. A lock closure duration limiting their supply of commodities beyond 30-days would force the facility to close or significantly cut their production. These companies could lose their competitive edge. Additionally, alternative customer sources such as sell their goods via the Great Lakes may not be a viable opportunity if the market were to become saturated.

To validate the responses provided in the 2011 survey, the GLMRIS-BR study team conducted a more focused survey was issued in 2016 to a subset of shippers who participated in the 2011 survey. The 2016 GLMRIS-BR shipper and carrier survey effort accounted for 39% of tonnage included in the base year tonnage estimates (years 2012 through 2014). This representative sample included the dominant shippers (tonnage level) in each major commodity group, and were identified using data reported by vessel operators as part of the WCSC data collection process. This subset of responses were used as a validation tool to assess the impact of a scheduled versus unscheduled lock closure. The team compared the 2011 and 2016 surveys to confirm shipper responses about how changes in waterway availability and operations affect their ability to remain profitable (i.e., stay in business). This comparison found that of those shippers' responses to questions are still the same (e.g., unable to accommodate lock closures of certain durations due to limited on-site storage; small profit margins inhibit ability to accommodate additional transportation costs, etc.).

Due to this just-in-time sensitivity, shippers that identified plant closure due to experiencing a lock closure duration of 31 to 60 days were removed from the demand files for the technology alternatives in the year 2023. This reaction is used as a proxy for the impact of the 40-day lock closure experienced in the first year of construction for the technology alternatives. These plant closures were identified by UT-CTR at a movement level. The affect in the analysis is that these shippers and respective movements will bear the full reduction in transportation rate savings. It is important to note that the Corps P&G guidance acknowledges that the impact to the NED account is the full loss of transportation savings.

D.3.3.4.8 NIM Verification, Calibration, and Validation of Shipping-Plans

NIM, like any model, requires validation that it is capable of replicating observed shipper behavior and system performance and operating characteristics. To determine individual movement level equilibrium, and ultimately system equilibrium, movement shipping-plan characteristics and the shipping-plan cost must be known. There are three primary calibration steps: calibration of loaded barge flows; calibration of empty barge flows (movement barge dedication); and calibration of the shipping-plans.

Remember that WCS data only provides annual origin-to-destination barge flows by commodity[1]; information on shipment tow-size, towboat utilization, and empty return characteristics is not available for individual movements. Tow characteristics are only recorded by the Lock Performance Monitoring System (LPMS) at each of the locks, albeit at a past-the-point rather than at an origin-to-destination level. As such, the first thing NIM must do is determine shipping-plans for each movement analyzed in the study area. Specifically, the model requires calibration of movement empty barge backhaul flows, movement tow-sizes (including towboat type), and movement re-fleeting (if applicable). During this calibration process, the description of the waterway system being modeled is fine-tuned so the model most accurately replicates observed shipping behavior in the system.

Given the network transportation constraint parameters, NIM essentially creates and costs all allowable movement shipping-plans and selects the least-cost shipping-plan for each movement. This process however, requires calibration and validation. Unfortunately, movement level targets are not available and the validation is achieved by comparison of the model results against statistics observed and recorded at the navigation projects in the system. In short, NIM calibrates movement level shipping-plans to replicate the observed lock project level vessel fleet characteristics. Once the network link shipping characteristic parameters are set to where lock project fleet targets (e.g., number of tows, average tow size, etc.) are replicated, the model is considered valid and equilibrium what-if tests can be performed.

To verify, calibrate, and validate NIM, first the calibration targets are required. The calibration targets represent lock performance statistics that the model should replicate to be considered verified and validated. For the Brandon Road analysis, NIM was calibrated and validated against an average of 2012 through 2014 WCS and LPMS data. Multiple years are used for a smoothing of the data to avoid individual year irregularities. Second, the NIM network transportation constraint parameters are calibrated.

[1] WCS TOWS does contain towboat trips, however, the data is incomplete and matching the towboat data to barge data has proved unsuccessful to date.

D.3.3.4.9 Lock Tonnage and Number of Loaded Barges Verification

The origin to destination WCS tonnage flows loaded into NIM are converted to loaded barge trips, which can then be used to tabulate the number of loaded barges transiting each navigation project. Through a barge draft algorithm NIM has the capability to calculate barge loadings for each movement based on route depth restrictions, the barge type loading capacity, and the commodity density. However, since the data are available, and barge loading characteristics are not expected to vary over the planning period in the Brandon Road analysis, the model is supplied the WCS barge loading for each movement. As a result, the model simply calculates the required number of barge trips to move the tonnage by dividing the annual tonnage by the average barge loading. As such the number of loaded barges target is more a verification test (rather than a validation test). NIM output display the WCS tonnage and number of loaded barges given the movement inputs loaded (as shown in Table 25).

Table 25 Brandon Road NIM Calibration - Targets vs. Model Output

barges						tonnage			tows			average horsepower		
loaded			empty											
target	model	percent difference	target	model	percent difference	target	model	percent difference	target	model	percent difference	target	model	percent difference
6,979	6,979	0.00%	4,062	4,063	0.03%	11,508,337	11,508,338	0.00%	2,482	2,479	-0.11%	2589	2588	-0.03%

Number of Empty Barges Targets. The derivation of the target number of empty barges through each navigation project is not as straightforward as the tonnage and loaded barge targets. The lock number of empty barges target was developed by the equation below. By taking the minimum of either 1.0 or the LPMS empty to loaded barge ratio, the target is capped to no more than 50% empty.

$$\text{Lock No. of Empty Barges} = \text{MIN}\left(1\ ,\ \frac{\text{LPMS No. of Empty Barges}}{\text{LPMS No. of Loaded Barges}}\right) \times \text{Target No. of Loaded Barges} \qquad (3)$$

Movement level empty trips are recorded by WCS, however, the data files have been found to be incomplete (although improving through time). As a result, backhaul characteristics between specific origin-destinations can only be estimated. Empty barge flows in NIM are controlled through a movement level barge dedication factor specifying how dedicated the loaded barges are to the movement. This is done at the movement level so that the loaded front-haul movement can be cost with applicable charges for empty return trips.

If the dedication factor is 0.0, the barges are completely undedicated, meaning that when they have finished the loaded trip from the movement's waterside origin to its waterside destination, they are free to move to another movement and are no longer part of the movement's cost calculation. If the dedication factor is 1.0, the barges are totally dedicated to the movement, meaning that when they have finished the trip from the movement's origin to its destination, they are required to move empty back to the movement's origin. If the dedication factor is between 0.0 and 1.0, the barges are partially dedicated, and the dedication factor indicates what portion of the set of barges must make the trip back to the movement's origin empty.

Empty Barge Calibration. While the movement dedication factors can be manually set and adjusted by the user, an automated calibration program called the Movement Barge Dedication Factor Calibrator was developed. In this process, the dedication factor is assigned using a set of linear programming problems. In the first linear program the objective is to minimize the deviation from the target number of empty barges at each navigation project, given the path that each of the movements is taking. Solving this, the program determines a total "*best deviation from targets*" value. In general, there may be several assignments of dedication factors to movements that will achieve this best deviation. Tanker barges are more likely to be dedicated than are hopper barges, due to the nature of the cargo that they carry. The second linear program attempts to maximize the dedication factors for the tanker classes of barges, and minimize the dedication factors for the hopper classes of barges. Using this objective and the added constraint that the total deviation is equal to the "*best deviation*" found in the first linear program, the model determines a final setting of the dedication values which are then stored.

The empty barge flows are then aggregated and summarized at each navigation project in the system and compared against observed behavior. As shown in Table 25, calibration of movement level dedication factors reproduce system empty barge flows quite well.

Since the empty barge flows are generated from loaded movements through the movement's dedication factor, when the model is exercised with a future traffic demand, the empty barge flows automatically adjust as the loaded barge flows adjust to equilibrium. Given that the demand growth and equilibrium mix of movements could, and most likely will be, different than in the calibrated year, the percent empty barges at the projects can, and most likely will, vary from the values shown. For an extreme example, say the demand for movements in the system with 0.0 barge dedication factors decline through time to zero, while demand for movements in the system with 1.0 barge dedication factors increase. Through time the percent empty at all projects will rise to 50% empty as more and more trips in the system require empty barge returns.

Tow-size and Towboat Horsepower Targets. Targets and calibration of the shipping-plan tow-size and towboat class is much more complex than calibration of the movement barge dedication factors. These shipping-plan characteristics are interrelated; larger tow-sizes require larger towboats. As such the network parameters used in the tow-size and horsepower specification are calibrated together.

The lock project average barges-per-tow (tow-size) and the barges-per-tow distribution for Brandon Road Lock in the analysis was calculated from 2012 through 2014 LPMS data.

The lock project average horsepower and horsepower distribution targets for Brandon Road was also calculated from 2012 through 2014 LPMS data. Since the LPMS database does not track vessel horsepower, the LPMS recorded vessel number was matched to horsepower data from the WCS TOWS master vessel database table.

$$\text{Lock No. of Tows} = \frac{\left(\text{Target No. of Loaded Barges} + \text{LPMS No. of Empty Barges}\right)}{\text{LPMS Av. Barges per Tow}} \qquad (4)$$

Horsepower selection in the NIM port-to-port algorithm least-cost shipping-plan is influenced through a link level towboat class efficiency factor. Each towboat class is identified with a maximum number of barges per tow it can maneuver by barge type. This efficiency can be reduced by towboat class by network link. Similar to the tow-size limit link constraints, the towboat efficiency factors limit and influence the selection of the least-cost shipping-plan towboat class.

D.3.3.4.10 Shipping-Plan Calibration

If movement tow-sizes and towboat types were set based solely on the physical limitations of the river and the towing capacity of the equipment, NIM would tend to produce shipping-plans with larger tows and smaller towboats than historically observed. This occurs because NIM calculates the resources (i.e., number towboats, trip time, and fuel consumption) required to satisfy the demand on a least-cost basis. Because of economies of scale, the smallest towboat to move the largest tow is the least-cost shipping plan, however, the world is not perfect and other factors are considered in the shipping-plan determination.

Unlike the calibration of empty barge flows in the system where movement dedication factors are adjusted, calibration of the movement shipping-plans involves two sets of calibration parameters specified at the river link or segment level (rather than at the movement level). When the model develops a shipping-plan for a movement, it considers all the river segment restrictions in its route. To account for the factors causing shippers to use smaller tow-sizes than possible, NIM contains a calibration parameter specifying river segment tow-size limitations. To account for the factors causing shippers to use larger horsepower towboats than possible, NIM contains a calibration parameter specifying river segment towboat class efficiency limitations. These two calibration parameters are interrelated in their effect on the selection of a movement's least-cost shipping plan and ultimately the fleet distributions observed at each navigation project.

Given a specified river segment tow-size limit and towboat class efficiency characteristic NIM calculates the least-cost shipping-plan for each movement in the system. Note that this shipping-plan might involve multiple waterway legs, each having their own tow-size and towboat characteristics. The shipping-plans for all the movements can then be aggregated and summarized at each navigation project in the system and compared against observed behavior (i.e., target number of tows and average horsepower).

Shipping-plan calibration is a sequential process involving iterative cycles; at each step in a cycle specific static components of the model's waterway system description / network (i.e., link tow-size limits and / or towboat class efficiency factors) are adjusted, the model is exercised at an observed historic level, and results are compared with corresponding target values.

In the past (late 1970's through mid-1990's) these calibrations were completed essentially manually; however, NIM now has automated routines to fine-tune the calibration parameters to the user specified target statistics (the Sector Tow-size Limits and Sector Towboat Efficiency Factor Calibrators). These auto tow-size and towboat type calibration programs use a heuristic approach to minimize the difference between the model's least-cost shipping plan tow configurations and the target (observed) lock statistics in the system. The calibration process begins by determining summary lock statistics and comparing them to the specified targets. It calculates three "*offness*" measures based on: (1) difference in the number of tows ("*offTows*"), (2) difference in the number of tows of each size ("*offTowSize*"), and (3) difference in average horsepower ("*offHorsepower*"). In each case, the absolute difference between the model results and the target at each lock is weighted by the lock's "*calibration weight*" which reflects the importance of the lock in the overall analysis. Generally speaking this heuristic approach generates a set of potential changes to each sector's tow-size and towboat constraints, regenerates all the movement shipping plans under each changed constraint one at a time, and then chooses the single change that produces the greatest improvement. This process continues until no significant improvement can be made. This automated calibration process is very CPU intensive, and to speed up the calibration process NIM allows the specification of a sector range to consider in calibration (i.e., not all sectors need to be considered for adjustment).

These three offness values are measured independently, but they are related. In general, as the number of tows at a lock decreases, the size of the tows going through the lock and the average horsepower of the towboats will tend to increase. For an overall measure of how well the model parameters have been calibrated to achieve the target values, a single system-wide "*calibration fitness*" value is calculated.

To calculate the calibration fitness value these three offness measures are combined. For the Brandon Road analysis only one lock, Brandon Road, is analyzed. This makes the lock project weights and offness factors more simplistic. The following weights were used:

- Brandon Road weighting factor = 1
- offTows weighting factor = 1
- offHorsePower weighting factor = 1
- offTowSize weighting factor = 500

NIM calibration results for the existing / WOPC are shown in Table 25.

D.3.3.4.1 With-Project Condition Fleet Adjustments

As mentioned in Brandon Road's Network Definition, there are certain known restrictions on tow configurations in some of the alternatives under consideration. In alternatives that include a continuously operating electric barrier, vessels are restricted from performing multiple cuts at the lock, and are also assumed to be confined to a 550' length restriction. This would force vessel operators to prepare their tow configurations to traverse the project 7-miles downstream of Brandon Road Lock. This not only has a significant impact on average vessel transit-time as calculated by the WAM model (See Attachment 1 - Capacity Analysis), but also would force barge operators to utilize more towboats to move the same amount of tonnage, greatly increasing trip costs. To mitigate against this increased tripping effect, the team has embedded the construction of a new mooring area downstream of Brandon Road into the alternatives with an electric barrier.

Through the flexibility of setting different network definitions, NIM has the ability to assess the impact that these restrictions may have on transportation costs for different alternatives.

Tow-size Adjustments. Given the cut and length restrictions imposed by a continuously operating electric barrier, the *TowSizeLimits* table was adjusted in NIM for the alternatives that include this feature. These adjustments were made by barge type, and can be seen in Table 26 below. This restriction is imposed on tows between the site of the new mooring area, and at the existing mooring area directly upstream of Brandon Road. Tows are given the opportunity to re-fleet into larger, more efficient configurations above and below these areas, but are restricted on waterway links between these two locations.

Table 26 Tow Size Restrictions with a Continuously Operating Electric Barrier

Barge Type ID	Barge Type	Length (ft)	Beam (ft)	Original Max Tow Size	Limited Tow Size
1	Non-Self-Propelled, Dry Cargo	198.6	35	15	6
2	Non-Self-Propelled, Dry Cargo	251.6	53.9	15	6
3	Non-Self-Propelled, Dry Cargo	198.8	35	6	2
4	Non-Self-Propelled, Tanker	197.5	35	15	2
5	Non-Self-Propelled, Tanker	288.9	53	15	2
6	Non-Self-Propelled, Tanker	188.3	53.6	15	6
7	Non-Self-Propelled, Tanker	197.5	35	15	6
8	Non-Self-Propelled, Tanker	297.1	53.9	5	4

Towboat Utilization Adjustments. Horsepower selection in the NIM port-to-port algorithm least-cost shipping-plan is influenced through a link level towboat class efficiency factor. Each towboat class is identified with a maximum number of barges per tow it can maneuver by barge type. This efficiency can be reduced by towboat class by network link. Similar to the tow-size limit link constraints, the towboat efficiency factors limit and influence the selection of the least-cost shipping-plan towboat class. As seen in Table 27, Towboat types 14, 15, and 16 were adjusted to a utilization factor of 0.13 for the waterway links between the upstream and downstream mooring areas. In effect, this restricts usage of these towboat types to 2 barges per tow. This is due to length restriction combinations with the barge types as seen in Table 26.

Table 27 Towboat Restrictions with a Continuously Operating Electric Barrier

Towboat Type ID	Horsepower	Length (ft)	Beam (ft)	Original Max Tow Size	Towboat Efficiency Factor	Limited Tow Size
14	6900	165	46.5	15	0.13	2
15	7925	182	49.8	15	0.13	2
16	8933	193	49.3	15	0.13	2

D.3.3.5 Results and Alternative Considerations

As stated in Section 1, the focus of the GLMRIS Brandon Road inland navigation economic analysis is on the evaluation and comparison of the existing waterway system with two basic alternative measures: 1) decreased lock capacity (increased transit times and thereby increased delay costs) and 2) reduced demand. Ultimately, the costs assessed as part of the navigation economic analysis are converted into average annual values and included in the decision matrix used in selecting the Tentatively Selected Plan.

D.3.3.5.1 Decreased Lock Capacity

For the alternative measures under consideration, the features and operating policies of each alternative can reduce lock capacity and increase transportation costs by decreasing tow-sizes and increasing the number of trip vessels. Similarly, lock closure increases transportation costs by forcing cargo to move by an overland mode. The intricate details of each alternative's operating policy and their effect on total lock capacity is fully documented in *Attachment 1 - Capacity Analysis* and is crucial to understanding the results and impact each alternative has on total transportation savings.

Figure 27 displays the NIM results for the most-likely transportation rate savings for each alternative. A major component of these results are the increased transit times and delay costs experienced by shippers under the most-likely projected traffic demand scenario. Since many of the alternatives share the same operational features such as the flushing lock, the total system savings do no vary significantly between alternatives, with the exception of the nonstructural alternative which is not expected to increase transit times. Lock closure is not displayed in these results, because closure of the lock is simply the complete loss of transportation savings for movements using Brandon Road. Therefore, lock closure results in an average system savings loss of $318.6 million annually throughout the analysis period (2021-2070).

The technology alternatives share a very similar lock closure schedule, since the electric barrier can be built simultaneously to the flushing lock and complex noise features without significant added impact. However, there are three primary considerations when evaluating the impact that each technology alternative has on transit-time and consequently total transportation savings: 1) the manner in which the electric barrier is operated, 2) the effect of cyclical maintenance events, and 3) total throughput.

D.3.3.5.2 Operating Assumptions for the Electric Barrier

A primary impact the electric barrier has on the NED benefits afforded by the existing project is the manner in which it will be operated. As discussed in Attachment 1 - Capacity Analysis, operating the electric barrier continuously would force operators to restrict their tow configurations considerably. Operators would not be allowed to perform a multi-cut lockage, and tow sizes would be limited to 550 feet. When operating the barrier intermittently, these restriction do not apply, since the barrier would be disabled while a tow is being processed through the lock. Part of this this effect can be seen in Figure 28. Average transit time is increased at any given tonnage level due to this restriction.

Figure 27 Most Likely Transportation Savings by Year by Alternative

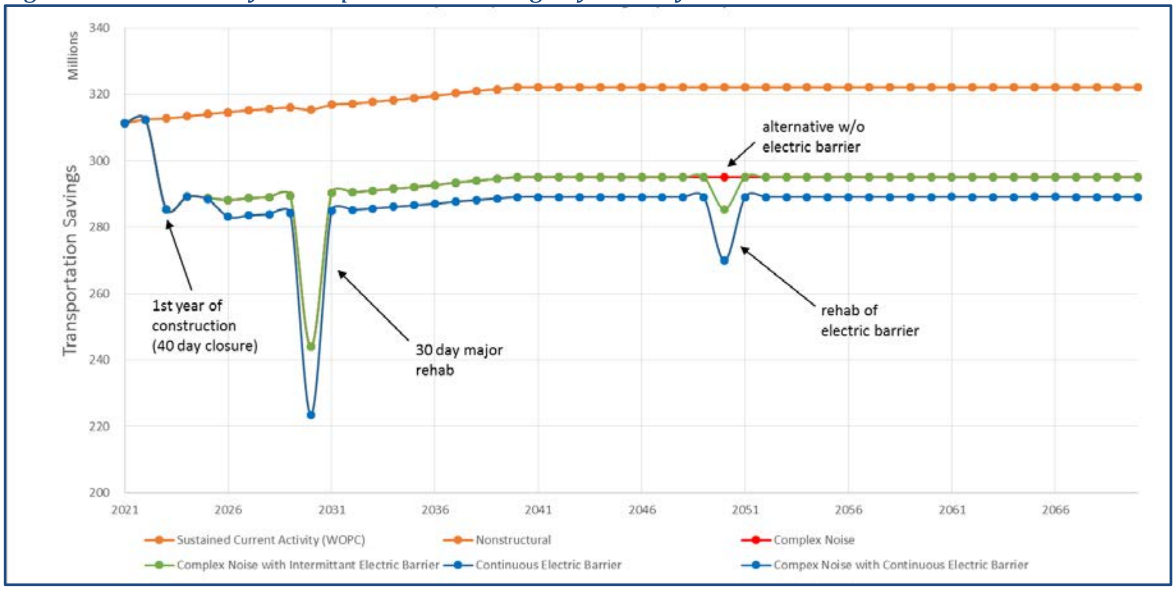
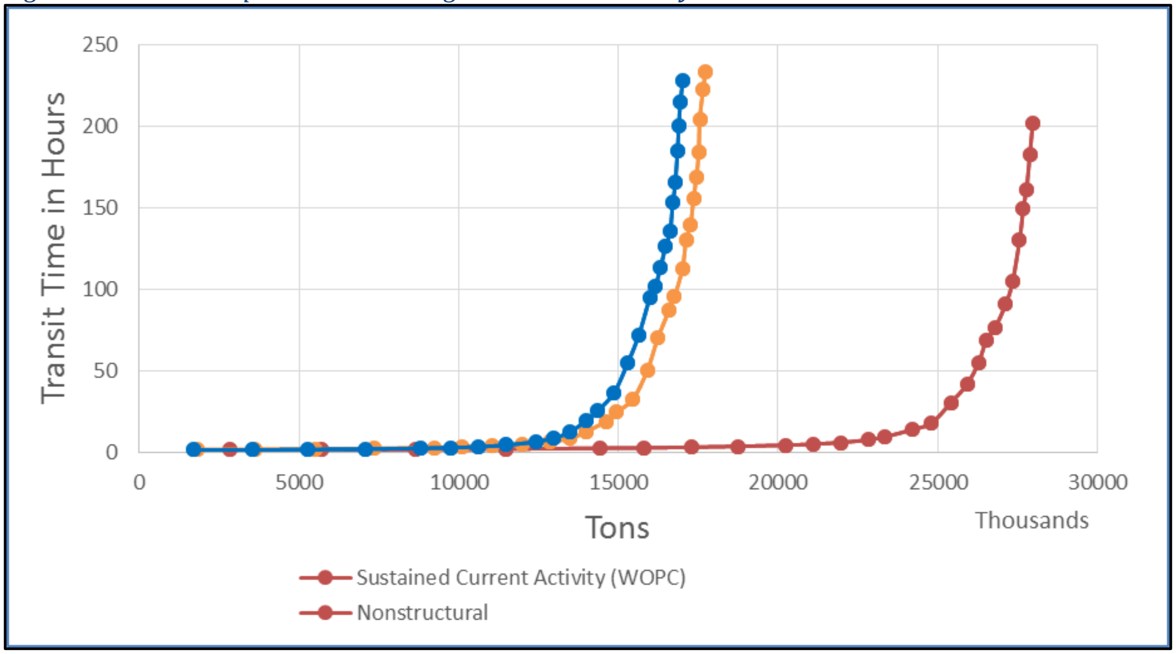


Figure 28 Normal Operations Tonnage-Transit Curves by Alternative



An additional impact is calculated in NIM, where these restrictions increase total transportation costs by requiring the use of additional trip vessels to move the same amount of cargo. In the WOPC, an average of 2,804 tows traverse Brandon Road from 2021 to 2070. If the electric barrier were to be operated continuously, total tows are projected to increase to an average of 4,589 throughout the analysis period. Conversely, operating the barrier intermittently yields 2,624 tows. It is important to note that the reduction in projected tows while operating the barrier intermittently (compared to the WOPC) is primarily due to reduced traffic demand from plant closures, and also diverted traffic to overland modes due to cyclical maintenance events. The transportation impact of operating the electric barrier continuously compared to intermittently is on average $5.3 million annually throughout the analysis period.

D.3.3.5.1 Effect of Cyclical Maintenance Events

Two major projected maintenance events were evaluated in the Brandon Road analysis. A 30-day lock closure for rehabilitation in 2030, and a closure in 2050 to rehab the electric barrier for those alternatives. As a result of the reduced capacity experienced in those years due to normal operations of the technology alternatives, combined with lock closure due to cyclical maintenance, total transportation savings experience a significant decline in those years. Additionally, these maintenance events cause traffic diversions to overland modes, as seen Figure 29. The sensitivity of total transportation savings to cyclical maintenance events is a major risk factor when considering the technology alternatives, since they all show substantial impacts due to reduced lock capacity and high transit times. Additional detail on the transit times experienced during the events can be found in *Attachment 1 - Capacity Analysis*.

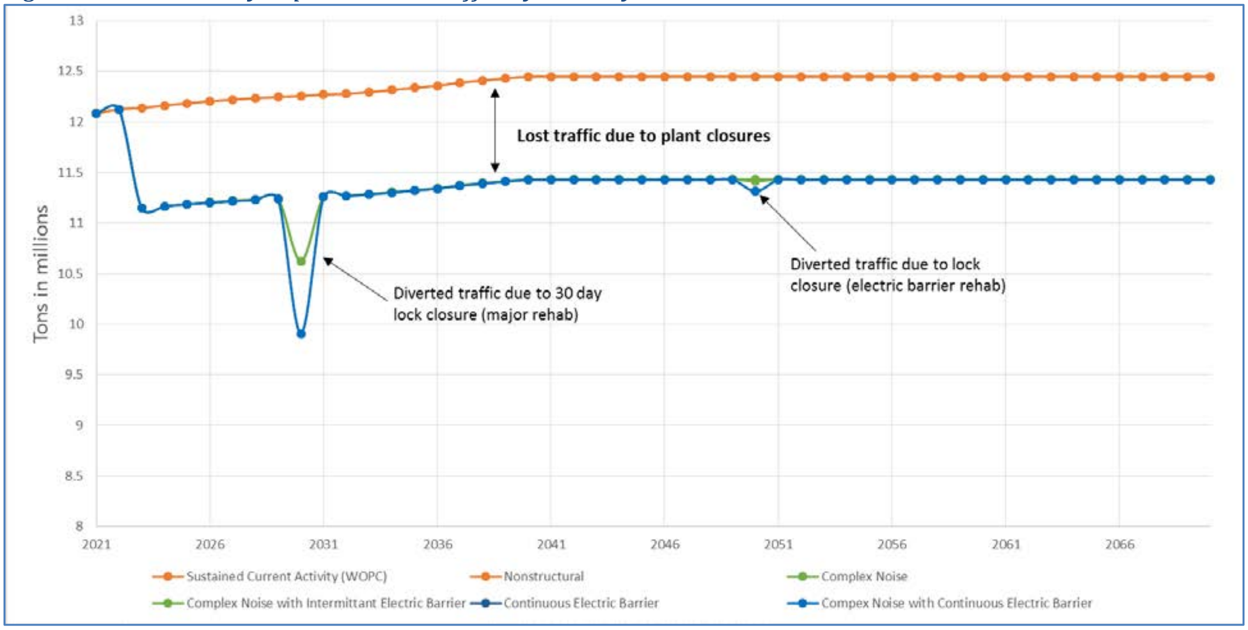
D.3.3.5.2 Total Lock Throughput

Although traffic demand is not projected to exceed 15 million tons throughout the analysis period, there is considerable risk given the significant reduction in throughput afforded by the project with the technology alternatives. Technology alternatives can reduce lock capacity to approximately 10 to 12 million tons annually. In addition, the technology alternatives cannot accommodate historically observed traffic levels. For example, traffic levels reach 17.8 million tons in 2006.

D.3.3.5.1 Reduced Demand

As mentioned in previous sections, shippers expressed sensitivity of their deliveries to particular durations of lock closure. Some of these shippers noted that they would be forced to close their facilities when faced with a lock closure duration of 31 to 90 days. This reduction in traffic demand is a primary impact driver, since the technology alternatives require a 40-day lock closure in the first year of construction. The effect of removing these demanders from the analysis is that those movements will no longer contribute to total system savings, and thereby experience a full reduction in transportation rate savings provided by the waterway system. The effect of the first year of construction is noted in Figure 27. Additionally, the effect on system equilibrium traffic when compared to sustaining current activities (WOPC) is seen in Figure 27. Although there are delay costs during construction, these are the primary impacts.

Figure 29 Most Likely Equilibrium Traffic by Year by GLMRIS-BR Alternative



D.3.3.5.2 Estimate of Average Annual Impacts to Navigation (NED Costs)

As previously stated, the impacts to average annual commercial cargo navigation are included as an NED cost of the alternatives and were included as project costs in the CE/ICA analysis. The estimated impacts on navigation account for all project phases, to include: construction, and the operation, maintenance, repair, rehabilitation, and replacement (OMRR&R) of ANS controls. This GLMRIS-BR navigation economic analysis found that several of the alternatives include measures that would *reduce the efficiency* of moving commodities on the waterway, consequently *increasing transportation costs*. Therefore, the GLMRIS-BR project alternatives are expected to result in navigation NED costs rather than NED benefits. In other words, there would be an overall *reduction in transportation cost savings*. Project alternatives that impose greater impacts on navigation are those that yield greater navigation NED costs.

As mentioned, the impacts to navigation (NED costs) assessed as part of the navigation economic analysis are converted into average annual values and included in the decision matrix used in selecting the Tentatively Selected Plan. The discount rate used for these values is the FY17 federal discount rate of 2.875% for project evaluation, and are given at an FY16 price level. Table 28 below displays the increases in average annual transportation costs (NED costs) by alternative.

Table 28 Estimated Impacts to Navigation (NED Costs) for GLMRIS-BR Alternatives

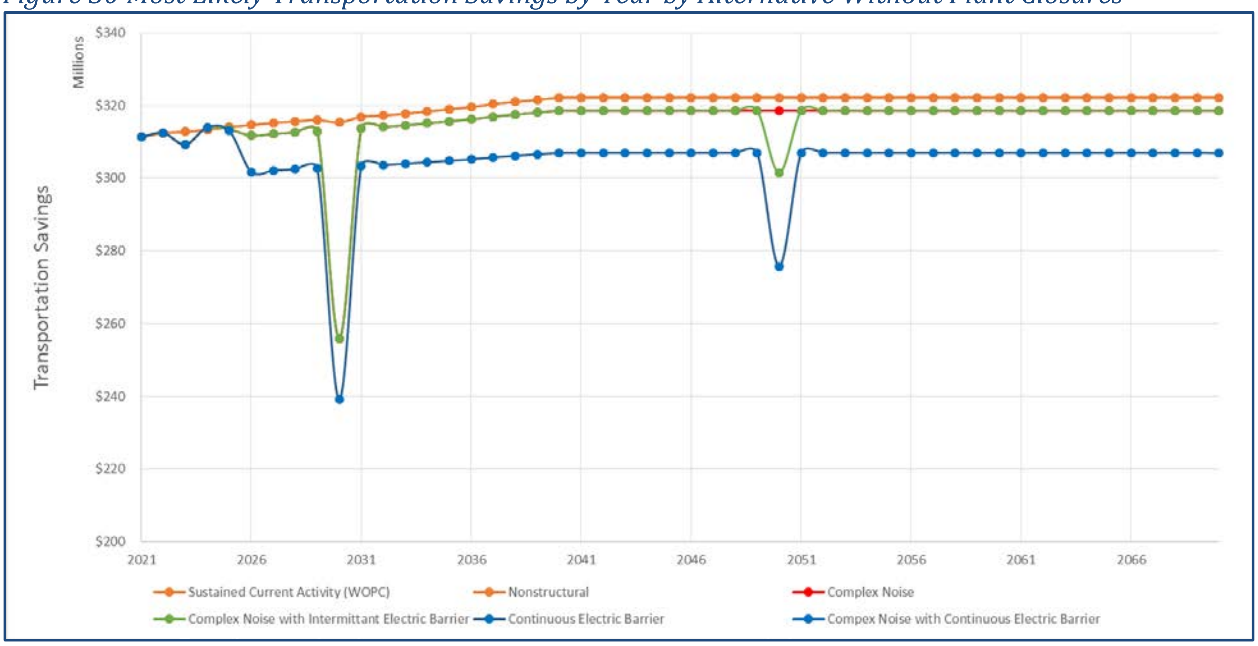
Alternative	Average Annual Transportation Cost Savings	**Impacts to Navigation**[1/] (Increase in Average Annual Transportation Costs Due to GLMRIS-BR Alternative)
No New Federal Action	$318,662,000	$0
Nonstructural Alternative	$318,662,000	$0
Technology Alternative –Electric Barrier	$287,213,000	($31,448,000)
Technology Alternative – Complex Noise	$292,642,000	($26,020,000)
Technology Alternative – Complex Noise with Electric Barrier		
Technology Alternative – Complex Noise with *Intermittent* Electric Barrier[2/]	$292,488,000	($26,173,000)
Technology Alternative –Complex Noise with *Continuous* Electric Barrier[2/]	$287,210,000	($31,451,000)
Lock Closure	$0	($318,662,000)

[1/] The technology alternatives and Lock Closure alternatives include measures that would *reduce the efficiency* of moving commodities on the waterway, consequently *increasing transportation costs*. This is a *reduction in transportation cost savings* relative to the No New Federal Action Alternative. Project alternatives that impose greater impacts on navigation are those that yield greater navigation NED costs.
[2/] The impacts to navigation for Technology Alternative – Complex Noise with Electric Barrier are presented for two operating parameters for the electric barrier (intermittent and continuous).

D.3.3.5.3 Sensitivity Analysis

Since the loss of traffic due to the first year of construction is an important factor, the team performed a sensitivity test of this impact using NIM. The observed plant closures were removed, and these movements were included back into the demand file. The results of this sensitivity test helps isolate the impact of transit time and delay costs when compared to the reduction in demand. Figure 30 displays the transportation savings by alternative.

Figure 30 Most Likely Transportation Savings by Year by Alternative Without Plant Closures



As seen in Figure 30, this alternate run of NIM produced less impactful results on an average annual basis. However, the results still show high sensitivity of the transportation savings to cyclical maintenance events, which is also observed in the most-likely case with plant closures. This is again driven by the constraints of total lock throughput and high delay costs. Figure 21 displays the average annual values for this alternate evaluation.

Of note, the impact of operating the continuous electric barrier compared to operating the electric barrier intermittently under this evaluation increases costs to an average of $9.6 million annually (compared to $5.3 average annual in the most-likely scenario). This increase in cost in driven by the increased delay costs experienced with these demanders included in the analysis.

Table 29 Estimated Impacts to Navigation (NED Costs) for GLMRIS-BR Alternatives (Assume No Plant Closures)

Alternative	Average Annual Transportation Cost Savings	**Impacts to Navigation**[1/] (Increase in Average Annual Transportation Costs Due to GLMRIS-BR Alternative)
No New Federal Action	$318,662,000	$0
Nonstructural Alternative	$318,662,000	$0
Technology Alternative –Electric Barrier	$304,216,000	($14,446,000)
Technology Alternative – Complex Noise	$314,117,000	($4,545,000)
Technology Alternative – Complex Noise with Electric Barrier		
Technology Alternative – Complex Noise with *Intermittent* Electric Barrier[2/]	$313,840,000	($4,822,000)
Technology Alternative –Complex Noise with *Continuous* Electric Barrier[2/]	$304,214,000	($14,448,000)
Lock Closure	$0	($318,662,000)

[1/] The technology alternatives and Lock Closure alternatives include measures that would *reduce the efficiency* of moving commodities on the waterway, consequently *increasing transportation costs*. This is a *reduction in transportation cost savings* relative to the No New Federal Action Alternative. Project alternatives that impose greater impacts on navigation are those that yield greater navigation NED costs.
[2/] The impacts to navigation for Technology Alternative – Complex Noise with Electric Barrier are presented for two operating parameters for the electric barrier (intermittent and continuous).

D.3.3.5.4 Uncertainty

Estimates of delay and total transit times at Brandon Road lock were developed for the No New Federal Action plan (future without project condition) and the action alternatives were developed using the Corps' certified navigation economic models (Waterway Investment Model and Navigation Investment Model) using best available economic data (e.g., USACE Waterborne Commerce Statistics Center and Lock Performance Management System), shipper response surveys (completed in support of the GLMRIS Report and GLMRIS-BR), and the best available engineering information about the construction and OMRR&R that would be required for the ANS controls. Uncertainty remains about what the *actual* processing, delay and total transit times would be if any of the project alternatives were implemented. Additional engineering and economic analysis, safety testing, and coordination with navigation stakeholders and the USCG would be completed during the PED phase to better inform these estimates.

D.3.4 RED Evaluation: Impacts to Commercial Cargo Navigation due to GLMRIS-BR Alternatives

This regional economic development (RED) analysis provides an estimate of economic impacts, arising from impacted industries in the Chicago Combined Statistical Area (CSA) due to proposed changes at BRLD. Impact estimates are limited to long-run impacts and do not take into account transitionary impacts that are expected to occur during the construction phase of this project. Neither does it account for the economic activity associated with efforts to construct structural ANS control features at BRLD. Rather, this analysis solely accounts for effects on industries expected to be impacted by navigational constraints introduced by the proposed changes to BRLD.

Navigational economic impacts to the Chicago CSA include all impacts that accrue to industries that use the port system and would be impacted by any modification to BRLD that may hinder their access to markets. This includes both local firms that ship goods through BRLD and those that receive shipments through the lock and dam. For this analysis, expected changes to transportation costs are linked to changes in total sales. This is to suggest that if shipping costs were to increase for those industries using the lock and dam to deliver or receive goods and commodities, then the selling price of those goods will be impacted. Should selling prices increase, the impacted firms will face a reduction in competitive advantage relative to other firms not impacted by the increased cost in shipping. It is from this basis that economic impacts are estimated.

Six scenarios are modeled, which represent the final array of alternative plans considered in GLMRIS-BR. The first two scenarios are not expected to have a long-run impact on transportation costs in and out of the Chicago CSA. The six scenarios include:

- **Scenario 1.** No New Federal Action (No Action);
- **Scenario 2.** Nonstructural Alternative;
- **Scenario 3.** Technology Alternative –Electric Barrier;
- **Scenario 4.** Technology Alternative – Complex Noise;
- **Scenarios 5 (a) and (b).** Technology Alternative – Complex Noise with Electric Barrier (Intermittent and Continuous); and
- **Scenario 6.** Lock Closure.

The operating parameters for electric barrier in the Technology Alternative – Complex Noise with Electric Barrier (Scenario 5) is uncertain. Depending how frequently the electric barrier operates (intermittently or continuously), increases to transportation costs will be affected to varying degrees. To capture this uncertainty related to the operating parameters of the electric barrier, two conditions are modeled for Scenario 5. The first condition reflects an electric barrier that is only operational when vessels are not present in the vicinity of BRLD; this intermittently operating electric barrier is denoted as Scenario 5a. Alternately, Scenario 5b reflects the condition where an electric barrier is operating continuously.

To estimate the regional economic impacts (changes to the RED account) due to changes in transportation costs the USACE Regional Economic System (RECONS) model framework, is applied to modeling impacts of expected changes in navigation through BRLD. Five sources of impacts are recognized but not necessarily modeled. The impacts recognized include:

1. Short-term construction and installation impact,
2. Short-term navigation diversion impact,
3. Long-term impact in the production and utilization of commodities transiting BRLD, and
4. Long-term impact from changes in cargo handling at ports due shifts in transportation use.

5. Long-term impact from changes in OMRR&R costs at BRLD.

This analysis focused only on the third source of impact, as the first two sources are limited to the time period of construction and do not represent the ongoing concern of the operations of the BRLD, while the fourth source will largely be negligible at the macroeconomic scale, as shippers reducing the use of the port will likely shift to alternate modes of transportation. For the latter, recognizing total regional reduction in commodities shipments is sufficient in recognizing the reduction in commodity handling activities.

There are limitations to this modeling approach. First, the structure of the RECONS model is such that impacts on selling price or production cost changes cannot be directly estimated, but rather have to be transformed into estimated reductions in sales based on expected purchasers' response to higher prices. The resulting changes in expected sales are then imputed into the RECONS model for estimating the economic impacts. Second, the analysis is at the margin in that, we can only anticipate change in the aggregate based on the marginal change in selling price. Actual outcomes should take into account that some firms may be located in the Chicago CSA because of the water transportation option and that losing that option may force absolute closure of economic activity, rather than marginal changes in output. For example, since the analysis assumes change in shipping costs drive a reduction in competitiveness and sales, a firm that produces commodities that can only be shipped via the port would have an absolute restraint on sales. However, the RECONS model cannot capture these special cases, but rather assumes all firms have access to alternative transportation options.

D.3.4.1 RED Analysis Methods

The navigation impact estimates (changes to RED account) used the Civil Works Regional Economic System (RECONS) model, developed by the USACE Institute for Water Resources. Because the existing RECONS model was not pre-populated with all of the relevant industry sectors required for the navigation RED analysis, the RECONS framework and method was duplicated outside of the existing online tool. This Excel-based replication is referred to as the GLMRIS Navigation RED Model. In this model, the expected direct changes in output per industry sector are identified. Such estimates were based on the expected change in shipping costs of key commodities transiting BR multiplied by Armington elasticities. Armington elasticities are import/export elasticity estimates that relate the expected change in exports/imports from a given change in relative prices of local supply to baseline global prices. Elasticity estimates are provided for all industrial sectors and collected from existing academic literature (Donnelly et al., 2004) and are expressed in percentages. As in the RECONS online model, this information is applied to the IMpact on PLANning (IMPLAN) software and data system as estimates of direct effects.

The RECONS model makes use of the same nine USACE commodity code classifications as presented in the navigation NED analysis, to include: coal, petroleum, chemicals, ores and minerals, crude petroleum, aggregates, grains, iron and steel, and all others. This requires that the IMPLAN Categories have to be aggregated up to these commodity classifications, as described in the technical documentation.

Direct effects were estimated based on the underlying data in the RECONS model, based on a 13-county region making up the Chicago Combined Statistical Area. These include the following counties:

- Cook County, IL
- DeKalb County, IL
- DuPage County, IL
- Grundy County, IL
- Kane County, IL
- Kendall County, IL
- McHenry County, IL
- Will County, IL
- Jasper County, IN
- Lake County, IN
- Newton County, IN
- Porter County, IN
- Kenosha County, WI

An IMPLAN model, based on these 13 counties was compiled. The same regional-specific, IMPLAN parameters underlying the RECONS model was then transferred to the spreadsheet adaptation of the RECONS model for generating economic impacts. As opposed to conventional uses of the RECONS model, an added step is introduced where the underlying data is used, along with expected changes in transportation costs and the literatures estimated Armington elasticities, to estimate direct effects. In the RECONS model, direct effects are measured in dollar terms. As such, direct effects are the expected change in dollar value of sales.

Consistent with standard input-output modeling, direct effects drive larger macroeconomic impacts through well-established economic multiplier process (Coughlin and Mandelbaum, 1991). Direct effects, measured in sales, are estimated based on expected delivered final prices of commodities shipping from the Chicago CSA and commodities shipping into the Chicago CSA, where changes in the costs of shipping drive the changes in total delivery purchase prices of commodities.
Changes in shipping costs were estimated as a part of the GLMRIS-BR navigation NED analysis. Details about these cost estimates can be found commercial cargo navigation NED analysis section.

In estimating the direct effects, it is assumed that a one-dollar increase in the shipping costs of goods impacted by changes in BRLD will increase the selling price by exactly one dollar. This is consistent with the structure of the RECONS model in that it assumes the value of industry sales is the sum of its expenditures on intermediate inputs (including transportation services), payments to labor and capital owners and indirect business taxes. Impact estimates take two forms that are estimated separately. The first impact estimates provide the estimated change in sales of commodities produced in the Chicago CSA. The second impact estimates provide the estimated change in sales of all Chicago goods production who buy goods shipped through BR as intermediate inputs. For this second estimate, if the cost of acquiring inputs increases, the sales price of locally produced goods will increase, thereby reducing the competitiveness of Chicago goods in the global local and global market places.

The process of estimating the first impact on sales of commodities shipped through BR starts with the estimated change in shipping costs. The data underlying the RECONS model was used to determine the share of total sales that is made up of the cost of shipping. This share was then allocated to the percent of sales that were shipped via water transportation. In this, the value of water transportation expenditures was divided by the total transportation costs by industry to calculate the share of sales shipped via water transportation. Together, this determines the increase in shipping costs, and by assumption, the change in selling price. Applying elasticities to these provides the expected decrease in total sales.

The process of estimating the second impact is much more involved, as changes in shipping costs of intermediate inputs has to be allocated across all purchasing industries. Estimates start with the change in commodity prices as inputs into goods producing sectors. In this, the change in commodity prices calculated above is added to the costs of intermediate inputs. The implied assumption is that the prices of all affected commodities are equally impacted by the change in selling costs of those goods transiting BR. If markets are competitive, this assumption should largely hold true. Because the sum of total expenditures equals the total sale value, summing the change in total purchases by industry provides the change in total selling price by industry, assuming physical output remains unchanged. Then estimating the change in physical output in dollar terms is completed by multiplying this by the corresponding elasticity.

This change in price is then multiplied by the corresponding Armington elasticities, as reported in Donnelly et al. (2004). The Armington elasticities measure the response in local demand to a relative price increase – local markets to global markets and are the cornerstone to more elaborate regional economic simulation models called computable general equilibrium (CGE) models.(Partridge and

Rickman, 2010). The logic is that if local prices increase relative to global prices, local producers will become less competitive in export markets. Similarly, the price competitiveness of local producers supplying the local market will erode to relatively cheaper producers operating outside the local market. Both effects will drive down the value of sales to local suppliers.

The estimated direct effects are then the direct changes in Chicago CSA production of commodities shipped through BR due to higher selling costs and the changes in all Chicago CSA goods producing firms due to higher prices of commodity inputs due to reduced access to such inputs. The direct effects drive the RECONS model of economy-wide impacts, providing impact estimates in terms of sales (output), employment, labor income and value added (region's contribution to gross domestic product). These larger impacts account for all expected secondary transactions that would have gone into the production of the lost direct output. The RECONS model uses standard input-output multipliers in calculating these total effects, where the multipliers entail the direct, indirect and induced effects. Indirect effects are those industry-to-industry transactions necessary to make a given level of output. Induced effects are sales arising from changes in household and institutional incomes. Each sector has unique multipliers depending on their respective purchasing patterns, where total effects always exceed the direct effects that set in motion economy-wide impacts.

Since most goods transit Brandon Road from sources outside of the Chicago CSA to destinations outside of the Chicago CSA, we anticipate the impacts to be relatively small to minor for the Chicago CSA economy. This is not to suggest that industries will not be impacted, but the effort is to recognize those industries in the Chicago CSA that will be impacted and to estimate the aggregate of such impacts.

D.3.4.2 Results

Seven scenarios are considered. The expected change in shipping costs for those goods that traverse BRLD are provided in Table 30. These estimates were generated by the GLMRIS-BR navigation NED analysis. As evident in Table 30, Scenario 06, Lock Closure, is expected to generate the most substantial impact on shipping costs, while Scenarios 01 and 02, "No Action" and "Nonstructural," are expected to have no measurable impact on shipping costs. Lock closure, under Scenario 07, is expected to increase shipping costs by $318.770 million, while the remaining impactful scenarios have expected distributed costs totaling between $26,086,000 and $31,563,000.

Table 30 Expected Increases in Transportation Costs by Commodity Group [a, b]

Commodity Group	Scenario (Alternatives)						
	01	02	03	04	5a	5b	06
Coal	$0	$0	$13,540,000	$12,842,000	$12,857,000	$13,540,000	$84,530,000
Petroleum	$0	$0	$1,703,000	$903,000	$944,000	$1,704,000	$43,097,000
Chemicals	$0	$0	$1,971,000	$657,000	$688,000	$1,971,000	$53,757,000
Ores & Minerals	$0	$0	$2,980,000	$2,758,000	$2,763,000	$2,980,000	$31,958,000
Crude Petroleum	$0	$0	$5,893,000	$5,368,000	$5,394,000	$5,894,000	$33,003,000
Aggregates	$0	$0	$2,175,000	$1,123,000	$1,139,000	$2,175,000	$35,077,000
Grains	$0	$0	$2,920,000	$2,291,000	$2,308,000	$2,920,000	$17,499,000
Iron & Steel	$0	$0	$213,000	$100,000	$105,000	$213,000	$7,504,000
All Others	$0	$0	$167,000	$43,000	$46,000	$167,000	$12,343,000
Total	**$0**	**$0**	**$31,560,000**	**$26,086,000**	**$26,244,000**	**$31,563,000**	**$318,770,000**

[a] Source: Results of GLMRIS-BR NED Analysis
[b] Scenarios represent the following alternative plans: (Scenario 1) No New Federal Action; (Scenario 2) Nonstructural; (Scenario 3) Technology Alternative –Electric Barrier; (Scenario 4) Technology Alternative – Complex Noise; (Scenarios 5a and 5b). Technology Alternative – Complex Noise with Electric Barrier (intermittent and continuously operating electric barrier); (Scenario 6) Lock Closure.

These shipping cost estimates are then allocated to respective industries shipping goods out of the Chicago CSA to estimate the expected changes in total sales under higher selling prices necessary to deliver final products. In this, local producing firms face reduced competitiveness in global markets resulting in lost sales.

Estimated direct effects are measured in dollars and transformed into employment, labor income and value added based on fixed ratios, as detailed in the RECONS model documentation. Table 31 shows the estimated, aggregated direct and total effects. They are aggregated in that both the impacts of reduced out-shipments of commodities traversing BRLD and the distributed impacts on all producing sectors purchasing costlier commodity inputs are combined. In addition, they are aggregated in that impacts over all industries are combined into single measures.

As shown in Table 31, the first two scenarios are expected to generate no long-term impacts because they are expected to generate no long-term change in shipping costs. The largest expected impact occurs under the Lock Closure alternative, which corresponds with the highest change in shipping costs, as shown in Table 31. Under all scenarios, the expected impact appears to be marginal in contrast to the size of the market. This reflects that while BRLD may be vitally important to the businesses that use it to ship or receive goods, its contribution to the overall Chicago CSA economy is relatively small.

The findings are also consistent with *a priori* expectations that the overall estimated impact is likely to be relatively limited in that the shipping costs make up a relatively small component of overall costs of production. However, as pointed out in the introduction, the RECONS model cannot account for those firms that absolutely require unfettered access to water transportation and BRLD. Incorporating such consideration in the estimates, is likely to raise the overall assessed impacts.

Table 31 Annual Regional Economic Impact in Chicago CSA Due to Increases in Long-Term Shipping Costs As a Result of GLMRIS-BR Alternative Plans [a, b, c, d]

Scenarios	Direct Sales	**Total Impact in Chicago CSA as a Result of Increases in Long-Term Shipping Costs Due to GLMRIS-BR Alternative Plans** (Direct and Secondary Effects)			
		Sales	Employment	Labor Income	Gross Regional Product
Scenario 01	$0	$0	0	$0	$0
Scenario 02	$0	$0	0	$0	$0
Scenario 03	-$946,000	-$1,588,000	-5	-$345,000	-$637,000
Scenario 04	-$792,000	-$1,322,000	-4	-$279,000	-$526,000
Scenario 5a	-$796,000	-$1,329,000	-4	-$281,000	-$529,000
Scenario 5b	-$946,000	-$1,588,000	-5	-$345,000	-$637,000
Scenario 06	-$8,200,000	-$13,783,000	-45	-$3,115,000	-$5,647,000

[a] Source: IMPLAN and GLMRIS Navigation RED Model (RECONS model modification)

[b] Scenarios represent the following alternative plans: (Scenario 1) No New Federal Action; (Scenario 2) Nonstructural; (Scenario 3) Technology Alternative –Electric Barrier; (Scenario 4) Technology Alternative – Complex Noise; (Scenarios 5a and 5b). Technology Alternative – Complex Noise with Electric Barrier (intermittent and continuously operating electric barrier); (Scenario 6) Lock Closure.

[c] Chicago CSA includes eight counties in Illinois (Cook, DeKalb, DuPage, Grundy, Kane, Kendall, McHenry, and Will), four counties in Indiana (Jasper, Lake, Newton, and Porter), and Kenosha County, Wisconsin.

[d] Direct effects are changes to directly affected industries. Secondary effects are indirect and induced effects. Indirect effects account for changes to supporting industries. Induced effects occur from household expenditures or consumer spending associated with the direct and indirect workers spending their earnings within the impact area. Negative values indicate reductions in sales, employment, labor income and gross regional product. Dollars values at a 2016 price level.

D.3.4.3 Conclusions

This report details the methods used to estimate the navigation impacts of proposed changes to BRLD. Estimates were derived from expected changes in goods producing sectors in the Chicago CSA. Table 32 combines the non-zero impact estimates into a single summary table with average, maximum and minimum impacts in terms of lost sales (output), employment, labor income and value added (gross regional product). The ranking of impacts is consistent with the rankings of the expected change in shipping costs associated with changes to BRLD. In this direct effects in terms of sales lost ranged from $792,000 to $8,200,00. This corresponds to total economic impacts on sales from $1.322 million to $13,783 million. Employment impacts ranged between a minimum of four jobs foregone to 45 with labor income from $279,000 to $3,115,000. Finally, depending on which restrictive scenario plays out, changes to gross regional product will range between a decrease of just over half a million dollars to $5.647 million.

Table 32 Summary of Annual Regional Economic Impacts in Chicago CSA Due to Increases in Long-Term Shipping Costs As a Result of GLMRIS-BR Alternative Plans

	Direct Sales	Total Effects for Scenarios 03-06 (Direct and Secondary Effects)[1/]			
		Sales	Employment	Labor Income	Gross Regional Product
Average	-$2,336,000	-$3,922,000	-13	-$873,000	-$1,595,000
Maximum	-$8,200,000	-$13,783,000	-45	-$3,115,000	-$5,647,000
Minimum	-$792,000	-$1,322,000	-4	-$279,000	-$526,000

[a] Source: IMPLAN and GLMRIS Navigation RED Model (RECONS model modification)
[b] Scenarios represent the following alternative plans: (Scenario 1) No New Federal Action; (Scenario 2) Nonstructural; (Scenario 3) Technology Alternative –Electric Barrier; (Scenario 4) Technology Alternative – Complex Noise; (Scenarios 5a and 5b). Technology Alternative – Complex Noise with Electric Barrier (intermittent and continuously operating electric barrier); (Scenario 6) Lock Closure.

D.3.5 Safety Analysis: Impacts from Diversions of Commercial Cargo Navigation to Land Modes Due to GLMRIS-BR Alternatives

D.3.5.1 Evaluation Procedure

As covered in other sections, several shippers indicated that they would close their facilities when faced with a lock closure duration of 31 to 60 days. The extent of impacts to the NED account is a full reduction in transportation rate savings (existing water rate compared to the least-cost all overland routing) for those movements. Similarly, the extent of impacts to this safety analysis is the increase in net overland miles when comparing the existing water route compared to the least cost all overland routing. These additional overland miles traveled would have externalized costs associated with them, which would be classified as a disruption cost (less any externalized costs originally associated with the diverted water shipment).

The types of externalized costs associated with additional rail and truck traffic range from noise, to vibrations, to air pollution from railroad engines, to additional accidents. This analysis is concentrated on developing external costs associated with the value of rail and truck accidents due to increased overland traffic. These additional overland miles traveled would generate external costs under the technology and lock closure alternatives. Fatalities and accidents for the existing water shipments in the WOPC (sustaining current activities) that the overland movements would replace are also calculated and subtracted from the total safety cost to derive the incremental safety cost.

The methodology used is a calculation used in the certified GL-SAND Model. This method was also used and reviewed in the Soo Locks Feasibility Study. The analysis of Safety Benefits calculated monetary annual safety benefits in three categories: 1) fatal accidents/trespass fatalities; 2) non-fatal accidents/incidents and 3) value of physical damages. All procedures are also used in the estimation process are in accord with the procedures used by the FRA to evaluate the economic impact of proposed FRA safety regulations.

D.3.5.2 Data Sources

The first two cost categories are based on "Willingness to Pay" values. The derivation of these values is based on guidance furnished by the Office of the Secretary of Transportation (OST) via memorandum June 17, 2015. This guidance provides recommendations on the treatment of the value of a statistical fatality and value of injuries in economic analyses. It specifies that values of a statistical fatality and value of injuries be based on the "willingness to pay" (WTP) by society for reduced risks of fatalities and injuries. The last category (property damages) is based upon actual property damages incurred by each mode. Information on Railroad safety statistics was obtained from the U.S. Department of transportation's (USDOT) Federal Railroad Administration (FRA). Railroad safety statistics were obtained from their *Railroad Safety Statistics, Annual Report 2012* (preliminary), in addition to 2014 Accident/Incident Counts and Rates tables available on their website[2]. Information on truck statistics was obtained from the US DOT Federal Motor Carrier Safety Administration (FMCSA) *Large Truck and Bus Fatal Crash Facts 2014* dated 15 April 2016. Information on waterway accidents, incidents, and property damage was obtained from the U.S. Coast Guard and mileage data was obtained from the USACE Waterborne Commerce Statistics Data. Information on tripping and loaded rates were derived from the Iowa Department of Transportation *Cargo Capacity Comparison* and the Texas Transportation Institute’s Report: *A Modal Comparison of Domestic Freight Transportation Effect on the General Public: 2001-*

[2] http://safetydata.fra.dot.gov/OfficeofSafety/publicsite/summary.aspx

2009. Movement level mileage information is provided by the UT-CTR as part of their 2011 research for GLMRIS.

D.3.5.3 Impact Values

The first step in the assessment of safety impact is to derive values for each of the three cost categories mentioned above (fatalities, injuries, and property damages).

Fatalities. The basic approach taken to value an avoided fatality is to determine how much an individual or group of individuals is willing to pay for a small reduction in risk. Once this amount is known, it is necessary to determine how much risk reduction is required to avoid one fatality. The total willingness to pay for the amount of risk reduction required to avoid one fatality is termed the value of a statistical life. For example, if people are willing to pay $3.50 to reduce the risk of a fatality by one chance in one million, this implies they will be willing to pay $3.5 million to prevent one fatality. From another perspective, $3.5 million represents the amount a group as a whole would be willing to pay to purchase the risk reduction necessary to avoid one expected fatality among its members. The "value of a statistical fatality" has no application to the actual death of any identifiable individual and it is not per se, the value of a human life.

The most recent OST guidance memorandum suggests that $9.4 million be used as the median value of a statistical fatality avoided. Alternate low and high values provided by the OST are also in this analysis to provide a potential range of impacts, which are $5.2 million and $13 million, respectively.

Injuries. OST guidance also established a procedure for valuing averted injuries based on the current value of a statistical fatality and the Abbreviated Injury Scale. The Abbreviated Injury Scale is a comprehensive system for rating the severity of accident-related injuries which recognizes five levels of injury severity. It classifies nonfatal injuries into five categories depending on the short-term severity of the injury. A sixth category corresponds to injuries that result in death after 30-days of the accident. The five nonfatal Abbreviated Injury Scale categories are based primarily upon the threat to life posed by an injury. The low, median, and high Value of Statistical Life (VSL) value and the Abbreviated Injury Scale were combined to produce the Abbreviated Injury Scale matrix in Table 33.

Table 33 Abbreviated Injury Scale Matrix

Abbreviated Injury Scale Level	Severity	**Fraction of** Value of Statistical Life	**Low** Value of Statistical Life	**Mid** Value of Statistical Life	**High** Value of Statistical Life
1	Minor	0.003	$ 15,600	$ 28,200	$ 39,000
2	Moderate	0.047	$ 244,400	$ 441,800	$ 611,000
3	Serious	0.105	$ 546,000	$ 987,000	$ 1,365,000
4	Severe	0.266	$ 1,383,200	$ 2,500,400	$ 3,458,000
5	Critical	0.593	$ 3,083,600	$ 5,574,200	$ 7,709,000

The low, median, and high values were then weighted across all Abbreviated Injury Scale injury levels to produce average values of $1,054,560, $1,906,320, and $2,636,400 respectively.

Property Damages. Finally, rail safety data indicated the value of physical damages per train/vehicle incident in a year. This included damages to both equipment and trackage. Total property damage impacts values are Coast Guard for the waterways. For truck, an accident rate-per-mile is first calculated (see below) and then multiplied by an average damage value per accident. All property damage values were indexed to FY16 dollar using an appropriate modal index from the Producer Price Index (PPI). These are similar indices from the Bureau of Labor Statistics that are used to index transportation rate values.

D.3.5.4 Incident Rates per Mile

The next step in the calculation involves developing an incident rate per mile. This incident rate per mile is then be multiplied times the values calculated above to develop a cost per additional mile for each cost category (fatalities, injuries, property damages). Incident rates per mile are simply derived by diving the total observed fatalities, injuries, and accidents in a year by the number of observed miles.

D.3.5.5 Cost per Mile

Once a rate-per mile has been calculated for each cost category, these values are multiplied by the impact values to derive the cost per mile. Each cost per mile is then totaled across each cost category (fatalities, injuries, damages) to develop a total cost per mile by mode. Table 34 through Table 36 below display the complete calculation for each mode.

Table 34 Calculation of Truck Damage Costs per Mile (FY2016 Price Level)

Category	Value
1) Fatal Accidents/Incidents	
Total Fatalities in Large Truck Accidents in 2014	3,903
Vehicle Miles Traveled by Large Trucks in 2014	279,132,000,000
Fatality Rate per Truck Mile	0.0000000139826
Low - Value of Statistical Life (VSL)	$5,200,000
Mid - Value of Statistical Life (VSL)	$ 9,400,000
High - Value of Statistical Life (VSL)	$13,000,000
Low - Fatality Cost per Truck Mile	$ 0.0727
Mid - Fatality Cost per Truck Mile	$ 0.1314
High - Fatality Cost per Truck Mile	$0.1818
2) Non-Fatal Accidents/Incidents	
Persons Injured in Large Truck Accidents in 2014	111,000
Vehicle Miles Traveled by Large Trucks in 2014	279,132,000,000
Injury Rate per Truck Mile	0.000000397661
Low - Value of Injury	$1,054,560
Mid - Value of Injury	$1,906,320
High - Value of Injury	$2,636,400
Low - Injury Cost per Truck Mile	$ 0.0147
Mid - Injury Cost per Truck Mile	$0.0267
High - Injury Cost per Truck Mile	$ 0.0369
3.) Property Damages	
Property Damage Accidents Involving Large Trucks in 2014	326,000
Vehicle Miles Traveled by Large Trucks in 2014	279,132,000,000
Property Damages per Truck Mile	0.00000116791
Avg - Property Damage Per Crash	$17,412
Avg - Property Damage Cost per Truck Mile	$ 0.0203
TOTAL Truck Damage Costs per Mile	
Low - Cost per Truck Mile	$ 0.1078

Category	Value
Mid - Cost per Truck Mile	$0.1784
High - Cost per Truck Mile	$ 0.2390

Table 35 Calculation of Rail Damage Costs per Mile (FY2016 Price Level)

Category	Value
1) Fatal Accidents/Incidents	
Total Fatalities in Train Accidents in 2014	767
Train Miles Traveled in 2014	765,966,997
Fatality Rate per Train Mile	0.0000010013486
Low - Value of Statistical Life (VSL)	$ 5,200,000
Mid - Value of Statistical Life (VSL)	$ 9,400,000
High - Value of Statistical Life (VSL)	$ 13,000,000
Low - Fatality Cost per Train Mile	$5.2070
Mid - Fatality Cost per Train Mile	$ 9.4127
High - Fatality Cost per Train Mile	$ 13.0175
2) Non-Fatal Accidents/Incidents	
Persons Injured in Train Accidents in 2014	8,702
Train Miles Traveled in 2014	765,966,997
Injury Rate per Train Mile	0.000011360803
Low - Value of Injury	$1,054,560
Mid - Value of Injury	$1,906,320
High - Value of Injury	$2,636,400
Low - Injury Cost per Train Mile	$1.0560
Mid - Injury Cost per Train Mile	$1.9089
High - Injury Cost per Train Mile	$2.6400
3.) Property Damages	
Equipment and Track Damages in 2012	$ 221,830,000
Train Miles Traveled in 2012	740,377,156
Property Damage per Train Mile (FY13 dollars)	$ 0.2996
Property Damage per Train Mile (FY16 dollars)	$0.3032
TOTAL Train Damage Costs per Mile	
Low - Cost per Train Mile	$6.5662
Mid - Cost per Train Mile	$11.6247
High - Cost per Train Mile	$15.9607

Table 36 Calculation of Waterway Damage Costs per Mile (FY2016 Price Level)

Category	Value
1) Fatal Accidents/Incidents	
Total Fatalities due to Towing Operations in 2014	4
Domestic Internal Waterway Miles Traveled in 2014	469,300,000
Fatality Rate per Waterway Mile	0.0000000085233
Low - Value of Statistical Life (VSL)	$ 5,200,000
Mid - Value of Statistical Life (VSL)	$ 9,400,000

Category	Value
High - Value of Statistical Life (VSL)	$13,000,000
Low - Fatality Cost per Waterway Mile	$ 0.0443
Mid - Fatality Cost per Waterway Mile	$ 0.0801
High - Fatality Cost per Waterway Mile	$ 0.1108
2) Non-Fatal Accidents/Incidents	
Injuries involving a towing vessel or barge in 2014	1,797
Domestic Internal Waterway Miles Traveled in 2014	469,300,000
Injury Rate per Waterway Mile	0.000003829107
Low - Value of Injury	$1,054,560
Mid - Value of Injury	$1,906,320
High - Value of Injury	$2,636,400
Low - Injury Cost per Waterway Mile	$ 0.0090
Mid - Injury Cost per Waterway Mile	$0.0162
High - Injury Cost per Waterway Mile	$ 0.0225
3.) Property Damages	
Damages in 2011	$64,600,000
Waterway Miles Traveled in 2011	486,000,000
Property Damage per Waterway Mile (2011 dollars)	0.00000116791
Property Damage per Waterway Mile (2015 dollars)	$0.1329
Average - Property Damage Cost per Truck Mile	$ 0.1442
TOTAL Waterway Damage Costs per Mile	
Low - Cost per Waterway Mile	$ 0.1976
Mid - Cost per Waterway Mile	$0.2406
High - Cost per Waterway Mile	$ 0.2775

D.3.5.6 Diverted Tonnage

As mentioned in the evaluation procedure, the diverted tonnage as part of this analysis is due to plant closures. Since the transportation rate information provides the least-cost all overland movement information (both cost and mileage) to move from the same ultimate origin to the same ultimate destination, this information provides the upper bounds that this lost traffic has in terms of NED impacts. However, it is both difficult and outside the scope of this study to determine and quantify where this lost production may actually be made up, and what mode and mileage might be utilized by that producer. Therefore, both the savings values and the mileage for the existing movements serve as a proxy for the impact as part of a partial equilibrium assessment.

Ton Miles per Trip. The basic methodology to identify the net increase in overland mileage was to identify each of the origin/destination pairs that would be affected by the 40-day lock closure in the first year of construction of the technology alternatives. These are the user who indicated closure of their plant due to a 31-60 day lock closure. For the lock closure alternative, this includes all movements, since the lock would no longer be operational. As mentioned earlier, net overland miles subtracts out any overland miles already associated with the exiting ultimate origin to ultimate destination waterway move. However, there are no overland modes associated with the ultimate O-D's for users that identified plant closure due to a 31-60 lock closure. Each of these movements is an all-water movement. Therefore, any diverted traffic due to construction of the technology alternatives would always yield some type of increase in overland miles. For the lock closure alternative, existing overland miles were subtracted from the least-cost all overland routing to determine the net increase.

On average, one million annual waterway tons divert to overland modes as a result of the technology alternatives throughout the analysis period (2021-2070). On average, 841 thousand tons move by rail, and 172 thousand tons move by truck. For rail, this results in an average increase of 774 thousand ton miles per trip. For truck, the ton miles per trip average 48.7 million through the analysis period.

For lock closure, 12.4 million average annual tons are diverted through the analysis period. The tons miles per route (by mode) are displayed in Table 37. As noted earlier, special care is taken to ensure that only the net overland miles are used and any existing overland miles associated with the current water routing are subtracted.

Table 37 Average Annual Ton Miles by Route and Mode (2021-2070)

	Overland Ton Miles (millions)	Water Ton Miles (millions)
Rail	7,196	79
Truck	890	32
Barge	-	11,238

Total Front Haul Miles. Since the values above are simply measures distances for origin to destination, an assumption must be made as the amount of trips it would take to move the respective cargo for each mode. One of the significant benefits of the waterway system is the ability to move large quantities of bulk commodities in comparatively fewer trips.

For this calculation, the number of potentially diverted tons, by origin/destination pair, was converted to the number of unit trains and trucks. These were then multiplied by the miles per trip to determine the total front-end miles. The loading rates used were derived by the Iowa Department of Transportation, and have also been utilized by the Texas Transportation Institute in similar calculations. The estimates assume a 108-car unit train with a carrying capacity of 11,880 tons. For truck, a large-semi is assumed with a carrying capacity of 25 tons. For the waterway, a 15-barge tow is assumed, with a carrying capacity of 26,250 tons.

Total Miles Including Back Haul. Since the mileage determined above only represents front-end mileage (origin to destination), an assumption has to be made on what increased mileage would result due to empty backhaul. For this calculation, a 50% empty backhaul is assumed for truck and rail. For barge transport, the empty backhaul rate is set to 74%. According to LPMS data, Brandon Road Lock traffic averages approximately 37% empty barges, and 63% loaded.

D.3.5.7 Results

Once the increase in overland miles had been determined, these miles were simply multiplied by the costs per mile within each cost category. Values per year were then discounted at the current project evaluation discount rate of 2.875% and annualized over the analysis period (2021-2070) for their consideration in the decision making process. Since the technology alternatives all share the same diverted mileage impact due to the 40-day closure, results are not broken out by specific technology alternative. The impacts of the lock closure alternative are presented in different tables, and are substantially greater. Given the variation in the Value of a Statistical Life, a range of potential impacts is presented for the fatality and injury cost categories.

D.3.5.7.1 Technology Alternative Impacts

The costs due to implementing a technology alternative is displayed in Table 38 though Table 40

Table 38 Average Annual Fatality Costs due to GLMRIS-BR Technology Alternatives

	Low	Mid	High
Water	$3,119	$5,638	$7,798
Rail	$470,557	$850,622	$1,176,391
Truck	$196,795	$355,744	$491,986
Incremental	**$664,232**	**$1,200,727**	**$1,660,580**

Table 39 Average Annual Injury Costs due to GLMRIS-BR Technology Alternatives

	Low	Mid	High
Water	$633	$1,143	$1,581
Rail	$95,429	$172,506	$238,572
Truck	**$39,910**	**$72,145**	**$99,775**
Incremental	**$134,706**	**$243,507**	**$336,766**

Table 40 Average Annual Property Damage Costs due to GLMRIS-BR Technology Alternatives

	Average
Water	$10,151
Rail	$27,397
Truck	$55,040
Incremental	**$72,286**

D.3.5.7.2 Lock Closure Impacts

The costs due to implementing the lock closure alternative is displayed in Table 41 through Table 43.

Table 41 Average Annual Fatality Costs due to Lock Closure Alternative

	Low	Mid	High
Water[1/]	$223,234	$403,539	$558,086
Rail	$4,710,599	$8,515,313	$11,776,496
Truck	$3,874,823	$7,004,488	$9,687,058
Incremental	**$8,362,187**	**$15,116,262**	**$20,905,468**
[1/]Includes truck and rail costs associated with the complete movement.			

Table 42 Average Annual Injury Costs due to Lock Closure

	Low	Mid	High
Water[1/]	$45,272	$81,838	$113,180
Rail	$955,309	$1,726,905	$2,388,273
Truck	$785,814	$1,420,510	$1,964,535
Incremental	**$1,695,852**	**$3,065,578**	**$4,239,629**
[1/]Includes truck and rail costs associated with the complete movement.			

Table 43 Average Annual Property Damages due to Lock Closure

	Average
Water[1/]	$148,822
Rail	$274,262
Truck	$1,083,718
Incremental	**$1,209,158**
[1/]Includes truck and rail costs associated with the complete movement.	

D.3.5.7.3 Nonstructural Impacts

For clarity, it should be noted that there is no diverted traffic or safety impacts associated with the nonstructural alternative.

D.3.6 Impacts to Non-Cargo Navigation due to GLMRIS-BR Alternatives

The alternative plans considered in the GLMRIS-BR, if selected, could also impact non-cargo navigation users of Brandon Road Lock, during construction and/or post-construction when new operating parameters would be imposed. Some of these user groups include: passenger boats and ferries, federal government vessels, non-federal government, and recreation vessels. These non-cargo users of BRLD are few in number; Table 44 presents the number of lockages through BR by non-cargo user group for years 2006 through 2015.

Table 44 Brandon Road Lock: Non-Cargo Lockages by Vessel Type (2006-2015)

Non-Cargo Vessel Type	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Federal Government Vessel	23	62	20	42	24	9	8	10	16	11
Non-federal Government Vessel	2	2	5	6	2	2	-	-	-	-
Other	-	-	-	-	-	-	1	-	-	-
Passenger Boat or Ferry	2	2	-	2	3	2	-	-	-	-
Recreational Vessels	1,018	1,013	755	808	718	628	677	555	442	536
Total	**1,045**	**1,079**	**780**	**858**	**747**	**641**	**686**	**565**	**458**	**547**

As previously identified, the final array of GLMRIS-BR alternatives include the following:

- No New Federal Action;
- Nonstructural Alternative;
- Technology Alternative –Electric Barrier;
- Technology Alternative – Complex Noise;
- Technology Alternative – Complex Noise with Electric Barrier; and
- Lock Closure.

A qualitative assessment was completed to characterize how each alternative plan would impose new challenges for non-cargo navigation users of BRLD. As previously described, the final array of alternative plans includes the No New Federal Action and combinations of one or more structural and/or nonstructural ANS control measures, including the following: nonstructural measures; engineered channel; water jets; complex noise; electric barrier; flushing lock; and lock closure.

To describe if and how these ANS control measures would impact non-cargo users of BRL, a few simplifying assumptions were utilized. These assumptions are consistent with those used in the GLMRIS Report's *Future With-Project Assessment of Non-Cargo Chicago Area Waterway System (CAWS) Traffic* (October 2013), and include:

- Historical traffic forms the basis for estimates of future traffic (i.e., approximate number of users affected). As such the number of non-cargo users wanting to use BRLD will not diminish as a result of implementation of any of these alternatives;
- Non-structural measures currently under consideration will not interfere with non-cargo vessel operations;
- Electric barrier measures operating parameters are the same as the current electric dispersal barriers located in Romeoville, Illinois.
-

D.3.6.1 Description of Impacts on Non-Cargo Users of Brandon Road Lock

A description of impacts to non-cargo users given the implementation of the ANS control measures included in each alternative is based on best available information. The impacts will continue to be informed by the physical model of the flushing lock completed to support the design and optimization of operating parameters ; any new information about the ANS control technologies; and the U.S. Coast Guard (USGS) and USACE evaluation of the operation of new ANS control technologies and subsequent navigation regulation.

No New Federal Action (No Action) Alternative

This plan does not consist of any new ANS controls measures, and therefore does not impose impacts on non-cargo navigation users of BRL.

Nonstructural Alternative

This plan does not consist of any structural ANS controls measures. Consistent with the projections made for the commercial cargo navigation analysis, additional nonstructural measures do not impose impacts on non-cargo navigation users of BRL.

Technology Alternatives

Technology Alternatives include a higher level of effort for nonstructural measures compared to the No Action Alternative. Consistent with the projections made for the commercial cargo navigation analysis, this increased effort does not impose impacts on non-cargo navigation users of BRL.

The following structural ANS control measures are included in one or more of the technology alternatives: (1) flushing lock; (2) engineered channel; (3) complex noise; (4) electric barrier; and (5) water jets. Mooring cells is a supporting measure for the Technology Alternative – Electric Barrier and Technology Alternative – Complex Noise with Electric Barrier. Boat launches are a supporting measure for all alternatives except for the No New Federal Action. Figure 10 displays an aerial view of Brandon Road Lock with outlines of the proposed measure locations. Restrictions imposed on non-cargo users of BRLD during the construction, operation, and periods of maintenance, repair, replacement, and rehabilitation of any given alternative are consistent with those projected for commercial cargo navigation users. An abbreviated summary of these restrictions to all navigation users of Brandon Road Lock during the construction of these ANS controls is provided below, along with a description of impacts unique to non-cargo navigation users.

Flushing Lock

Construction. Construction of the flushing lock would occur at the beginning of the construction period and take approximately 40 days to construct. These 40 days of construction require a complete, scheduled lock closure. The impact to non-cargo navigation at BRLD would be the inability to transit the lock during this shutdown.

Operation. The overall flushing process, as assumed for the navigation analyses, requires that vessels approaching the lock wishing to pass from the Dresden Island pool to the Brandon Road pull will approach the lock as usual, tie off to the long wall on the right-descending bank, and wait for the lock chamber to flush. Once the flushing process has completed, the vessel will untie from the wall and enter the chamber to process normally. T The impact to non-cargo navigation at BRLD could include increased wait times due to accommodate flushing procedures and depending on the results of the physical model and operating evaluation, the staging of these vessels farther downstream of the lock due to exiting flows from the lock.

Engineered Channel

Construction. An engineered channel is included as a part of each technology alternative. The engineered channel is the main construction item of the technology alternatives evaluated in this analysis. The construction begins concurrently with the flushing lock and takes approximately 909 days to complete. Concurrent with the 960-hour (40-day) closure for flushing lock implementation, construction crews will be constructing the section of the engineered channel closest to the lock chamber to minimize the impact to navigation once the lock reopens. After this 960-hour (40-day) closure, the lock will be unavailable 12 hours per day for the next 30 days, or 360 hours, so that construction crews can complete the engineered channel near the lock to the point that the remainder of the construction can be completed with minimal navigation impacts. After the 360-hour (30 day) intermittent closure event, the lock will operate normally throughout the remainder of construction, aside from periodic closures totaling to 8 hours of closure per week. The impact to non-cargo navigation would be the inability to transit the lock during these shutdown times.

Operation. Post implementation of the engineered channel, there are no operational changes identified from operating the engineered channel in and of itself. There are no associated impacts to non-cargo navigation.

Fish Entrainment (Water Jets)

Construction. Water jets are included in the construction of the engineered channel, and do not impose a unique set of restrictions during construction, and do not impose restrictions on navigation during their post-construction operation. There are no associated impacts to non-cargo navigation.

Operation. Water jets are included in the construction of the engineered channel, and do not impose a unique set of restrictions during construction, and do not impose restrictions on navigation during their post-construction operation. To date, the physical model testing of water jets has focused on modeling large, heavy cargo navigation vessels. However, the preliminary assumption is that water jets would be turned off while non-cargo vessels pass by them, and therefore, this ANS control will not impact non-cargo navigation. This is a preliminary assumption pending the operation evaluation and development of water jet operational parameters.

Complex Noise

Construction. Construction of the complex noise system is assumed to be the final construction activity in this analysis. For alternatives including the complex noise system, speaker installation is expected to take approximately 45 calendar days to complete. During this implementation phase, the lock will be closed for approximately 8 hours per day, 5 days a week. The impact to non-cargo navigation would be the inability to transit the lock during these shutdown times.

Operation. The complex noise system, once implemented, is not anticipated to have an impact on navigation through Brandon Road Lock. The speakers will require periodic maintenance and replacement, but such activities are projected to be both random and minor, and are therefore not captured in this analysis. Based on a current understanding of the technology, it is assumed that the operation of complex noise will not impose impacts to non-cargo users.

Electric Barrier

Construction. Implementation of the electric barrier requires work by divers to complete electrode and parasitic placement. This work requires the lock to be shut down for 8 hours per day, 5 days per week for a construction period of approximately 22 calendar days. In alternatives with both an electric barrier (D) and a complex noise system (C), the implementation of the measures are assumed to occur concurrently. The electric barrier is projected to have a design life of approximately 25 years, therefore this analysis assumes the system will have to be rehabilitated every 25 years throughout the planning horizon. This rehabilitation is projected to require the same downtime period as the implementation, so the rehabilitation is considered to occur within 22 calendar days and require 8 hour per day closures, 5 days per week. The impact to non-cargo navigation would be the inability to transit the lock during these shutdown times.

Operation. Two operating parameters were considered for the electric barrier: intermittent and continuous operating parameters. See Chapter 6 of the main report for more information regarding operating parameters.

***Operation - Intermittent Electric Barrier*.** For alternatives that include two swimmer controls, electric barrier and complex noise, the electric barrier was assumed to be turned off while vessels were approaching the downstream channel, while they were in the channel, and while they were in the lock. The second swimmer control would be available when the electric barrier was off. By shutting off the electric barrier in the presence of vessels, the navigation restrictions for a continuous electric barrier are assumed to be avoided, and navigation is assumed to not be appreciably altered.

***Operation - Continuous Electric Barrier*.** As noted above, assumptions regarding operating parameters were developed with the intention of being protective of life safety. If an alternative is implemented, USACE and USCG would test and evaluate measures included in the alternative to address site-specific operating considerations that cannot be addressed until after construction. These assumptions may or may not be a more restrictive than what would actually be imposed under a continuously operated electric barrier.

It is assumed that USCG restrictions on non-cargo navigation vessels transiting through a continuously operating electric barrier at BRL would be similar to USCG restrictions imposed on vessels transiting through the Chicago Sanitary and Ship Canal Electric Dispersal Barrier. Those restrictions are:

- Vessels that are 20-feet or less in length may not pass through the electric barriers.
- Kayaks may not pass through the electric barriers.
- Yachts and sailboats of sufficient length may pass through the electric barriers provided other operating criteria are met.
- All non-cargo users transiting the barrier would have to be inside the cabin.

Mooring Cells for Downstream Approach Channel

Construction. Mooring cells would be constructed for technology alternatives that include an electric barrier. These mooring cells are projected for construction south of the lock away from the main approach area. They are not predicted to have any impact on navigation during construction. There are no associated impacts to non-cargo navigation.

Operation. Mooring cells are intended to help alleviate impacts of potential new navigation restrictions that could arise given the operation of an electric barrier in the BRLD downstream approach channel. There are no associated impacts to non-cargo navigation.

Boat Launches for Downstream Approach Channel

Navigation Considerations During Construction of Boat Launches. Construction of the boat launches are not expected to have any impact on non-cargo navigation.

Navigation Considerations for Operation of Boat Launches. The boat launches are not anticipated to have an impact on non-cargo navigation through Brandon Road Lock.

Lock Closure Alternative

Permanent lock closure is solely included in the Lock Closure alternative. This ANS control measure would result in the following impacts on the various non-cargo users of BRLD:

Federal Government Vessels. The Marine Safety Unit Chicago has 53 active duty, reserve, and civilian personnel conducting armed port security patrols, inspecting commercial vessels, conducting pollution and marine casualty investigations, enforcing safety zones, conducting waterfront facility exams for regulatory compliance, and other Homeland Security missions. Marine Safety Unit Chicago would have to modify their operations to maintain the same level of service in this basin separation alternative. USACE vessels include debris collectors, tenders, dredge vessels, research vessels, survey and patrol vessels, towboats, and multiple types of barges. USACE would also have to modify its operations to maintain the same level of service. Lock closure would prevent transfer of maintenance equipment. All agencies operating on water would have to modify operations and/or increase costs to maintain same level of service.

The Lock Closure alternative could result in additional impacts that are not quantified in the GLMRIS-BR Report. As one example, the locks upstream of Brandon Road Lock, Lockport, T.J. O'Brien and Chicago utilize USACE maintenance barges and cranes that originate from the Illinois Waterway System. A crane is needed to dewater the locks, which occurs approximately every 10 years, and to perform other larger-scale maintenance. If Brandon Road Lock was closed, these locks would be required to obtain those services via rental contracts or from USACE facilities located along the Great Lakes; thereby, increasing the costs of lock maintenance.

Non-Federal Government Vessels. Chicago Police, Fire Departments, and all other rescue boats would need to change operations to maintain the same level of service. This could entail having duplicate services (i.e. boats, divers, equipment) on both sides of the four concrete dams. Illinois Department of Natural Resources (IDNR) would need to modify and/or enhance their current management, protection, and sustainability program to account for the separation of the water bodies.

Recreational Vessels. All recreational vessels would no longer be able to transit the lock.

D.4 Average Annual Cost of Alternative Plans

Aside from the No New Federal Action plan, each plan considered in the GLMRIS-BR is a combination of nonstructural and/or structural ANS control measures, as a way to prevent the upstream transfer of ANS from the MRB to the GLB through the Chicago Area Waterways in the vicinity of BRLD. Table 45 identifies the ANS control measures included in each alternative. The final array alternative plans include:

- No New Federal Action;
- Nonstructural Alternative;
- Technology Alternative – Continuous Electric Barrier;
- Technology Alternative – Complex Noise;
- Technology Alternative – Complex Noise with Electric Barrier; and
- Lock Closure.

Table 45 Review of ANS Control Measures and Features per Alternative Plan

GLMRIS-BR Alternative	ANS Control Measures/Features									
	Sustained Current Activities	Nonstructural	Boat Launches	Flushing Lock	Engineered Channel	Water Jets	Complex Noise	Electric Barrier	Mooring Cells	Lock Closure
No New Federal Action	×									
Nonstructural Alternative	×	×	×							
Technology Alternative – Electric Barrier	×	×	×	×	×	×		×	×	
Technology Alternative – Complex Noise	×	×	×	×	×	×	×			
Technology Alternative – Complex Noise with Electric Barrier	×	×	×	×	×	×	×	×	×	
Lock Closure	×	×	×							×

In order to estimate the average annual cost (AAC) of each alternative plan, a schedule of the costs required for the construction and/or operation of each ANS control measure was developed in collaboration with the GLMRIS-BR Engineering Team. Aside from the No New Federal Action plan, each alternative includes nonstructural measures. The Lock Closure and Technology Alternatives also include structural ANS control measures and/or features. Estimates of AAC were developed for each of the six GLMRIS-BR alternatives. These estimates reflect a careful consideration of the ANS control measures and associated costs that will be required for each plan to achieve its identified level of risk reduction. A summary of the types of costs that are included in each plan is presented below.

Costs for No New Federal Action Alternative

- This plan does not consist of any costs above those that are expected to occur in absence of implementing a GLMRIS-BR alternative.

Costs for Nonstructural Alternative

- Nonstructural measures;
- Monitoring and adaptive management;
- Construction, preconstruction engineering and design (PED), and construction management (CM) for 2 boat launches; and
- Operation, maintenance, repair, replacement, and rehabilitation (OMRR&R) for the boat launches.

Costs for Technology Alternative – Electric Barrier

- Nonstructural measures;
- Real estate acquisition;
- Construction, PED, and CM for the engineered channel, water jets, electric barrier, 4 mooring cells, 2 boat launches, and the flushing lock;
- Mitigation during construction
- Monitoring and adaptive management; and
- OMRR&R.

Costs for Technology Alternative – Complex Noise

- Nonstructural measures;
- Real estate acquisition;
- Construction, PED, and CM for the engineered channel, water jets, complex noise, 2 boat launches, and the flushing lock;
- Mitigation during construction
- Monitoring and adaptive management; and
- OMRR&R.

Costs for Technology Alternative – Complex Noise with Electric Barrier

- Nonstructural measures;
- Real estate acquisition;
- Construction, PED, and CM for the engineered channel, water jets, complex noise, electric barrier, 4 mooring cells, 2 boat launches, and the flushing lock;
- Mitigation during construction
- Monitoring and adaptive management; and
- OMRR&R.

Costs for Lock Closure Alternative

- Nonstructural measures, and
- Construction, PED, and CM for 2 boat launches and lock closure; and
- OMRR&R for the boat launches.

D.4.1 Overview of Costs for Nonstructural and Structural ANS Control Measures and Features

The following sections provide a summary of the cost estimates provided by the GLMRIS-BR Engineering Team. Each nonstructural and structural ANS control measure/feature described is included in one or more alternative plans.

D.4.1.1 Nonstructural Measures

Aside from the No New Federal Action Plan, nonstructural measures are included as a part of all alternatives. Nonstructural measures do not require construction of a permanent feature. Examples include but are not limited to: electrofishing and netting. The annual level of effort for these measures varies across alternatives. Nonstructural ANS controls would begin in FY2021 and continue through the 50-year period of analysis. Table 46 displays the nonstructural measures and associated costs for each alternative.

Table 46 Summary of Nonstructural Measures, Costs, and Schedule per Alternative

Alternative	Nonstructural ANS Controls[1/]	Schedule and Cost[2/]
No New Federal Action	NA	NA
Nonstructural Alternative	**PY1-50:** Current MRP + monitoring for scud. Double overfishing effort every year and triple every 2 years.	**PY1:** \$10,710,000 **PY2:** \$12,210,000 Repeat until PY50
Technology Alternative – Electric Barrier	**PY1-14:** Current MRP + monitoring for scud. Double overfishing effort every year and triple every 2 years. **PY15-50:** Triple overfishing every 3 years.	**PY1:** \$10,710,000 **PY2:** \$12,210,000 Repeat though PY14 **PY15:** \$10,710,000 **PY16:** \$10,710,000 **PY17:** \$12,210,000 Repeat through PY50
Technology Alternative – Complex Noise	**PY1-14:** Current MRP + monitoring for scud. Double overfishing effort every year and triple every 2 years. **PY15-50:** Triple overfishing every 3 years.	**PY1:** \$10,710,000 **PY2:** \$12,210,000 Repeat though PY14 **PY15:** \$10,710,000 **PY16:** \$10,710,000 **PY17:** \$12,210,000 Repeat through PY50
Technology Alternative – Complex Noise with Electric Barrier	**PY1-14:** Current MRP + monitoring for scud. Double overfishing effort every year and triple every 2 years. **PY15-50:** Triple overfishing every 3 years.	**PY1:** \$10,710,000 **PY2:** \$12,210,000 Repeat though PY14 **PY15:** \$10,710,000 **PY16:** \$10,710,000 **PY17:** \$12,210,000 Repeat through PY50
Lock Closure	**PY1-13:** Current MRP + monitoring for scud. Double overfishing effort every year and triple every 2 years. **PY14-50:** Reduce overfishing to 2016 levels and reduce R&D funding.	**PY1:** \$10,710,000 **PY2:** \$12,210,000 Repeat through PY13 **PY14-50:** \$7,720,000

[1/]MRP indicates the monitoring and response plan that is currently in place. Details about the MRP and additional nonstructural measures are included in Chapter 2 of the main report.
[2/]All costs presented in FY16 price levels. Project year 1 (PY1) corresponds with FY2021. Cost estimates reflect those above anticipated expenditures given the No New Federal Action plan.

D.4.1.2 Real Estate Acquisition

The Technology Alternatives require the acquisition of real estate. The proposed project footprint includes privately owned lands. This property has been identified as the location to temporarily stage construction materials and equipment; to dewater sediment; to temporarily store the blasted rock from the approach channel awaiting reuse; and to permanently house the ancillary buildings and other support features for the TSP. As of the date of this report, a Phase II Environmental and Geotechnical Investigation has not been completed. The estimated real estate costs do not include costs for possible regulatory coordination and response action. This cost is estimated at $206,000 for each Technology Alternative, and would be incurred in FY21 (the first year of PED).

Table 47 Summary of Real Estate Acquisition Costs for GLMRIS-BR Technology Alternatives

Alternative	Fiscal Year	Real Estate Acquisition Cost[1/]
Technology Alternative – Electric Barrier	2021	$206,000
Technology Alternative – Complex Noise	2021	$206,000
Technology Alternative – Complex Noise with Electric Barrier	2021	$206,000

[1/]All costs presented in FY16 price levels and rounded to the nearest thousand. Details about real estate costs are included in the GLMRIS-BR Real Estate Appendix.

D.4.1.3 Boat Launches

In order to facilitate effective monitoring and emergency response actions in the area of Brandon Road, two new boat launches would be installed (1 upstream and 1 downstream) of BRLD. The boat launches are included in each GLMRIS-BR alternative, aside from the No New Federal Action plan. Table 48 provides a summary of the construction schedule and costs for the two (2) boat launches in each relevant alternative.

Table 48 Summary of Schedule and Costs for Boat Launches for GLMRIS-BR Alternatives

GLMRIS-BR Alternative	Construction Begins (Month & Year)[1/]	Construction Ends (Month & Year)	Total Cost[2/]
Nonstructural Alternative	December 2022	May 2023	$516,000
Technology Alternative – Electric Barrier	December 2022	May 2023	$516,000
Technology Alternative – Complex Noise	December 2022	May 2023	$516,000
Technology Alternative–Complex Noise with Electric Barrier	December 2022	May 2023	$516,000
Lock Closure Alternative	December 2022	May 2023	$516,000

[1/]Details about the cost and schedule for the water jets are included in the GLMRIS-BR Cost Appendix.
[2/]All costs presented in FY16 price levels and rounded to the nearest thousand. Cost estimate displayed in this column does include PED or CM costs.

D.4.1.4 Flushing Lock

The purpose of the flushing lock is to prevent the transfer of floating life stages of ANS by flushing them out of the lock when the lock is at the lower pool prior to a lockage. Vessels are staged downstream on the right descending bank when water from the upper pool (Brandon Road Pool) is diverted through the lock filling and emptying culverts and through open downstream miter gates to flush the lock chamber. A flushing lock is included as a part of each technology alternative. Modifications will be made to Brandon Road Lock in order to facilitate this ANS control measure; the associated construction activities would span approximately 2 months in FY23. A summary of the construction schedule and costs for the flushing lock as a part of each technology alternative is presented in Table 49.

Table 49 Summary of Schedule and Costs for Flushing Lock for GLMRIS-BR Technology Alternatives

GLMRIS-BR Alternative	Construction Begins (Month & Year)[1/]	Construction Ends (Month & Year)	Total Cost[2/]
Technology Alternative – Electric Barrier	December 2022	January 2023	$1,329,000
Technology Alternative – Complex Noise	December 2022	January 2023	$1,329,000
Technology Alternative–Complex Noise with Electric Barrier	December 2022	January 2023	$1,329,000

[1/]Details about the cost and schedule for the water jets are included in the GLMRIS-BR Cost Appendix.
[2/]All costs presented in FY16 price levels and rounded to the nearest thousand. Cost estimate displayed in this column does include PED or CM costs.

D.4.1.5 Engineered Channel

An engineered channel is included as a part of each technology alternative, and serves as a platform for other ANS control technologies such as water jets, an electric barrier and/or complex noise. Construction of the engineered channel will begin in December 2022. The completion date varies by alternative to account for the construction activities required to accommodate the other aforementioned ANS controls. A summary of the construction schedule and costs for the engineered channel portion of each alternative is included in Table 50.

Table 50 Summary of Schedule and Costs for Engineered Channel for GLMRIS-BR Technology Alternatives

GLMRIS-BR Alternative	Construction Begins (Month & Year)[1/]	Construction Ends (Month & Year)	Total Cost[2/]
Technology Alternative – Electric Barrier	December 2022	September 2024	$62,375,000
Technology Alternative – Complex Noise	December 2022	May 2025	$84,126,000
Technology Alternative – Complex Noise with Electric Barrier	December 2022	September 2024	$62,375,000

[1/]Details about the cost and schedule for the engineered channel are included in the GLMRIS-BR Cost Appendix.
[2/]All costs presented in FY16 price levels and rounded to the nearest thousand. Cost estimate displayed in this column does include PED or CM costs. The cost of the engineered channel for the Technology Alternative – Complex Noise is accounted for differently than the technology alternatives that include an electric barrier. For the technology alternatives with an electric barrier, the cost for the portion of the engineered channel with the electric barrier is attributed to the electric barrier rather than the engineered channel. For Technology Alternative – Complex Noise, the entire length of the engineered channel is represented as a single estimate.

D.4.1.6 Fish Entrainment Mitigation (Water Jets)

Water jets would be attached to the channel bottom and be used to remove or dislodge fish from up-bound tows must contend with vessel-induced motion that transports fish along with the vessel. Water jets are included in all technology alternatives. Construction of the water jets would span approximately 2 months in FY23. The construction start and end dates were identified by the GLMRIS-BR Engineering Team. Table 51 provides a summary of the construction schedule and costs for the water jets in each technology alternative.

Table 51 Summary of Schedule and Costs for Water Jets for GLMRIS-BR Technology Alternatives

GLMRIS-BR Alternative	Construction Begins (Month & Year)[1/]	Construction Ends (Month & Year)	Total Cost[2/]
Technology Alternative – Electric Barrier	December 2022	January 2023	$2,809,000
Technology Alternative – Complex Noise	December 2022	January 2023	$2,809,000
Technology Alternative – Complex Noise with Electric Barrier	December 2022	January 2023	$2,809,000

[1/]Details about the cost and schedule for the water jets are included in the GLMRIS-BR Cost Appendix.

2/All costs presented in FY16 price levels and rounded to the nearest thousand. Cost estimate displayed in this column does include PED or CM costs.

D.4.1.7 Complex Noise

Speakers for the complex noise measure would be installed within the downstream approach channel and/or the Brandon Road lock chamber. The purpose of complex noise is to allow for vessel transportation while reducing the risk to the maximum extent possible of Asian carp transferring during lockages. Complex noise is included in the following plans: Technology Alternative – Complex Noise, and Technology Alternative – Complex Noise with Electric Barrier. The placement of speakers for this ANS control will span approximately 2 months in FY25. A summary of the construction schedule and costs for speaker placement in each alternative with complex noise is included in Table 52.

Table 52 Summary of Schedule and Costs for Speaker Placement (Complex Noise)

GLMRIS-BR Alternative	Construction Begins (Month & Year)1/	Construction Ends (Month & Year)	Total Cost2/
Technology Alternative – Complex Noise	May 2025	June 2025	$3,733,000
Technology Alternative – Complex Noise with Electric Barrier	May 2025	June 2025	$3,733,000
1/Details about the cost and schedule for speaker placement are included in the GLMRIS-BR Cost Appendix. 2/All costs presented in FY16 price levels and rounded to the nearest thousand. Cost estimate displayed in this column does include PED or CM costs.			

D.4.1.8 Electric Barrier

An electric dispersal barrier consists of steel electrodes mounted across the floor of the downstream approach channel and on-land power generation and distribution equipment. The electric barrier was determined to be the most effective technology for preventing fish passage, not including physical barriers. An electric dispersal barrier would be located within the approach channel downstream of Brandon Road Lock and Dam at the southernmost end of the approach channel to minimize safety concerns for tow and barge personnel, as well as lock personnel, and influence of the electric dispersal barrier on the lock structure.

An electric barrier is included in the following plans: Technology Alternative – Electric Barrier, and Technology Alternative – Complex Noise with Electric Barrier. For both alternatives, construction of the electric barrier would begin in FY24 and end in FY25. The construction start and end dates were identified by the GLMRIS-BR Engineering Team. The construction of this feature spans multiple fiscal years. While the total cost was identified, the allocation of costs per fiscal year is not yet confirmed. To facilitate the AAC estimate, costs were allocated to each fiscal year to reflect the proportion of construction (months) completed in the given fiscal year relative to the total months of construction. Table 53 provides a summary of the construction schedule and costs for the electric barrier in each relevant alternative.

Table 53 Summary of Schedule and Costs for Electric Barrier for GLMRIS-BR Alternatives

GLMRIS-BR Alternative	Construction Begins (Month & Year)1/	Construction Ends (Month & Year)	Total Cost2/
Technology Alternative – Electric Barrier	September 2024	June 2025	$135,545,000
Technology Alternative – Complex Noise with Electric Barrier	September 2024	June 2025	$139,215,000
1/Details about the cost and schedule for the electric barrier are included in the GLMRIS-BR Cost Appendix. 2/All costs presented in FY16 price levels and rounded to the nearest thousand. Cost estimate displayed in this column does include PED or CM costs.			

D.4.1.9 Mooring Cells

The two technology alternatives that include an electric barrier (Technology Alternative – Electric Barrier and Technology Alternative – Complex Noise with Electric Barrier) also include four new mooring cells. The addition of these features are intended to help alleviate impacts of potential new navigation restrictions that could arise given the operation of an electric barrier in the BRLD downstream approach channel. The construction of these mooring cells would begin in FY 2024 and be completed in FY2025. A summary of the construction schedule and costs for the four mooring cells is presented in Table 54.

Table 54 Summary of Schedule and Costs for Downstream Approach Channel Mooring Cells for GLMRIS-BR Alternatives

GLMRIS-BR Alternative	Construction Begins (Month & Year)[1/]	Construction Ends (Month & Year)	Total Cost[2/]
Technology Alternative – Electric Barrier	September 2024	June 2025	$21,761,000
Technology Alternative – Complex Noise with Electric Barrier	September 2024	June 2025	$21,761,000

[1/]Details about the cost and schedule for the mooring cells are included in the GLMRIS-BR Cost Appendix.
[2/]All costs presented in FY16 price levels and rounded to the nearest thousand. Cost estimate displayed in this column does include PED or CM costs.

D.4.1.10 Lock Closure (ANS Control Measure)

Lock closure involves the removal of the upstream operational gates from the Brandon Road Lock and replaces them with a permanent concrete wall that ties into the existing concrete gate sill and existing lock walls to structurally separate the upper pool from the lower pool. Permanent lock closure is solely included in the Lock Closure alternative. Construction would span approximately 2 months in FY23. A summary of the construction schedule and costs for lock closure is presented in Table 55.

Table 55 Summary of Schedule and Costs for Lock Closure (ANS Control Measure)

GLMRIS-BR Alternative	Construction Begins (Month & Year)[1/]	Construction Ends (Month & Year)	Total Cost[2/]
Lock Closure	December 2022	December 2023	$2,412,000

[1/]Details about the cost and schedule for lock closure are included in the GLMRIS-BR Cost Appendix.
[2/]All costs presented in FY16 price levels and rounded to the nearest thousand. Cost estimate displayed in this column does include PED or CM costs.

D.4.1.11 Mitigation During Construction

Each technology alternative and the Lock Closure alternative also include mitigation activities for project area impacts. These mitigation activities would span across the construction period for each alternative. The mitigation costs are estimated at $2,500,000 (2016 price level) for each alternative. For technology alternatives, these activities and costs will be distributed evenly across the three fiscal years in which construction occurs (FY23-25). For the Lock Closure alternative, these activities and costs ($2,500,000) will occur in the year that construction occurs (FY23).

D.4.1.12 Monitoring and Adaptive Management

Each GLMRIS-BR alternative (aside from the No New Federal Action and Nonstructural plans) also consist of monitoring and adaptive management activities after construction is complete. The total cost for these activities is estimated to be 10% of the total construction cost (prior to discounting) for each alternative. For example, the total construction cost (prior to discounting) for Technology Alternative – Electric Barrier is $224,335,000. Therefore, the cost for monitoring and adaptive management activities for this alternative is derived by the product of $224,335,000 and 0.10 (or 10%); the result is $22,433,500. This total monitoring and adaptive management cost is then distributed across 10 years following construction.

Monitoring and adaptive management costs are not identified for the Nonstructural Alternative because the nonstructural monitoring is already adaptive in nature. The Asian Carp Regional Coordinating Committee Monitoring and Response Workgroup (ACRCC MRWG) convenes on an annual basis to make necessary adjustments to the plan and apply lessons learned. In addition, the MRWG has applied a contingency plan that clearly lays out adaptive measures if AC are found in new locations. This alternative does not include the implementation of a control point that requires performance monitoring and adaptive management.

Table 56 Monitoring and Adaptive Management Costs for Technology Alternative – Electric Barrier

FY	Technological Monitoring of ANS Control Features	Biological Monitoring	Adaptive Management	Total[1/]
2026	$800,000	$200,000	$1,865,025	$2,865,025
2027	$800,000	$200,000	$1,865,025	$2,865,025
2028	$800,000	$200,000	$1,865,025	$2,865,025
2029	$800,000	$200,000	$1,865,025	$2,865,025
2030	$800,000	$200,000	$932,513	$1,932,513
2031	$800,000	$200,000	$932,513	$1,932,513
2032	$800,000	$200,000	$932,513	$1,932,513
2033	$800,000	$200,000	$932,513	$1,932,513
2034	$800,000	$200,000	$621,675	$1,621,675
2035	$800,000	$200,000	$621,675	$1,621,675
Total	**$8,000,000**	**$2,000,000**	**$12,433,500**	**$22,433,500**
[1/]Additional information is located in Monitoring and Adaptive Management Appendix.				

Table 57 Monitoring and Adaptive Management Costs for Technology Alternative – Complex Noise

FY	Technological Monitoring of ANS Control Features	Biological Monitoring	Adaptive Management	Total[1/]
2026	$100,000	$200,000	$937,695	$1,237,695
2027	$100,000	$200,000	$937,695	$1,237,695
2028	$100,000	$200,000	$937,695	$1,237,695
2029	$100,000	$200,000	$937,695	$1,237,695
2030	$100,000	$200,000	$468,848	$768,848
2031	$100,000	$200,000	$468,848	$768,848
2032	$100,000	$200,000	$468,848	$768,848
2033	$100,000	$200,000	$468,848	$768,848
2034	$100,000	$200,000	$312,565	$612,565
2035	$100,000	$200,000	$312,565	$612,565
Total	**$1,000,000**	**$2,000,000**	**$6,251,300**	**$9,251,300**
[1/]Additional information is located in Monitoring and Adaptive Management Appendix.				

Table 58 Monitoring and Adaptive Management Costs for Technology Alternative – Complex Noise with Electric Barrier

FY	Technological Monitoring of ANS Control Features	Biological Monitoring	Adaptive Management	Total[1/]
2026	$900,000	$200,000	$1,826,070	$2,926,070
2027	$900,000	$200,000	$1,826,070	$2,926,070
2028	$900,000	$200,000	$1,826,070	$2,926,070
2029	$900,000	$200,000	$1,826,070	$2,926,070
2030	$900,000	$200,000	$913,035	$2,013,035
2031	$900,000	$200,000	$913,035	$2,013,035
2032	$900,000	$200,000	$913,035	$2,013,035
2033	$900,000	$200,000	$913,035	$2,013,035
2034	$900,000	$200,000	$608,690	$1,708,690
2035	$900,000	$200,000	$608,690	$1,708,690
Total	**$9,000,000**	**$2,000,000**	**$12,173,800**	**$23,173,800**

[1/]Additional information is located in Monitoring and Adaptive Management Appendix.

Table 59 Monitoring and Adaptive Management Costs for Lock Closure Alternative

FY	Technological Monitoring of ANS Control Features	Biological Monitoring	Adaptive Management	Total[1/]
2026	-	$97,600	-	$97,600
2027	-	-	-	-
2028	-	-	-	-
2029	-	-	-	-
2030	-	$97,600	-	$97,600
2031	-	-	-	-
2032	-	-	-	-
2033	-	-	-	-
2034	-	-	-	-
2035	-	$97,600	-	$97,600
Total	-	**$292 ,800**	-	**$292 ,800**

[1/]For this alternative, biological monitoring would begin upon the permanent closure of Brandon Road Lock (FY21; project authorization). Additional information is located in Monitoring and Adaptive Management Appendix.

D.4.1.13 Operation, Maintenance, Repair, Rehabilitation, and Replacement (OMRR&R)

Each GLMRIS-BR alternative (aside from No New Federal Action) requires operation, maintenance, repair, replacement, and rehabilitation (OMRR&R) of one or more ANS control measures/features that will begin once construction is complete (FY25) and continue until the end of the 50-year project evaluation period (FY70). Annual O&M activities and costs vary for each alternative plan. Periodic RR&R of some equipment will also take place. Table 60 summarizes the annual O&M costs, while Table 61 displays the RR&R costs.

Table 60 Summary of Annual O&M Costs for Alternative Plans

Alternative	Annual O&M Costs[1/]					
	Electric Barrier	Water Jets	Complex Noise[2/]	Flushing Lock	Boat Launches	Total
Nonstructural Alternative	-	-	-	-	$20,000	**$20,000**
Technology Alternative – Electric Barrier	$7,000,000	$500,000	-	$300,000	$20,000	**$7,820,000**
Technology Alternative – Complex Noise	-	$500,000	$800,000	$300,000	$20,000	**$1,620,000**
Technology Alternative – Complex Noise with Electric Barrier	$7,000,000	$500,000	$500,000	$300,000	$20,000	**$8,320,000**
Lock Closure	-	-	-	-	$20,000	**$20,000**

[1/] O&M costs will begin once construction of the given alternative is complete and will occur annually until the end of the 50-year project evaluation period (FY70). A description of how annual O&M costs were calculated for each ANS control measure or feature is located in the GLMRIS-BR Cost Appendix.
[2/]For the Technology Alternative – Complex Noise with Electric Barrier, the staff for the electric barrier is also assumed to operate the complex noise system. In the Technology Alternative – Complex Noise, additional staff will be needed at the site to run the system; 2 full time employees are assumed at $150,000 for an additional $300,000.

Table 61 Summary of RR&R Costs for Technology Alternatives

Alternative[1/]	**Electric Barrier**		**Mooring Area**	**Water Jets**	**Complex Noise**	
	Replace Electrical Equipment	Replace Electrodes	Dredge 20,000cy	Replace Pumps	Replace Speakers	Total
Technology Alternative – Electric Barrier	$12,000,000 (FY35, FY45, FY55, FY65)	$3,700,000 (FY50)	$10,000,000 (FY50)	$300,000 (FY40, FY55, FY70)	-	**$26,000,000**
Technology Alternative – Complex Noise	-	-	-	$300,000 (FY40, FY55, FY70)	$300,000 (FY40, FY55, FY70)	**$600,000**
Technology Alternative – Complex Noise with Electric Barrier	$12,000,000 (FY35, FY45, FY55, FY65)	$3,700,000 (FY50)	$10,000,000 (FY50)	$300,000 (FY40, FY55, FY70)	$300,000 (FY40, FY55, FY70)	**$26,300,000**

[1/]A description of how the RR&R costs were calculated for each ANS control measure or feature is located in the GLMRIS-BR Cost Appendix. There are no RR&R costs for the No New Federal Action, Nonstructural, or Lock Closure Alternatives.

D.4.2 Estimates of AAC for Alternative Plans

In order to facilitate the comparison of these alternatives, an estimate of the total project cost (present value) and the associated AAC for each plan was developed. All project costs were identified for the 50-year period of analysis, the first project year (PY1) being Fiscal Year 2021 (FY21). The GLMRIS-BR Cost Appendix outlines how cost estimates were derived for each plan. The project cost time stream was converted to an average annual value using a 50-year period of analysis, the FY2017 Federal discount rate (FDR) of 2.875 percent, and FY2016 price levels. The annuity factor is determined by utilizing the FY2017 Federal discount rate of 2.875% and FY2016 price levels. It is used to derive average annual costs (AAC). These economic values are displayed in Table 62.

Table 62 Economic Values Used for AAC Estimation

Period of Analysis	Project Year 1 (PY1)	Project Year 50 (PY50)	Federal Discount Rate (FDR)	Discount Rate	Annuity Factor
50 Years	FY 2021	FY 2070	FY17	2.875%	.0379

The following schedule and cost assumptions were utilized for each structural ANS control measure.

Construction Schedule. The construction start and end dates were identified by the GLMRIS-BR Engineering Team. The construction of several features span multiple fiscal years. While the total cost was identified, the allocation of costs per fiscal year is not yet confirmed. To facilitate the AAC estimate, costs were allocated to each fiscal year to reflect the proportion of construction (months) completed in the given fiscal year relative to the total months of construction. For example, since construction of the engineered channel for the Technology Alternative – Electric Barrier is approximately 22 months, beginning in December 2022 and ending in September of 2024. Since 10 months of the 22 months of construction occur in FY23 (or 45% of the total construction duration), 45% of the total construction cost for the engineered channel was allocated to FY23 for this alternative. This process was repeated for each structural component of each alternative.

Preconstruction Engineering and Design (PED). In addition to the construction cost, PED costs were accounted for. The PED cost is determined as 17% of construction costs for each structural ANS control measure/feature. PED begins 2 years prior to construction and occurs over the 2 years until construction begins. Fifty percent of the total PED cost is allocated to PED year 1, and the remaining 50% is allocated to PED year 2.

Construction Management (CM). In addition to the construction cost and PED costs, CM were accounted for. This cost is determined as 7% of construction costs incurred for each measure/feature in the given year.

D.4.2.1 AAC Estimate: No New Federal Action

This plan does not consist of any costs above those that are expected to occur in absence of implementing a GLMRIS-BR alternative.

D.4.2.2 AAC Estimate: Nonstructural Alternative

The AAC estimate for the Nonstructural Alternative is presented in Table 63. The following cost components are included this estimate:

- Nonstructural measures;
- Construction, PED, and CM for two (2) boat launches.
- Monitoring and adaptive management; and

Table 63 AAC Estimate for the Nonstructural Alternative

Cost Category	Total Cost *(Prior to Discounting)*	Total Cost *(Present Value)*	AAC[1/]	Rounded AAC[2/]
RE Acquisition	$0	$0	$0	$0
Construction, PED, and CM	$639,840	$591,189	$22,434	$22,000
Mitigation	$0	$0	$0	$0
Monitoring & Adaptive Mngmt.	$0	$0	$0	$0
Nonstructural Measures	$573,000,000	$301,711,437	$11,449,372	$11,449,000
OMRR&R	$960,000	$488,697	$18,545	$19,000
Total	**$574,599,840**	**$302,791,323**	**$11,490,351**	**$11,500,000**

[1/]The annuity factor (0.038) is determined by utilizing the FY2017 Federal discount rate of 2.875% and FY2016 price levels. It is used to derive average annual costs (AAC).
[2/]AAC estimate rounded to nearest thousand.

D.4.2.3 AAC Estimate: Technology Alternative – Electric Barrier

The AAC estimate for the Technology Alternative – Electric Barrier is presented in Table 64. The following cost components are included this estimate:

Table 64 AAC Estimate for Technology Alternative – Electric Barrier

Cost Category	Total Cost *(Prior to Discounting)*	Total Cost *(Present Value)*	AAC[1/]	Rounded AAC[2/]
RE Acquisition	$206,001	$200,244	$7,599	$8,000
Construction, PED, and CM	$278,175,400	$247,352,075	$9,386,538	$9,385,000
Mitigation	$2,500,000	$2,232,631	$84,724	$85,000
Monitoring & Adaptive Mngmt.	$22,433,500	$17,003,194	$645,239	$645,000
Nonstructural Measures	$564,000,000	$297,919,740	$11,305,484	$11,305,000
OMRR&R	$422,320,000	$204,677,070	$7,767,103	$7,767,000
Total	**$1,289,634,901**	**$769,384,954**	**$29,196,686**	**$29,197,000**

[1/]The annuity factor (0.038) is determined by utilizing the FY2017 Federal discount rate of 2.875% and FY2016 price level. It is used to derive average annual costs (AAC).
[2/]AAC estimate rounded to nearest thousand.

D.4.2.4 AAC Estimate: Technology Alternative – Complex Noise

The AAC estimate for the Technology Alternative – Complex Noise is presented in Table 65. The following cost components are included this estimate:

- Nonstructural measures;
- Construction, PED, and CM for the engineered channel, water jets, electric barrier, two (2) boat launches, four (4) mooring cells, and the flushing lock;
- Mitigation during construction
- Monitoring and adaptive management; and
- OMRR&R.

Table 65 AAC Estimate for Technology Alternative – Complex Noise

Cost Category	Total Cost *(Prior to Discounting)*	Total Cost *(Present Value)*	AAC[1/]	Rounded AAC[2/]
RE Acquisition	$206,001	$200,244	$7,599	$8,000
Construction, PED, and CM	$114,716,120	$104,497,558	$3,965,482	$3,965,000
Mitigation	$2,500,000	$2,232,631	$84,724	$85,000
Monitoring & Adaptive Mngmt.	$9,251,300	$7,038,044	$267,080	$267,000
Nonstructural Measures	$564,000,000	$297,919,740	$11,305,484	$11,305,000
OMRR&R	$76,320,000	$37,358,449	$1,417,682	$1,418,000
Total	**$766,993,421**	**$449,246,666**	**$17,048,051**	**$17,048,000**

[1/]The annuity factor (0.038) is determined by utilizing the FY2017 Federal discount rate of 2.875% and FY2016 price level. It is used to derive average annual costs (AAC).
[2/]AAC estimate rounded to nearest thousand.

D.4.2.5 AAC Estimate: Technology Alternative – Complex Noise with Electric Barrier

The AAC estimate for the Technology Alternative – Complex Noise is presented in Table 66. The following cost components are included this estimate:

- Nonstructural measures;
- Construction, PED, and CM for the engineered channel, water jets, complex noise, electric barrier, four (4) mooring cells, 2 boat launches, and the flushing lock;
- Mitigation during construction
- Monitoring and adaptive management; and
- OMRR&R.

Table 66 AAC Estimate: Technology Alternative – Complex Noise with Electric Barrier

Cost Category	Total Cost *(Prior to Discounting)*	Total Cost *(Present Value)*	AAC[1/]	Rounded AAC[2/]
RE Acquisition	$206,001	$200,244	$7,599	$8,000
Construction, PED, and CM	$287,355,120	$255,393,491	$9,691,694	$9,690,000
Mitigation	$2,500,000	$2,232,631	$84,724	$85,000
Monitoring & Adaptive Mngmt.	$23,173,800	$17,548,715	$665,940	$666,000
Nonstructural Measures	$564,000,000	$297,919,740	$11,305,484	$11,305,000
OMRR&R	$446,220,000	$216,342,993	$8,209,802	$8,210,000
Total	**$1,323,454,921**	**$789,637,813**	**$29,965,243**	**$29,965,000**

[1/]The annuity factor (0.038) is determined by utilizing the FY2017 Federal discount rate of 2.875% and FY2016 price level. It is used to derive average annual costs (AAC).
[2/]AAC estimate rounded to nearest thousand.

D.4.2.6 AAC Estimate: Technology Alternative – Lock Closure Alternative

The AAC estimate for the Lock Closure alternative is presented in Table 67. The following cost components are included this estimate:

- Nonstructural measures, and
- Construction, PED, and CM for two (2) boat launches and lock closure.

Table 67 AAC Estimate: Technology Alternative – Lock Closure Alternative

Cost Category	Total Cost *(Prior to Discounting)*	Total Cost *(Present Value)*	AAC[1/]	Rounded AAC[2/]
RE Acquisition	$0	$0	$0	$0
Construction, PED, and CM	$3,630,720	$3,339,367	$126,723	$126,000
Mitigation	$2,500,000	$2,296,204	$87,137	$87,000
Monitoring & Adaptive Mngmt.	$292,800	$253,087	$9,604	$10,000
Nonstructural Measures	$433,870,000	$242,904,970	$9,217,779	$9,218,000
OMRR&R	$960,000	$488,697	$18,545	$19,000
Total	**$441,253,520**	**$249,282,324**	**$9,459,787**	**$9,460,000**

[1/]The annuity factor (0.038) is determined by utilizing the FY2017 Federal discount rate of 2.875% and FY2016 price level. It is used to derive average annual costs (AAC).
[2/]AAC estimate rounded to nearest thousand.

D.4.2.7 Summary of AAC Estimates for the Final Array of GLMRIS-BR Alternatives

Table 68 provides a summary of the AAC estimates for each alternative plan.

Table 68 AAC for Final Array of GLMRIS-BR Alternatives

Cost Category	Total Cost *(Prior to Discounting)*	Total Cost *(Present Value)*	AAC[1/]	Rounded AAC[2/]
No New Federal Action	$0	$0	$0	$0
Nonstructural Alternative	$574,599,840	$302,791,323	$11,490,351	$11,500,000
Technology Alternative – Electric Barrier	$1,289,634,901	$769,384,954	$29,196,686	$29,197,000
Technology Alternative – Complex Noise	$766,993,421	$449,246,666	$17,048,051	$17,048,000
Technology Alternative – Complex Noise with Electric Barrier	$1,323,454,921	$789,637,813	$29,965,243	$29,965,000
Lock Closure	$441,253,520	$249,282,324	$9,459,787	$9,460,000

[1/]The annuity factor (0.038) is determined by utilizing the FY2017 Federal discount rate of 2.875% and FY2016 price level. It is used to derive average annual costs (AAC).
[2/]AAC estimate rounded to nearest thousand.

D.5 References

Bureau of Economic Analysis, 2016. Regional Economic Accounts. U.S. Department of Commerce, Washington, DC.

Bureau of Labor Statistics, 2016. Consumer Price Indexes, March 14, 2016 ed. Bureau of Labor Statistics, Washington, DC.

Bureau of Labor Statistics, 2016. CPI Inflation Calculator. U.S. Department of Labor, Washington, DC.

Christensen, V., C.J. Walters, 2004, Ecopath with Ecosim: methods, capabilities and limitations. Ecological Modelling 172, 109-139.

Coughlin, C.C., T.B. Mandelbaum, 1991, A consumer's guide to regional economic multipliers. Federal Reserve Bank of St. Louis Review 73.

Donnelly, W.A., K. Johnson, M.E. Tsigas, D.L. Ingersoll, 2004, Revised Armington elasticities of substitution USITC model and the concordance for constructing consistent set for the GTAP model. Available at SSRN 970539.

Freeman, A. M., J. A. Herriges, and C. L. Kling. 2014. The Measurement of Environmental and Resource Values: Theory and Methods, 3rd Edition, New York: RFF Press.

Haab, T.C., and K.E. McConnell. 2002. Valuing Environmental and Natural Resources: The Econometrics of Non-Market Valuation. Edward Elgar Publishing.

Institute for Water Resources, 1986. IWR Report 86-R-4 National Economic Development Procedures Manual: Recreation Volume 1; Recreation Use and Benefit Estimation Techniques. US Army Corps of Engineers, Washington DC.

Institute for Water Resources, 1990. IWR Report 90-R-11 National Economic Development Procedures Manual: Recreation Volume 2; A Case Study Application of the Contingent Valuation Method for Estimating Urban Recreation Use and Benefits. US Army Corps of Engineers, Washington DC.

Institute for Water Resources, 2016. Regional Economic Systems (RECONS). US Army Corps of Engineers, Washington, DC.

Johnston, R.J., J. Rolfe, R.S. Rosenberger, and R. Brouwer. 2015. "Introduction to Benefit Transfer Methods," in Johnston, , R.J., J. Rolfe, R.S. Rosenberger, and R. Brouwer, ed., Benefit Transfer of Environmental and Resource Values: A Guide for Researchers and Practitioners. New York: Springer, pp. 19-59.

Kotchen, M., M. Moore, F. Lupi, and E. Rutherford. "Environmental Constraints on Hydropower: An Ex-Post Benefit-Cost Analysis of Dam Relicensing in Michigan." Land Economics, 82:(3):384-403, 2006.

Lucente, J.E., T. Gabriel , G. Davis , C. Wellington and F. Lichtkoppler. 2012. Ohio's 2010 Lake Erie Charter Fishing Industry, Fisheries, 37(12):532-541

Lupi, F., and J.P. Hoehn. 2001. "Case Study of a Travel-Cost Analysis: The Michigan Angling Demand Model," in Revealing the Economic Value of Protecting the Great Lakes (A. Cangelosi, ed.). Northeast Midwest Institute: Washington D.C., pages 111-120.

Lupi, F., J. Hoehn, H. Chen and T. Tomasi,. 2001. The Michigan Recreational Angling Demand Model, in Macrobehavior and Microresults: Proceedings of International Institute of Fisheries Economics and Trade, (Ann Shriver, ed.), Oregon State University, Corvalis OR.

MDNR. 2016. Michigan Fishing Report System, Great Lakes Fishing Report, Michigan Department of Natural Resources, Lansing, MI.

Melstrom, R., F. Lupi. 2013. Valuing Recreational Fishing in the Great Lakes. North American Journal of Fisheries Management 33:1184–1193.

Murray, C., and M. Shields, 2004. Creel Analysis and Economic Impact of Pennsylvania's Lake Erie Tributary Fisheries in Erie County, Pennsylvania, with Special Emphasis on Landlocked Steelhead Trout (Oncorhynchus mykiss), Pennsylvania Fish and Boat Commission, Lake Erie Research Unit, Fairview, PA

NOAA. 2015. Great Lakes Landings by Lake with State Details. National Marine Fisheries Service (NMFS).

NYSDEC. 2015. Lake Erie 2014 Annual Report. New York State Department of Environmental Conservation, Albany, NY

ODW, Ohio Division of Wildlife. 2015. Ohio's Lake Erie Fisheries, 2014. Annual status report. Federal Aid in Fish Restoration Project F-69-P. Ohio Department of Natural Resources, Division of Wildlife, Lake Erie Fisheries Units, Fairport and Sandusky, OH.

Partridge, M.D., D.S. Rickman, 2010, Computable General Equilibrium (CGE) Modelling for Regional Economic Development Analysis. Regional Studies 44, 1311-1328.

Poe, G., T. Lauber, N. Connelly, S. Creamer, R. Ready and R. Stedman. 2012. Net Benefits of Recreational Fishing, Beachgoing, and Boating in the Great Lakes, Upper Mississippi River, and Ohio River Basins: A Review of the Literature. HDRU Series No 12-2, Cornell University.

Ready, R.C., G.L. Poe, T.B. Lauber, S. Creamer, N.A. Connelly, R.C. Stedman, 2012, Net Benefits of Recreational Fishing in the Great Lakes, Upper Mississippi River, and Ohio River Basins.

Ready, R.C., G.L. Poe, T.B. Lauber, S. Creamer, N.A. Connelly, R.C. Stedman, 2012, Net Benefits of Recreational Fishing in the Great Lakes, Upper Mississippi River, and Ohio River Basins.

RMA. 2016. Finfish Fishing 2015-16 Annual Statements Data, data pulled from proprietary data available from Risk Management Association, www.rmahq.org/estatement-studies.

U.S. Census Bureau, 2016. Monthly and Annual Retail Trade. U.S. Census Bureau, Washington, DC.

USACE Institute for Water Resources, W.C.S.C., 2015. RECONS Rate Workbook, in: Research, I.f.W. (Ed.).

USACE, 2000. Planning Guidance Notebook. US Army Corps of Engineers, Washington, DC.

USACE, 2016. Economics Guidance Memorandum, 16-03, Unit Day Values for Recreation for Fiscal Year 2016. US Army Corps of Engineers, Washington DC.

USFWS 2013, 2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation – Michigan, U.S. Department of the Interior, U.S. Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau, Washington DC.

Water Resources Council, 1983, Economic And Environmental Principles And Guidelines For Water And Related Land Resources Implementation Studies. Water Resources Council, Washington, DC.

Watson, P., J. Wilson, D. Thilmany and S. Winter. 2007. Determining Economic Contributions and Impacts: What is the difference and why do we care? J. of Regional Analysis and Policy. 37(2):1-15.

Zhang, H., E.S. Rutherford, D.M. Mason, J.T. Breck, M.E. Wittmann, R.M. Cooke, D.M. Lodge, J.D. Rothlisberger, X. Zhu and T.B. Johnson. 2016. Forecasting the Impacts of Silver and Bighead Carp on the Lake Erie Food Web, Transactions of the American Fisheries Society, 145(1):136-162.

Great Lakes and Mississippi River Interbasin Study (GLMRIS) - Brandon Road

Appendix D - Economics

Attachment 1- Capacity Analysis

Table of Contents

1 Introduction **1**

1.1 Geographic Scope *1*

1.2 Project Setting *1*

1.3 Capacity Analysis *2*

1.3.1 Timing Definitions 2

1.3.2 Model Runs 3

1.3.3 Tonnage-Transit Curves 3

1.3.4 Service Disruption Tonnage-Transit Curves 4

1.3.5 Relevant Range 5

2 Model Description **6**

2.1 Processing Time Components *6*

2.2 WAM Lockage Process *7*

2.3 WAM Modeling Process *7*

2.4 Input Preparation *8*

2.4.1 Lock Data 8

2.4.2 Downtime 10

2.4.3 Vessels 11

2.4.4 Shipment List 13

2.4.5 Shipment List Generator 13

2.4.6 Shipment List Calibration 14

2.4.7 Tow Arrival Rescheduling 15

2.5 Model Execution *15*

2.5.8 Making a WAM Run 15

2.5.9 Making a WAM Curve 15

Output Review and Adjustment *16*

2.5.1 Outlier Removal 16

2 Brandon Road Lock Without-Project Condition (No New Federal Action) Capacity Analysis **17**

2.6 Background *17*

2.7 Existing Condition Input Data *18*

2.7.2 Processing Times 19

2.7.3 Random Minor Downtimes 21

2.7.4 Fleet 22

2.7.5 Vessel Types 22

2.7.6 Towboat Types 23
2.7.7 Barge Types 23
2.8 WAM Existing Condition Calibration and Validation 23
2.8.1 Shipment List Calibration 24
2.8.2 Processing Time & Delay Validation 24
2.9 Existing / Without-Project Condition Capacity Analysis 26
2.9.1 Identification of Optimal Lockage Policy 26
2.9.2 Without-Project Condition Capacity Results 26
2.9.3 Full-Operations Tonnage-Transit Curves 27
2.9.4 Service Disruption Tonnage-Transit Curves 28
2.9.5 The Family of Brandon Road Lock Tonnage-Transit Curves 28
3 Brandon Road Lock With-Project Condition Capacity Analysis 30
3.1 With-Project Condition Input Data 35
3.2 WAM With-Project Condition Calibration and Validation 36
3.3 With-Project Condition Capacity Analysis 36
3.3.1 Technology Alternative – Complex Noise 37
3.3.2 Technology Alternative – Complex Noise with Intermittent Electric Barrier 40
3.3.3 Technology Alternative - Electric Barrier 42
3.3.4 Technology Alternative – Complex Noise with Continuous Electric Barrier 45
3.3.5 Sensitivity Analysis – Mooring Cells 48

TABLES

TABLE 1 WAM LOCKAGE 7
TABLE 2 OUTLIER THRESHOLD VALUES (MINUTES) 10
TABLE 3 WAM PROBABILITY DISTRIBUTION TYPES FOR TIMING INPUTS 10
TABLE 4 LPMS DOWNTIME TYPES 11
TABLE 5 TOWBOAT CLASSES, HORSEPOWER, AND DIMENSIONS 12
TABLE 6 BARGE TYPES AND DIMENSIONS 12
TABLE 7 SHIPMENT LIST STATISTICS OF INTEREST 14
TABLE 8 SUMMARY STATISTICS FOR 2000-2013 BRANDON ROAD LOCK COMPONENT PROCESSING TIMES [A] 20
TABLE 9 BRANDON ROAD LOCK HISTORIC LPMS RANDOM MINOR STALLS AND WAM DOWNTIME [A] 22
TABLE 10 BRANDON ROAD LOCK NUMBER OF VESSELS BY TYPE [A] 22
TABLE 11 BRANDON ROAD LOCK TOWBOAT TYPES, HORSEPOWER, AND DIMENSION ASSUMPTIONS [A] 23
TABLE 12 BRANDON ROAD LOCK BARGE DATA [A] 23
TABLE 13 BRANDON ROAD LOCK SHIPMENT LIST CALIBRATION [A] 24
TABLE 14 BRANDON ROAD LOCK PROCESSING TIME VALIDATION [A] 26
TABLE 15 BRANDON ROAD LOCK EXISTING / WOPC CAPACITY AND TRANSIT TIMES 27

Table 16 ANS Control Measures Included in GLMRIS-BR Alternative Plans......................................30
Table 17 Brandon Road Lock Continuous Electric Barrier Maximum Barges per Tow by Towboat Size 34
Table 18 Component Processing Time Changes by Measure [A]..36
Table 19 Capacity and Transit Times (Brandon Road Lock) for Technology Alternative - Complex Noise 37
Table 20 Capacity and Transit Times (Brandon Road Lock) for Technology Alternative – Complex Noise with Intermittent Electric Barrier 40
Table 21 Capacity and Transit Times (Brandon Road Lock) for Technology Alternative – Electric Barrier..43
Table 22 Capacity and Transit Times (Brandon Road Lock) for Technology Alternative – Complex Noise with Continuous Electric Barrier...45

FIGURES

Figure 1 Brandon Road Lock and Dam Geographical Setting 1
Figure 2 Visual Representation of Processing Time Components 2
Figure 3 WAM Sample Simulation Iterations..3
Figure 4 Typical Capacity Curve and Capacity 4
Figure 5 Component Processing Time Histogram 6
Figure 6 WAM Modeling Process...7
Figure 7 Examples of Data with Very Little, Moderate, and Severe Rounding..............................9
Figure 8 Shipment List Generator Flow Chart 14
Figure 9 Brandon Road Lock and Dam...17
Figure 10 Brandon Lock Lower Approach Area 18
Figure 11 Brandon Road Lock –LPMS Arrival and Approach Areas...19
Figure 12 Brandon Road Lock Existing / Without-Project Tonnage-Transit Curve....................27
Figure 13 Brandon Road Lock Existing / Without-Project Tonnage-Transit Curve Family 29
Figure 14: Brandon Road Lock Existing / Without-Project Family of Curves - Relevant Range29
Figure 15 Brandon Road Lock – With-Project Condition Features...31
Figure 16 Construction Tonnage-Transit Curve Family (Brandon Road Lock) for Technology Alternative - Complex Noise 38
Figure 17 Operation Family of Curves (Brandon Road Lock) for Technology Alternative - Complex Noise 38
Figure 18 Operation Family of Curves – Relevant Range (Brandon Road Lock) for Technology Alternative – Complex Noise 39
Figure 19 Construction Tonnage-Transit Curve Family (Brandon Road Lock) for Technology Alternative – Complex Noise with Intermittent Electric Barrier...41

FIGURE 20 OPERATION FAMILY OF CURVES (BRANDON ROAD LOCK) FOR TECHNOLOGY ALTERNATIVE – COMPLEX NOISE WITH INTERMITTENT ELECTRIC BARRIER 41
FIGURE 21 OPERATION FAMILY OF CURVES – RELEVANT RANGE FOR TECHNOLOGY ALTERNATIVE – COMPLEX NOISE WITH INTERMITTENT ELECTRIC BARRIER (BRANDON ROAD LOCK) 41
FIGURE 22 CONSTRUCTION TONNAGE-TRANSIT CURVE FAMILY FOR TECHNOLOGY ALTERNATIVE – ELECTRIC BARRIER (BRANDON ROAD LOCK) 43
FIGURE 23 OPERATION FAMILY OF CURVES (BRANDON ROAD LOCK) FOR TECHNOLOGY ALTERNATIVE – ELECTRIC BARRIER 43
FIGURE 24 OPERATION FAMILY OF CURVES– RELEVANT RANGE (BRANDON ROAD LOCK) FOR TECHNOLOGY ALTERNATIVE – ELECTRIC BARRIER 44
FIGURE 25 CONSTRUCTION TONNAGE-TRANSIT CURVE FAMILY FOR TECHNOLOGY ALTERNATIVE – COMPLEX NOISE WITH CONTINUOUS ELECTRIC BARRIER (BRANDON ROAD LOCK) 46
FIGURE 26 OPERATION FAMILY OF CURVES (BRANDON ROAD LOCK) FOR TECHNOLOGY ALTERNATIVE – COMPLEX NOISE WITH CONTINUOUS ELECTRIC BARRIER 47
FIGURE 27 OPERATION FAMILY OF CURVES– RELEVANT RANGE (BRANDON ROAD LOCK) FOR TECHNOLOGY ALTERNATIVE – COMPLEX NOISE WITH CONTINUOUS ELECTRIC BARRIER 47

FIGURE 28 FULL OPERATION CURVES (BRANDON ROAD LOCK) - COMPLEX NOISE WITH CONTINUOUS EB WITH AND WITHOUT MOORING CELLS 48
FIGURE 29 FULL OPERATION CURVES – RELEVANT RANGE (BRANDON ROAD LOCK) FOR COMPLEX NOISE WITH CONTINUOUS ELECTRIC BARRIER WITH AND WITHOUT MOORING CELLS 49

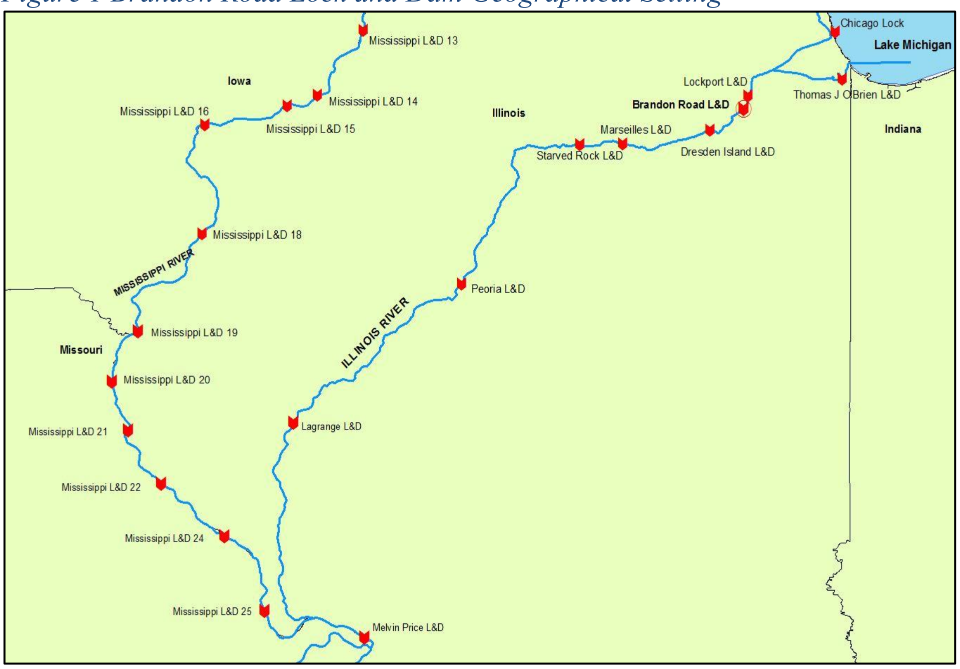
1 Introduction

This attachment documents the data sources, procedures, analytical methods and results of the Tonnage-Transit Time (Capacity) analysis completed in support of the U.S. Army Corps of Engineers (USACE) Great Lakes and Mississippi River Interbasin Study at Brandon Road (GLMRIS-BR) commercial cargo navigation national economic development (NED) analysis. This attachment is not intended to serve as a stand-alone document, but rather, is a complement to the *GLMRIS-BR Report: Appendix D – Economic Analysis.*

1.1 Geographic Scope

Brandon Road Lock and Dam (BRLD) is located on the Illinois River at Mile 286 near Joliet and Rockdale, IL. Brandon Road Lock is located approximated 15 miles upstream from Dresden Island Lock and Dam and approximately 5 miles downstream from Lockport Lock.

Figure 1 Brandon Road Lock and Dam Geographical Setting



1.2 Project Setting

The Illinois Waterway is a system of rivers which connect Lake Michigan at the mouth of the Calumet River to the mouth of the Illinois River as it flows into the Mississippi River in Grafton, Illinois. The system encompasses the Calumet River, the Chicago Sanitary Ship Canal (CSSC), the Illinois River, and a short navigable section of the Des Plaines River. USACE manages eight lock projects on the system, which include Thomas J. O'Brien on the Calumet River, Lockport and Brandon Road on the Des Plaines River, and Dresden Island, Starved Rock, Peoria, and Lagrange on the Illinois River. The Illinois Waterway serves as the sole commercially navigable inland link between the Great Lakes and the Mississippi River Basin. The waterway is not only important to American commerce, it supports a variety of other public purposes, such as flood control, waterside commercial development, effluent discharge, and water-based recreational activities.

1.3 Capacity Analysis

1.3.1 Timing Definitions

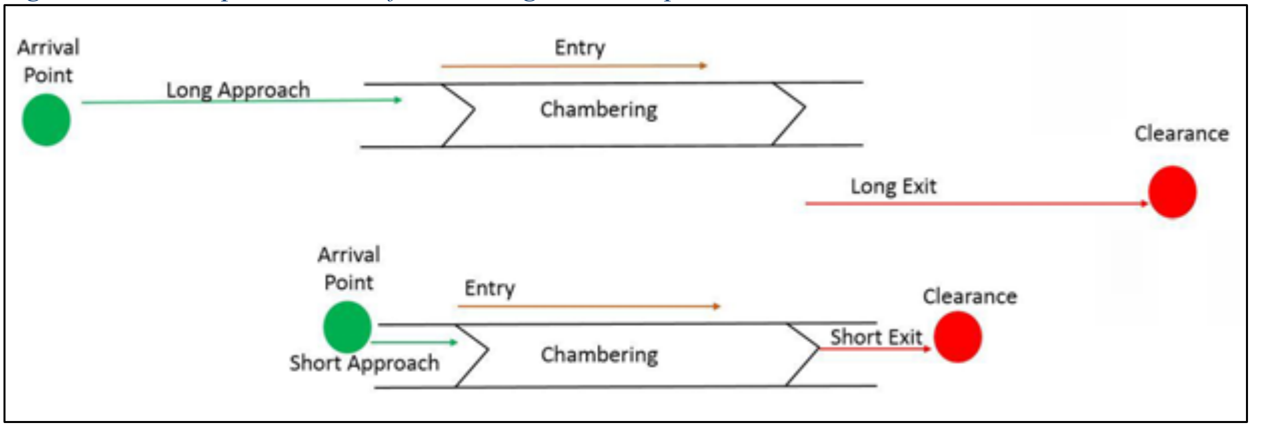
A capacity analysis is generally a reflection of the performance of a lock, system, or river's performance in allowing for the movement of traffic along its extent. For a lock, this performance is measured in terms of transit time.

Transit time is the measured time period between when a vessel arrives at a lock and the time it sufficiently clears the lock area so that another lockage can occur. Transit time is broken down into two elements, delay time and processing time.

Delay time is the time period between when a vessel arrives at the lock and when the lock is ready to being processing that vessel. Delay can occur because another vessel is utilizing the chamber or the chamber is out of operation.

Processing time is the time related to the actual lockage process. A simplified visual representation can be found in
Figure 2. Processing time is further broken down into the five components of processing time: approach, entry, chambering, exit, and turnback. These times are tracked by direction and can be further broken down according to the type of approach or exit, which are determined by their interactions with other vessels in the system. A long approach signifies a vessel approaching the lock from the beginning of the arrival point, which means that the vessel had to wait for a different vessel traveling in the opposite direction to clear the project area or the vessel arrived in the absence of another vessel. Likewise, a long exit means that the vessel exiting the chamber is interfering with another vessel entering the chamber from the opposite direction, and thus must clear the area completely for the other vessel to begin its approach. A short approach usually signifies that the vessel has arrived as another vessel traveling in the same direction is utilizing the lock chamber. This allows the vessel to make its approach and wait immediately below the chamber gates as no interference is caused by the exiting vessel. Similarly, a short exit signifies the lack of another vessel traveling in the opposite direction, meaning the exiting vessel is not interfering with another vessel and the lockage can be considered complete when the vessel has left the vicinity of the project gates. Entry time is the time period between when the bow of the vessel crosses the lock sill and the vessel is ready for the chambering process. The chambering process is the time it takes for the lock to change the elevation within the chamber. Turnback is the time period between when a vessel exits the chamber and the chamber's elevation can be changed to serve another vessel traveling in the same direction.

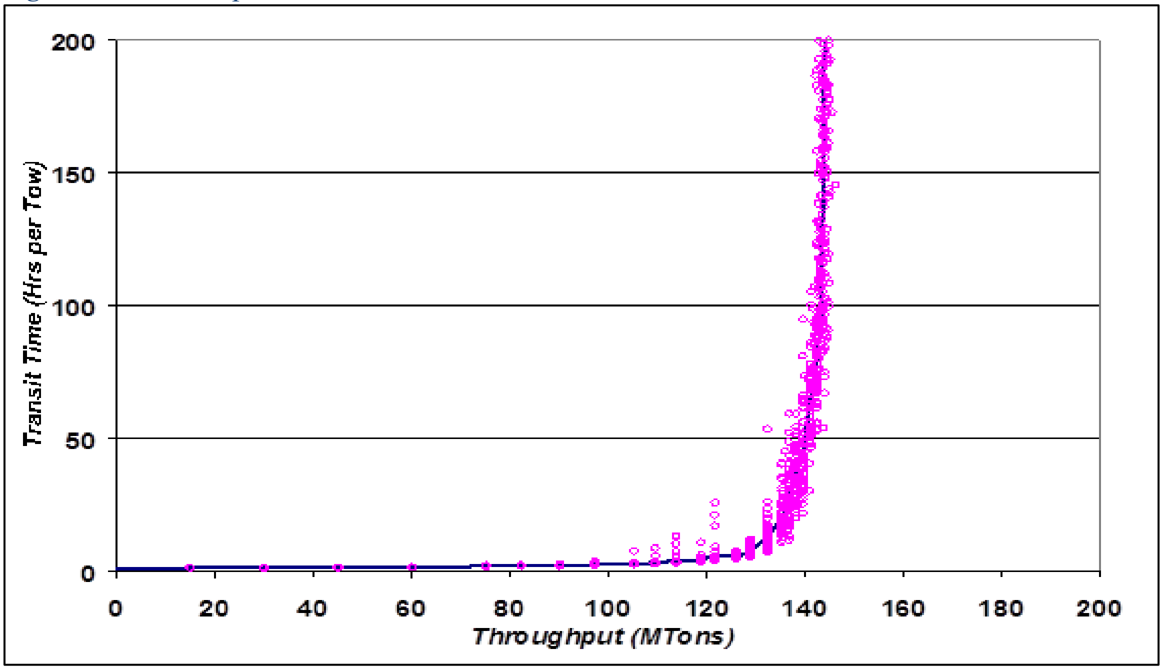
Figure 2 Visual Representation of Processing Time Components



1.3.2 **Model Runs**

The Waterways Analysis Model (WAM) was used to make traffic-transit time estimates in this study (see Section 2). The WAM is a discrete event computer simulation model and with each simulation iteration the model produces estimates of how the modeled system performs. Many output statistics are generated during each run. The most important of these are the total amount of traffic served and the time needed to serve it. If many simulation iterations are made at several different traffic levels, the performance of a system over its full range of utilization can be estimated, as shown in Figure 3. Each circle in the figure represents a single run. A WAM curve, or tonnage-transit curve, is usually defined by the average of 50 runs at 27 different traffic levels. For curves representing more restrictive activity, more runs may be required at each point in order to produce a smoother curve. The analysis of Brandon Road Lock incorporated a minimum of 125 runs at each of the 27 points to produce well-behaved curves. In the context of a capacity analysis, 'well-behaved' curves mean the relationship between transit time and throughput is relatively consistent as throughput accelerates and the resulting curve is smooth.

Figure 3 WAM Sample Simulation Iterations



1.3.3 **Tonnage-Transit Curves**

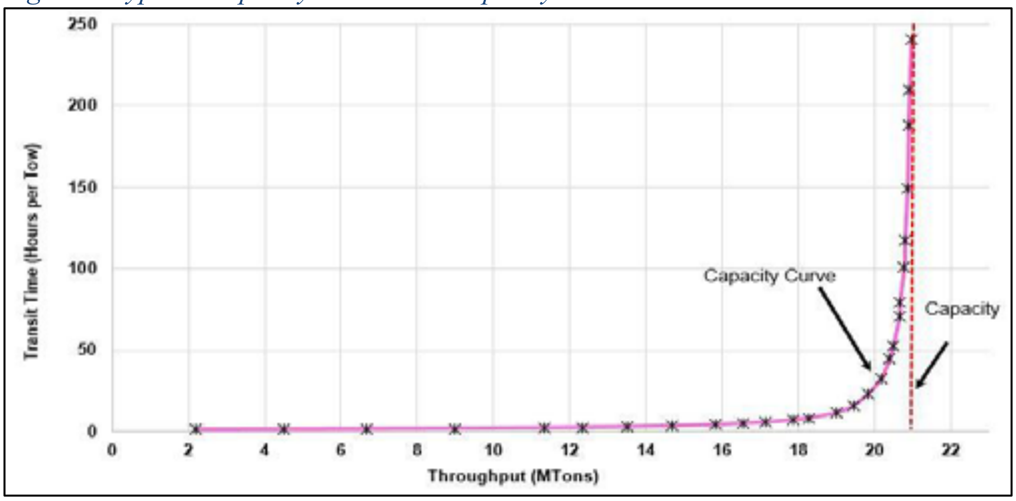
A capacity curve defines the relationship between project throughput and transit time. is typical of many capacity curves in this analysis. At most locks, transit times remain very low until demand reaches about 80% of capacity. As traffic levels increase from that level, transit times increase rapidly. Throughput is measured as annual tons served, and transit time includes both the time needed to "process" the vessel and the time the vessel is "delayed".

A vessel's processing time begins when either the lock operator signals a waiting tow that the lock is ready for processing, or the tow is at the arrival point and the lock is idle. Process time ends when the lock is free to serve another vessel. Delay occurs when a vessel arrives at a lock and cannot be served immediately. Capacity is defined as the level of tonnage where the capacity curve reaches its vertical asymptote. At this point, additional demand results in increased delay but no increase in throughput.

Figure 4 is typical of many capacity curves in this analysis. At most locks, transit times remain very low until demand reaches about 80% of capacity. As traffic levels increase from that level, transit times increase rapidly. Throughput is measured as annual tons served, and transit time includes both the time needed to "process" the vessel and the time the vessel is "delayed".

A vessel's processing time begins when either the lock operator signals a waiting tow that the lock is ready for processing, or the tow is at the arrival point and the lock is idle. Process time ends when the lock is free to serve another vessel. Delay occurs when a vessel arrives at a lock and cannot be served immediately. Capacity is defined as the level of tonnage where the capacity curve reaches its vertical asymptote. At this point, additional demand results in increased delay but no increase in throughput.

Figure 4 Typical Capacity Curve and Capacity



1.3.4 **Service Disruption Tonnage-Transit Curves**

Every capacity curve represents the relationship between tonnage and transit time for a given, very specific, set of circumstances. Many factors are considered when developing capacity curves. Some factors that have an effect on the shape of the curve, and the ultimate capacity of the project include: number of chambers, interference characteristics between the chambers, fleet size and loadings, processing times (by direction, chamber, and flotilla size), arrival and inter-arrival patterns, and service policies.

Chamber downtime, generally referred to as service disruption, is also factor. In some cases, a service disruption may only impact certain vessels. For purposes of this BRL capacity analysis, downtime is defined as time when all traffic is unable to use a lock chamber. Downtime can occur because the chamber itself is unavailable (e.g., maintenance), or for other reasons such as weather or bridge curfews. When a chamber is "down", processing stops and vessels must either use another chamber (if available) another route (if available) or wait until the downtime ends.

For the purposes of this study, service disruptions were identified only for scheduled major events such as major rehabilitation work, scheduled construction work, and emergency aquatic nuisance species (ANS) response activities. As a result, a series of tonnage-transit curves are needed for a given project alternative in addition to the Normal/Full-Operations tonnage-transit curve. Each one of these curves represent the annual tonnage-transit relationship to be expected if that particular service disruption event occurs. Hence, for Brandon Road Lock, an additional three curves were developed for the existing condition and between 3 and 8 curves were developed for each of the of the with-project condition (WPC) alternatives respective to the differences in the alternatives.

1.3.5 Relevant Range

While capacity is useful to demonstrate relative differences between alternatives, only the relevant range of a curve is used during an economic analysis. Relevant range is lock specific and depends on current and projected future traffic levels. The lower bound of a range is defined as the minimum expected demand, measured in tons, throughout the period of analysis. Conversely, the upper bound is set at the maximum expected tonnage. The capacity of a curve may lie above the relevant range, below the relevant range, or within the relevant range. The relevant range for Brandon Lock is projected at between 10 and 14 million tons annually based on historic tonnage levels and forecasted traffic demands.

2 Model Description

Tonnage-transit time (capacity) curves for the BR Lock analysis were developed using the Waterway Analysis Model (WAM). The WAM is a discrete event computer simulation model developed by the Corps of Engineers for use in simulating tow movements on the inland waterways system. It was developed as part of the U. S. Army Corps of Engineers Inland Navigation Systems Analysis Program (INSA) for the Office of the Chief of Engineers by CACI, Inc. WAM was written in the mid 1970’s and has been continually modified and improved since the early 1980’s. WAM has been used in navigation studies on the Ohio River and its tributaries for the last 30 years. The version of WAM used for GLMRIS-BR received an approval for use from the HQUSACE Model Certification Panel on 09 August 2016.

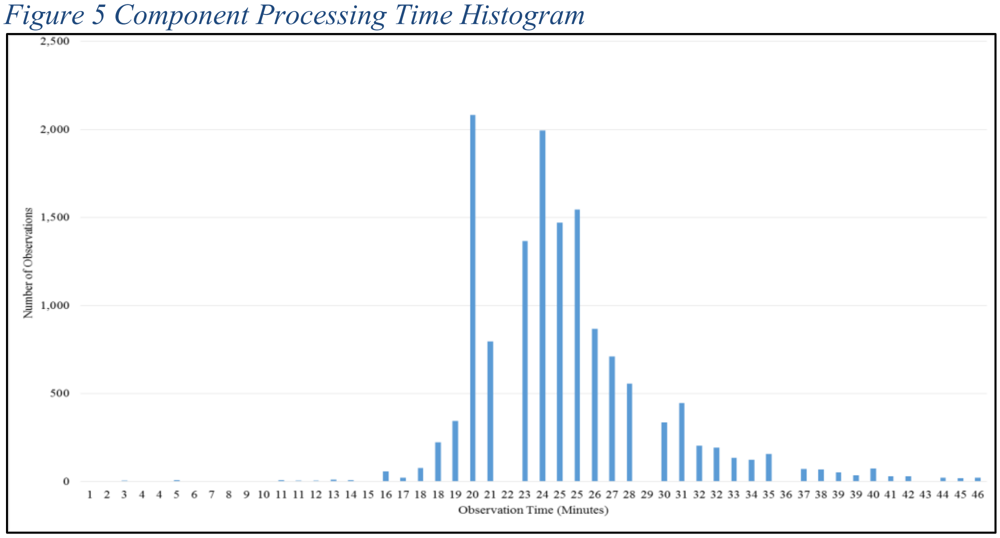
As a simulation model, the WAM incorporates the concept of variability into the modeling process. Instead of an action taking a fixed amount of time to accomplish, say 15 minutes every time, it may take any value between 5 and 30 minutes. Instead of every vessel arriving 60 minutes after the previous vessel, a vessel may arrive anywhere between a couple minutes and several hours after the previous vessel. This type of modeling is well suited for real world events, since real world events seldom take exactly the same amount of time every time they occur.

The interactions between the variability of the arrivals and the variability of the processing times causes times when the lock is idle and times when the lock is in use, with vessels waiting to process. The model monitors and accumulates many statistics as it executes. These statistics are written to files so the results of the model run can be reviewed and analyzed.

2.1 Processing Time Components

Figure 5 shows a histogram of an actual component time data set used in this study. The histogram indicates there is less than a 3% chance that the value will be less than 19 minutes. On the other hand, 93% of the values are between 19 and 35, inclusive. The chance of the value being greater than 35 minutes is about the same as it being less than 20 minutes. Over 20 data sets the type of information depicted in Figure 5 were used in this study.

Figure 5 Component Processing Time Histogram



Source: Lock Performance Monitoring System (LPMS)

2.2 WAM Lockage Process

WAM is a highly detailed lock simulation model. Vessels arrive at the lock where they either begin processing, or are made to wait because the facility is busy or "down". When the lock is ready to process the vessel, the vessel goes through the lockage process.

Table 1 shows a simplified representation of a standard lockage.

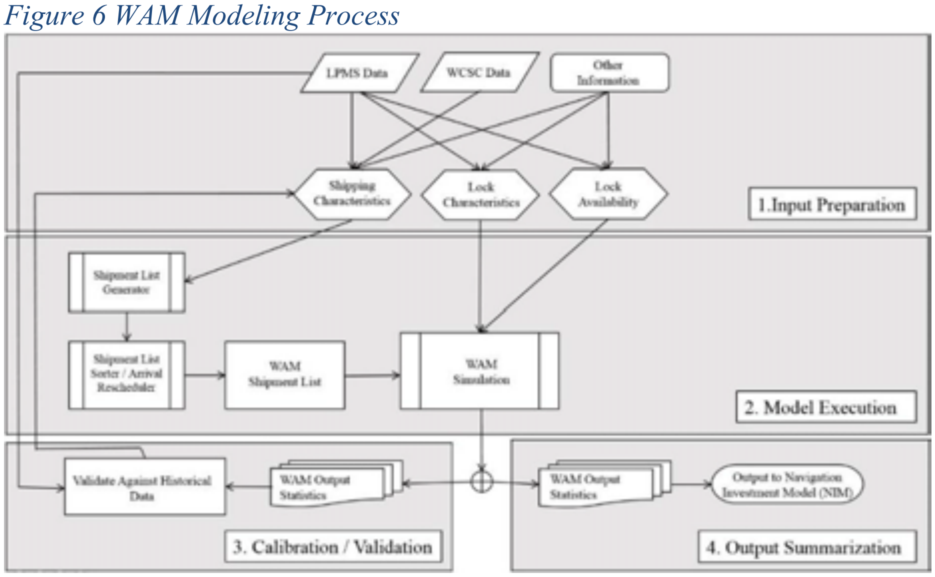
Table 1 WAM Lockage

Description	Wam Component	LPMS Time
Arrival	Input to WAM from Shipment list	Arrival
Delay	Determined by WAM based on Conditions at Lock	Start of Lockage
Approach	Approach Distribution Fit From Data	Bow Over Sill
Entry	Entry Distribution Fit From Data	End of Entry
Chambering	Chambering Distribution Fit From Data	Start of Exit
Exit	Exit Distribution Fit From Data	End of Lockage

2.3 WAM Modeling Process

WAM modeling consists of the following four basic steps: 1) input preparation, 2) system simulation, 3) calibration and validation, and 4) output summarization. The modeling process is summarized in Figure 6.

Figure 6 WAM Modeling Process



2.4 Input Preparation

The WAM simulation module "simulates" tow movement through navigation locks based on the model configuration. Many factors are included when configuring a WAM simulation; some key factors are listed below.

- the lock
- number of chambers
- chamber sizes
- processing times
- downtime
- interference characteristics (multi-chamber locks only)
- service policy
- the fleet using the lock
- towboat types and sizes
- barge types and sizes
- tow sizes/barges per tow
- empty movements
- recreation and other craft
- the fleet arrival pattern
- monthly variations
- daily variations
- hourly variations
- lock data
- recreation craft arrival variations

2.4.1 Lock Data

2.4.1.1 Processing Times, Sample Set Development

As stated earlier, standard lockages are simulated in the WAM by four sequential periods of time. They are in order of occurrence, the approach, entry, chambering and exit. A vessel's total processing time is the sum of the approach, entry, chambering and exit times. Processing time is added to the delay time, if any, to get total transit time for the vessel. Transit time is shown as the ordinate on capacity curve charts. The Corps Lock Performance Monitoring System (LPMS) serves as the data source for processing times used by WAM. Processing time data is retrieved from the LPMS system and grouped into the following components:

- Long Approach (Fly and Exchange)
- Short Approach (Turn back)
- Chamber Entry
- Chambering
- Long Exit (Fly and Exchange)
- Short Exit (Turn back)
- Chamber Turn back

Approaches and exits are grouped based on whether they are long or short. This is done because there is a large difference in these times, and the differentiation gives the model the ability to identify the most efficient lockage policy.

2.4.1.2 Sample Set Development, Overview

LPMS data was imported into a series of SQL Server tables, and from there queried into workbooks to select specific lock component times. Component times were grouped based on lock number, component type (i.e. long approach), chamber number (main or auxiliary), vessel direction (upstream or downstream), and number of cuts (1, 2 …or 5). LPMS summary data for the selected criteria was then displayed. Summary data included the locks' components' mean times, total observations, minimum and maximum value, and standard deviation for each year of the selected data sets.

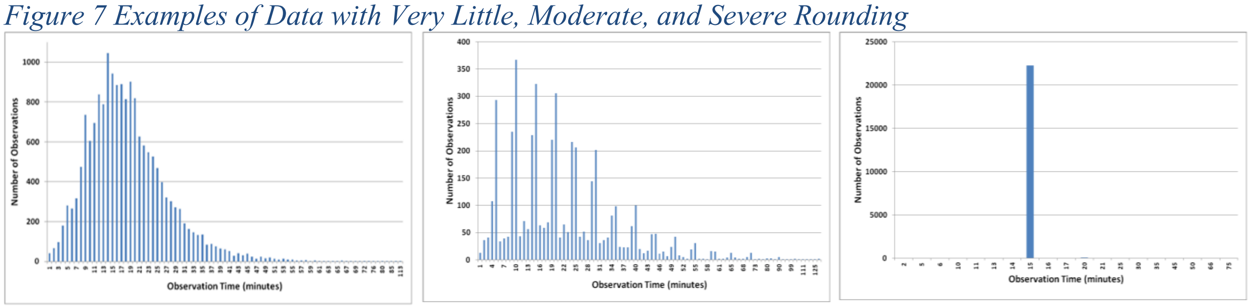
2.4.1.3 Sample Set Development, Sample Set Size and Data Years

The first activity associated with developing valid component processing time sample sets was to analyze data from years 2009-2013 and compare each year's data separately to determine whether the data sets for each year were valid when compared with the base year (year 2013). This involved visual and calculated comparisons. The visual comparison consisted of viewing various histograms of the selected data set in different single and multi-year scenarios. The skewness of each year's frequency distribution and general 'spread' of observations was considered and compared to the base year. The calculated comparison consisted of analyzing the LPMS summary data in various single and multi-year scenarios for each selected year or group of years. For each year, means, standard deviations, number of observations, and highest and lowest observations were compared with the base year. Each fell within standard ranges observed at similar projects.

2.4.1.4 Sample Set Development, Rounding

Lock component data recorded by lock operators had various degrees of rounding, ranging from very little to moderate and extreme rounding, as shown in Figure 7. Rounding occurs when lock operators record the LPMS tow processing times in increments of 5 minutes (e.g., 5, 10, 15) instead of the nearest minute. Moderate (subtle) rounding occurs when there are several times recorded in increments of 5 minutes in the data set while extreme (severe) rounding occurs when the times are recorded in only one or a few increments of 5 minutes or when nearly all occurrences are given the same time. Although some of the data sets contained some moderate rounding, all of the lock component data sets were used in this study.

Figure 7 Examples of Data with Very Little, Moderate, and Severe Rounding



2.4.1.5 Sample Set Development, Outliers

For purposes of this study, outliers are data that do not belong in the data set. They are considered invalid, and are not included in the final data set. Outliers can take the form of very low values, or very high values.

Low outliers were determined by first setting a lower threshold for each component type based on the number of occurrences of the lowest observation. If the lowest observation occurred several times in the data set, the time remained in the data set. Conversely, if the observation occurred only a few times in the data set, the observation was identified as an outlier and removed, and then the threshold value was determined based on the remaining values. The threshold was determined by examining the lockage process, and determining the shortest process time possible. For example, a single cut chambering time begins when the vessel is tied off in the chamber and ends when the gates are fully open and the vessel can begin its exit. During this period, one set of gates is closed, the chamber was filled or emptied, and the other gates are opened. If the upper and lower pools were approximately equal, the filling or emptying process would be very short, essentially zero. This leaves the minimum process time as the time it takes to close one set of gates and open the other. Table 2 shows the threshold values used in this study.

"High outliers" were removed only when they were considered extreme, and were unique to each selected data set. Examples of extreme outlier(s) would include an obvious typographical error such as the observation time of 999 minutes or high observation time(s) that contain large 'gaps' or differences in data values. An example of a large 'gap' in data would be a 100-minute time and the next highest values in the data set 30 minutes. In this case, the 100-minute time is over 3 times as large as the next largest value.

Table 2 Outlier Threshold Values (Minutes)

Component Type	Threshold Value
Long Approach	2
Short Approach	1
Entry	1
Chambering	1
Long Exit	2
Short Exit	1
Chamber Turn back	1
Straight Multi	2

2.4.1.6 **Processing Times, Distribution Fitting**

Valid sample sets (i.e., samples with outliers removed) were analyzed using a commercial software product called Decision Suite - @Risk by Palisade. @Risk provides automated probability distribution fitting capabilities that analyzes the sample set, fits 20 distribution types to the set, determines which distribution type best represents the set, and displays the parameters that describe the distribution. Table 3shows the distribution types considered by @Risk, and the parameters that define the distributions.

Table 3 WAM Probability Distribution Types for Timing Inputs

Distribution Type	Parameter 1	Parameter 2	Parameter 3	Parameter 4
Beta	Low End Point	High End Point	Shape #1	Shape #2
Chi-Square	Degrees Freedom	Location		
Constant	Value			
Erlang	Mean[1]	Shape	Location	
Exponential	Scale	Location		
Gamma	Mean[1]	Shape	Location	
Inverse Gaussian	Scale	Shape	Location	
Inverted Weibull	Scale	Shape	Location	
Johnson SB	Low End Point	High End Point	Shape #1	Shape #2
Lognormal	Mean[1]	Standard Deviation	Location	
Log-LaPlace	Scale	Shape	Location	
Log-Logistic	Scale	Shape	Location	
Normal	Mean	Standard Deviation		
Pareto	Scale	Location		
Pearson Type 5	(1/Scale)*Shape	Shape	Location	
Pearson Type 6	Scale	Shape #1	Shape #2	Location
Random Walk	Scale	Shape	Location	
Rayleigh	Scale	2	Location	
Uniform	Lower Limit	Upper Limit		
Weibull	Scale	Shape	Location	
[1] An adjusted mean equal to sample mean minus the location				

2.4.2 **Downtime**

Locks experience periods of time when traffic is unable to transit through the facility. These periods are referred to as downtime events. Downtimes happen for a variety of reasons and may last from a few minutes to over a month. Some downtimes are scheduled ahead of time while others occur without warning. This study addresses downtime by segregating these events into two groups, random minor downtimes and major maintenance downtimes. The Corps LPMS data is the main data source for downtimes. LPMS data includes fields for vessel stalls. These stall events are used to determine how often and for what duration lock chambers are unable to serve traffic.

2.4.2.1 Random Minor Downtime

Random minor downtimes are short duration, less than 1 day, unscheduled chamber closures. They are caused by various things such as the weather, mechanical breakdowns, river conditions, lock conditions, and other circumstances. LPMS categorizes the causes of downtime into 5 major groups, and then further subdivides each major group into subgroups, for a total of 19 different causes of downtime. These categories and sub-categories are shown in Table 4. Data was developed for each downtime subgroup by determining the number of events expected each year, and the total annual amount of downtime.

Table 4 LPMS Downtime Types

Classification	Description
Weather	Fog
	Rain
	Sleet or Hail
	Snow
	Wind
Surface Conditions	Ice
	River Currents / Out drafts
	Flood
Tow Conditions	Interference by Other Vessel
	Tow Malfunction
	Tow Staff Occupied with Other Duties
Lock Conditions	Debris
	Lock Hardware Malfunction
	Lock Staff Occupied with Other Duties
	Test and Maintain Lock
Others	Tow Detained By Coast Guard
	Collision or Accident
	Bridge Delay
	Other

Downtime files are developed by creating the events for each subgroup, and combining the events into one file. Each event in the downtime file is created keeping in mind the time of year that the event subgroup usually occurred, and in accordance with the distribution of event durations for that subgroup.

2.4.3 Vessels

The WAM allows each vessel to be classified based on several attributes. For the purposes of this analysis, the most important attributes are the length, width and carrying capacity. These attributes are used by WAM to determine the number of cuts needed to process a vessel, and the tonnage carried by that vessel. The WAM determines the number of cuts by comparing the lock chamber size with the number and size of the vessels in a shipment. Vessels are grouped into one of three types in this study. Tows are commercial towboats pushing one or more barges. Light-boats are commercial towboats without barges. Recreation craft are non-commercial, usually small, vessels. Commercial-passenger vessels, government vessels, and other vessel types are counted and included in the Light-boats group.

2.4.3.1 **Towboats**

Towboats were categorized into 9 groups based on horsepower. Table 5 lists the towboat types, horsepower and dimensions used in this study.

Table 5 Towboat Classes, Horsepower, and Dimensions

Class	Horsepower	Average Length (Feet)	Average Width (Feet)
1	0 - 999	2	24
2	1,000 - 1,499	98	29
3	1,500 - 1,899	115	30
4	1,900 - 2,299	131	31
5	2,300 - 3,099	141	35
6	3,100 - 4,199	151	40
7	4,200 - 5,499	162	42
8	5,500 and Greater	185	53

2.4.3.2 **Barge Types**

Tow size is a key input determinant when estimating lock capacity. Tow size is determined by the type and number of barges being pushed, and the towboat type. This study models 12 barge types which are typical on the Inland Waterway system. Table 6 shows the barge types and their dimensions.

Table 6 Barge Types and Dimensions

Class	Name	Average Length (Feet)	Average Width (Feet)
1	Sand Flat	135	27
2	Regular	175	26
3	Stumbo	195	26
4	Jumbo	195	35
5	Covered Jumbo	195	35
6	Super Jumbo	245	35
7	Super Super	260	52
8	Jumbo Tanker	195	35
9	147' Tanker	147	52
10	175' Tanker	175	54
11	265' Tanker	264	50
12	290' Tanker	290	54

2.4.4 **Shipment List**

The shipment list file contains a stream of vessel demands input to the WAM during program execution. It is generated based on historic LPMS and WCSC data, and may contain several thousand records. Every record represents a vessel that must be processed through the lock. The records contain information regarding the arrival time, direction, vessel type (tow, recreational craft, or Light-boat), commodity type and tonnage (if applicable), towboat type (if applicable), and type and number of barges (if applicable). When taken in total, a shipment list closely matches the overall characteristics of the actual 2013 fleet utilizing Brandon Road Lock.

2.4.4.1 **LPMS Summary Program**

The LPMS Summary Program was developed in conjunction with the shipment list generator program. The program summarizes the fleet through a lock project by predominate barge type and commodity in each tow. For example, if a tow has 4 jumbo hopper barges and 3 jumbo tankers, then the tow is counted as a 7-barge jumbo hopper barge tow. While most tows on the Illinois Waterway are configured homogeneously, some tows are a mix of barge types and commodities. The summary program assumes homogeneous tows.

The LPMS Summary Program reads an entire year of raw LPMS data and creates several tables that describe the fleet. Some of the most important ways that data is summarized include; the number of barges by barge type and direction, the total tonnage of each commodity carried in each barge type by direction, the number of empty barges by barge type and direction, the distribution of barges per tow by barge type and direction, the distribution of tows by month of year, day of week and hour of day. These summary tables are used by the shipment list generator to generate tows that reflect historical tow size distributions that arrive based on historical temporal distributions.

2.4.4.2 **WCSC Summary File**

The Waterborne Commerce Statistics Center (WCSC) input files are created using 2013 WCSC raw data for Brandon Road Lock. WCSC barge data is recorded by the shipping companies and collected at the Navigation Data Center. There are two WCSC input files created for each lock project to include a ".lst" file and a summary file. These files are used by WAM's shipment generator to create shipment lists. The WCSC input files describe the origin destination (O-D) pairs by barge type and commodity for barges traveling both in the upstream and downstream direction. Each lock project has its own unique O-D matrix which describes the number of loaded barges, the 9 LRH commodity groupings the barge carries, the average loading, and the total tonnage for each of the 12 barge types used in this study.

2.4.5 **Shipment List Generator**

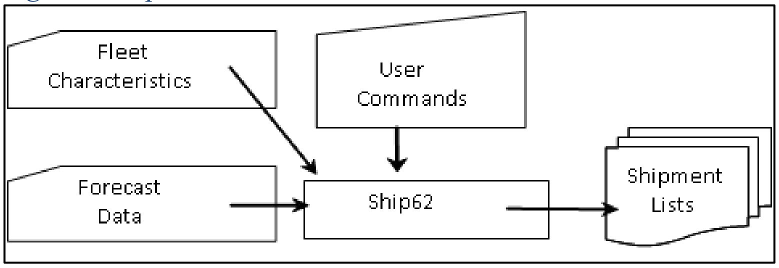
Shipment lists are generated by the WAM Shipment Generator (Ship62), which was developed in the 1995. The ultimate objective of Ship62 is to produce shipment lists that closely reflect historic fleet characteristics. Fleet characteristics can be described in two ways. First, the fleet can be described by its physical characteristics, the most important of which are listed in Table 7. Second, the fleet can be described temporally, that is, how arrivals are distributed on a monthly, daily and hourly basis.

Table 7 Shipment List Statistics of Interest

Number of Tows
Tons per Tow
Number of Barges
Number of Loaded Barges
Number of Empty Barges
Percent Empty Barges
Tons per Loaded Barge
Barges per Tow
Number of Recreation Craft
Number of Light Boats

Ship62 has three basic inputs: 1) the fleet characteristics summary files; 2) the forecast file and, 3) a control file containing user defined instructions. The fleet summary files are created by two standalone programs, LPMS Summary and WCSC Summary, described above. Although Ship62 has the ability to read forecasted demand flows to capture flow shifts, this feature was not used during this study. The forecasts used in the economic analysis did not indicate any shifts in fleet characteristics that would necessitate utilization of the forecast file for the capacity analysis. Furthermore, the forecasted demands are analyzed in full in the larger partial-equilibrium analysis. The user defined instructions file contains input and output file name information, a random number seed, and an escalation factor that determines the how many shipments are created in the shipment list. Figure 8 is a simplified shipment list generator flow chart.

Figure 8 Shipment List Generator Flow Chart



The Ship62 stochastically generates shipment lists, using target fleet distributions derived from LPMS and WCSC data. Performance statistics (e.g. transit time for a given annual tonnage) out of the WAM are sensitive to the arrival patterns in the shipment list, which are variable due to the generator's stochastic generation method. Therefore, 125 shipment lists are generated and run through the WAM to estimate average tow transit time for any given tonnage level.

2.4.6 Shipment List Calibration

The shipment list generator uses two data sources to develop shipment lists, the LPMS data and the WCSC data. These data sources each have their own strengths and weaknesses. For example, LPMS is a better data source for barge counts, tow and other vessel counts, and is the only source for empty barge and lock specific processing time information. On the other hand, WCSC is a better data source for tonnage moved per barge, and commodity type information. These two data sources, therefore, are used together to create shipment lists that reflect the actual fleet at a lock.

Before shipment lists can be used for WAM production runs, they must first be calibrated to insure that they truly reflect the fleet observed at the lock of interest. Shipment lists are calibrated by manually adjusting the LPMS summary data file until the generated fleet matches the observed fleet. The statistics most often adjusted are the number of empty barges, by barge type, and barges per tow percentages for each barge type.

2.4.7 Tow Arrival Rescheduling

The shipment list generator creates shipment lists that are valid for normal lock operation conditions. Shipment list arrival times reflect the actual 2013 arrival pattern for Brandon Road Lock.

During normal lock operations, tow arrivals vary by month of year, day of week and hour of day. At Brandon Road, there is very little variation in the rate of tow arrivals by month, day, or hour. When long, disruptive closures occur however, tow arrival patterns change dramatically. Since the Brandon Road Lock is a single chamber project, lock closures stop all traffic through the lock. When relatively long duration closures occur, historic data shows the number of arrivals decrease significantly during the closure. Tow arrival rescheduling mimics this decrease in arrivals by rescheduling arrivals around the closure(s) of interest.

2.5 Model Execution

As stated in Section 2.1 WAM was developed in the 1970's. Although WAM has been continually modified and enhanced since that time, it retains the original input-output mechanisms of the era, ASCII files.

2.5.8 Making a WAM Run

In its most simple form, WAM requires four fundamental input files to fully define the system and conditions which are to be simulated. These four files are: the shipment list, the network file, the downtime file, and the run control file.

The shipment list, which is created by the Shipment List Generator described in Section 2.2.3.3, contains the list of vessels seeking to use the lock. The network file describes the operational characteristics of the lock including chamber size, processing time distributions, service policy, open pass schedule, chamber packing criteria, and towboat and barge dimensions. The downtime file contains a list of downtime events which control when a chamber is able to serve traffic and when it is unavailable. The run control file contains information that controls how much simulated time WAM will execute, the type of and extent of WAM output, and the random number seed passed to the model.

In addition to the input files, five supporting programs are used while running WAM. These five programs are: the WAM executable, the shipment list generator, a shipment list sorting program, an arrival rescheduling program, and a downtime file warm-up program. It is beyond the scope of this report to describe each of these programs in detail. Suffice it say, a great deal of file manipulation and program execution is required to make one WAM run.

2.5.9 Making a WAM Curve

It generally requires at least 1,350 executions of the WAM to create one capacity curve. More executions may be necessary in order to create well-behaved curves. Every one of these model executions, called runs, is made with a set of four fundamental input files that are slightly different from all other runs. Obviously, it would be difficult if not impossible to manually create these input files, run WAM, and gather the relevant information from the output files. Therefore, an automated graphical user interface known as the WAMBPP was developed to facilitate the process of creating input files, executing WAM, gathering pertinent data from the output files, and appending this data into various SQL Server tables.

2.5.10 Output Review and Adjustment

WAM possesses the ability to produce vast quantities of output data. A user can trace every event of the modeling process if so desired. WAM gives the user full control over the amount and type of output produced.

Only two pieces of WAM output data are used when creating capacity curves, the tonnage processed during a run, and the average transit time for all tows that processed during the run. These two pieces of information, when averaged over the number of runs made at a traffic level, define a point on a capacity curve. The curve is created by connecting these average points over the range defined by the 27 traffic levels made for each curve.

2.5.11 Outlier Removal

Periodically, WAM will produce a run where either the tonnage processed or transit time is unreasonable. These runs are known as outliers. Although outlier runs are rare, their impact on a curve can be very large. At its most basic mathematical level, a capacity curve is defined by a set of x, y values in a 2 dimensional space. Therefore, outliers have two ways of appearing. Either a tonnage value is out of bounds or the transit time is out of bounds. Therefore, we search for outliers using two different set of bounds, one for tonnage, one for transit time.

Through years of experience and examination of data, the PCXIN has found that tonnage is seldom the outlier. Tonnage varies very little from run-to-run. This makes sense. It all comes down to how many tows are in queue at the end of the year. A typical lock on the Illinois Waterway serves 2,500 or more tows per year. If there are 20 or 200 tows in queue at the end of the year, it makes little difference. Therefore, the tonnage bounds were set at plus or minus 2% of the average tonnage.

Transit time on the other hand is highly variable. Once traffic starts entering the “elbow” of a capacity curve, transit times can easily vary by 100% from run-to-run. Experience has shown that transit time outliers are always high outliers. Therefore, no low boundary was set. The upper bound was set at 300% of the average transit time.

Using these rules, the summary data tables in each lock’s databases were searched for outliers. Outliers identified by the search were deleted from the table.

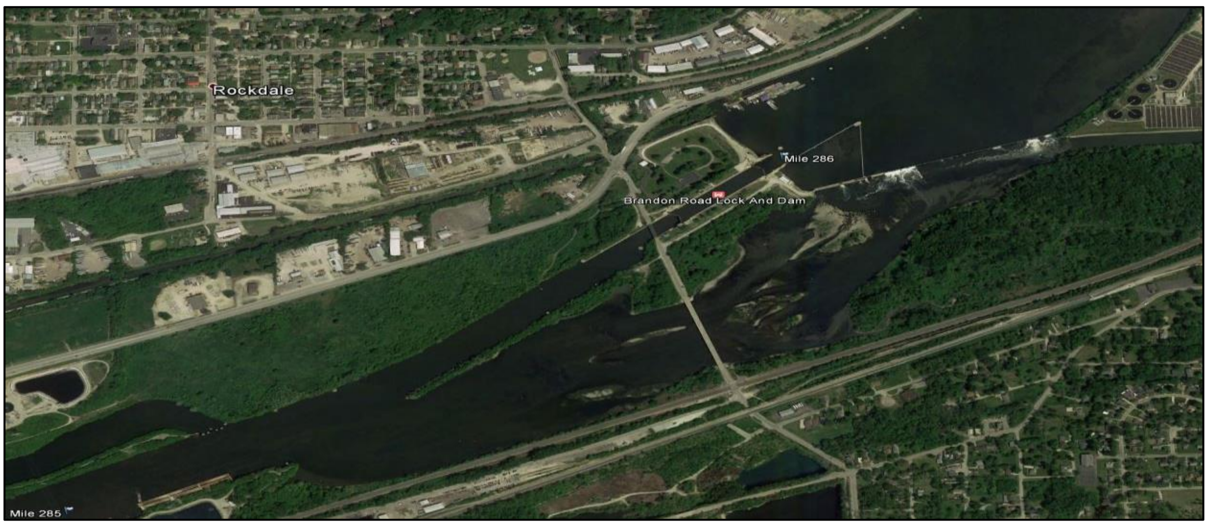
2 Brandon Road Lock Without-Project Condition (No New Federal Action) Capacity Analysis

A detailed discussion of the existing and without-project condition for the Brandon Road Lock capacity analysis follows.

2.1 Background

Brandon Road Lock and Dam (Figure 9) is located on between river miles 285 and 286 on the Illinois Waterway and consists of a single 600’ x 110’ main chamber with a lift of 34 feet at normal. The lock itself was built in 1933 and sits on the Des Plaines River approximately 13 river miles above where the confluence of the Des Plaines and Kankakee Rivers form the Illinois River.

Figure 9 Brandon Road Lock and Dam



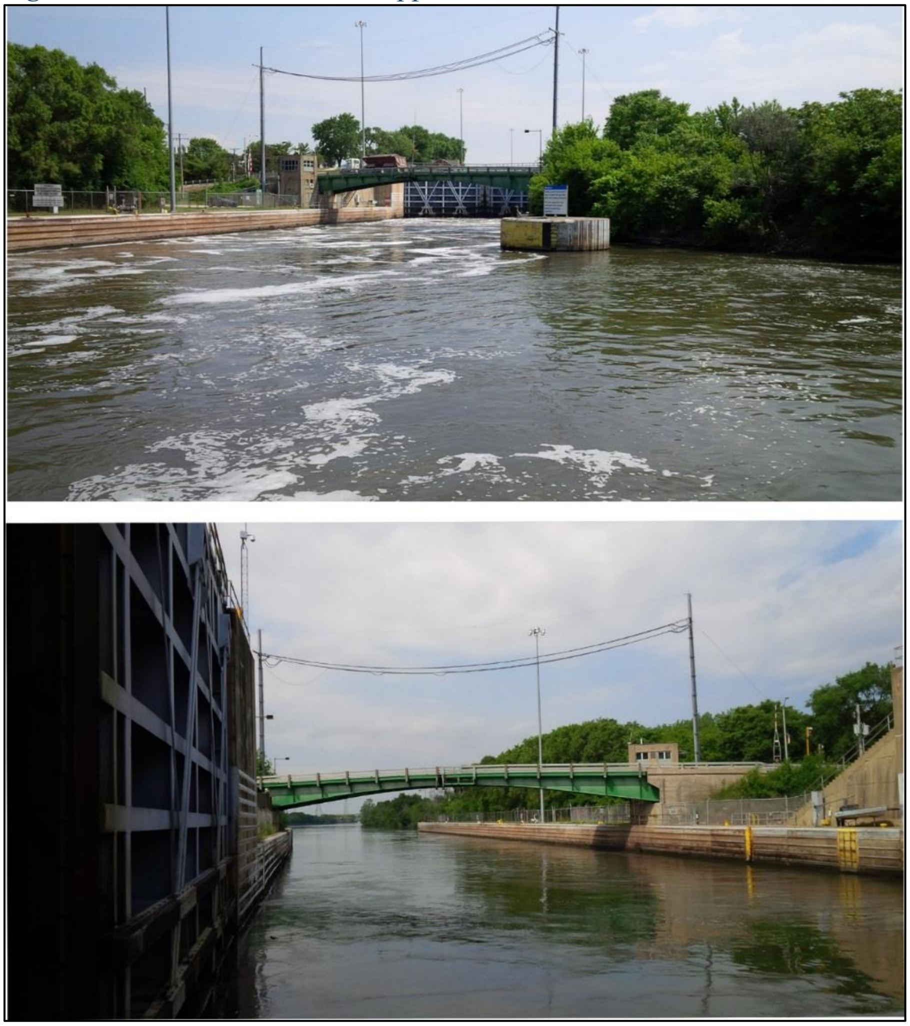
The Illinois Waterway serves as the sole commercially navigable inland waterway connecting the Mississippi River and the Great Lakes, allowing approximately 9.3 million tons of annual cargo between Brandon Road Lock and the Lower Mississippi River.1 Under the existing condition, Brandon Road Lock operates in a similar fashion to other locks in the region. The project has a tow-haulage unit on site to assist in the passage of large tows which cannot fit in the chamber in a single lockage operation, or a double cut tow. The first set of barges is loaded into the chamber, extracted with the tow-haulage unit and held on the other side of the project until it is rejoined by the rest of the tow. When vessels arrive in the LPMS arrival area they call into the lock to be assigned their arrival time and their queue position. As shown in Figure 9 and the Brandon Road Draw Bridge, crosses the project’s lower approach area with a vertical clearance of 17.8 feet when closed and 66.9 feet when open at flat pool. The bridge opens as needed to accommodate waterborne vessel traffic, and is not known to pose significant impacts to the movement of waterborne traffic through the project. Given this assessment the impact of the bridge was not assessed and to the extent it affects traffic is inherent to the data used for this analysis.

Figure 10 the Brandon Road Draw Bridge, crosses the project’s lower approach area with a vertical clearance of 17.8 feet when closed and 66.9 feet when open at flat pool.[2] The bridge opens as needed to

[1] Waterborne Commerce Statistics Center (WCSC) data from 2009-2013
[2] USACE Mississippi Valley Division – Rock Island District Navigation Charts Appendix B (http://www.mvr.usace.army.mil/Portals/48/docs/Nav/NavigationCharts/ILW/AppendixB.pdf)

accommodate waterborne vessel traffic, and is not known to pose significant impacts to the movement of waterborne traffic through the project. Given this assessment the impact of the bridge was not assessed and to the extent it affects traffic is inherent to the data used for this analysis.

Figure 10 Brandon Lock Lower Approach Area



**Top Image: View of Brandon Road Bascule Bridge as seen approaching the chamber up bound*
**Bottom Image: View of Brandon Road Bascule Bridge as seen from chamber heading down bound*

Since 2008, traffic levels have been around 10-13 million tons annually with delays of around 40 minutes per tow. In 2013 (LPMS), Brandon Road Lock processed 10.4 million tons of commodities (31.0% was crude petroleum), 2,370 tows with 10,063 barges, 555 recreation craft, and 698 light-boats. Average tow size was 4.2 barges per tow carrying 4,388 tons. Average processing time from 2009-2013 was 1.04 hours per tow with an average delay of 0.67 hours per tow.

2.2 Existing Condition Input Data

The primary existing condition data source is the USACE LPMS data. Additional information comes from USACE operations staff. Figure 10 shows the LPMS timing areas that serve as a rough approximation of the component processing time flags. The green shaded portions at the top and bottom of the image represent the end of the arrival area, with the beginning extending an average of 0.75 miles up and down river. Vessels entering this area can be considered arrived and their time is entered thusly. The yellow areas represent the approach areas and vessels typically do not enter these areas until they have received the go ahead to start their lockage. Approach times can be shorter if the next vessel in queue is traveling in the same direction as the vessel utilizing the chamber, as the vessel can tie off below the lock chamber while the first vessel is locking. This time the vessel is waiting is considered delay time instead of approach time. The red shaded area represents the lock chamber and time is measured entering the lock once the bow of the vessel has crossed the sill, the time spent in the chamber during elevation changes, and the time spent exiting the lock to the point that the lock can serve the next vessel. These times will vary, as the next vessel could be heading in the same direction which leads to a shorter exit time, or the next vessel could be traveling in the opposite direction and the first vessel needs to clear the area before the next vessel can approach. These times are compiled to calculate the processing time of each vessel, and is added to delay in order to calculate the overall transit time.

Figure 11 Brandon Road Lock –LPMS Arrival and Approach Areas

2.2.1 Processing Times

LPMS data from 2000 through 2013 served as the data source for defining detailed component processing time distributions. The development of processing time distributions is ideally completed using as large a sample set as possible. In order to select the period from which the timing data is pulled, analysts will typically look at historic times on a year-by-year basis and select the largest sample set consistent with the times recorded in the most recent complete record year. Over time, recorded lock component processing times can change. These changes can be the result of the implementation of a different measuring system (e.g., Automatic Identification System), significant changes in fleet characteristics (such as horsepower or speed changes), or lock performance through improvements or degradation of systems.

Six component processing time sample sets (long [fly or exchange] approach, short [turn back] approach, entry, chambering, long [fly or exchange] exit, and short [turn back] exit) were developed by direction, and lockage type (i.e., single-cut, double-cut, etc.). These sample sets were then analyzed with Palisade @RISK software to determine which WAM distribution type (Table 3) fits the data the best. These historical processing times are analyzed to assess how efficiently the lock is performing by determining the without-project-condition (WOPC) capacity.

Summary statistics for the various component processing times distributions can be seen in Table 8. Timing records from 2000-2013 were used as there were no obvious variations in operating policy or fleet characteristics that served as a break which made other years invalid. It should be noted that the sample size is the size of the sample for each component time after the removal of outliers, the process for which is discussed below.

Table 8 Summary Statistics for 2000-2013 Brandon Road Lock Component Processing Times [a]

Component Time		Up bound		Down bound	
		Sample Size[b]	Mean Time (minutes)	Sample Size [b]	Mean Time (minutes)
1-cut	Long Approach	12,767	14.2	13,738	10.0
	Short Approach	2,899	8.4	2,540	5.9
	Entry	15,666	15.1	16,278	12.4
	Chambering	15,666	25.1	16,278	17.7
	Long Exit	12,805	13.2	13,880	14.1
	Short Exit	2,861	14.1	2,396	14.6
2-cut	Long Approach	2,442	24.5	2,314	15.7
	Short Approach	671	13.9	349	8.2
	Entry	3,091	24.9	2,663	21.2
	Chambering	3,091	94.1	2,663	77.8
	Long Exit	2,309	34.7	1,920	40.8
	Short Exit	782	31.8	743	34.0

[a] Source: Lock Performance Monitoring System (LPMS)
[b] Sample size after the removal of outliers.

It should be noted that the sample size is the size of the sample for each component time after the removal of outliers. A total of 4,220 outliers were removed from the data set represented in Table 8. These outliers were removed due to the inability to fit into a long/short approach or exit group or instances where they were identified as a double cut but no information on either the first or second cut was found in the dataset. Removed records accounted for 5% of the total population and occurred almost solely in the approach or exit fields. The remaining sample size contained a sufficient amount of information to derive the distributions given the broad range of historic data available for analysis.

After removing outliers, the component processing time distributions for Brandon Road Lock are then fitted to a specific probability density curve using the Palisade @Risk software. Palisade's @Risk has a feature to automatically fit a distribution to one or more probability density curves that are each of a different probability distribution type (e.g., Gamma or Weibull Distribution) selected in the program. The selected distribution types to which component processing times are fitted can then be compared with one another to determine the "best fitting" distribution type.

@Risk uses maximum likelihood estimators to make an initial attempt at estimating the best probability distribution type to fit to the sample distribution. Maximum likelihood estimation is a technique to estimate the model parameters, i.e., the parameters (e.g., mean, shape, and location parameters) of the probability density function that allow the sample distribution to be fitted to a specific probability distribution. Maximum likelihood estimation selects the model parameter values that will maximize the likelihood or probability of simulating the observed sample distribution with a fitted probability density function of a specific distribution type.

The criteria for comparing and choosing the best-fitting probability distribution selected in @Risk is a multi-stage process that requires the user to exercise discretion. The first stage requires identify the distribution that seems to have a shape similar to the sample's actual probability density function. If this condition is met, then the best-fit distribution is selected based on which distribution has the lowest Akaike information criterion (AIC). AIC is a score that rewards goodness-of-fit (i.e., how well the model explains the actual sample probability distribution of a component's processing times) while penalizing overfitting (i.e., unnecessarily adding parameters to the model that explain the sample distribution well but not out-of-sample observations for the same processing time component, since the model is mistakenly treating some of the idiosyncrasies in the sample data as explainable that in fact cannot be explained by the model). Overfitting almost always increases goodness-of-fit and goodness-of-fit is not the only necessary criteria in determining the best-fitting distribution.

When @Risk fits the various distributions it calculates a set of parameters that correspond to the probability density function that describes the fitted density curve. Some or all of these parameters are then input into WAM to simulate the project's capacity in the WOPC and four alternative WPCs.

For example, exponential distributions, which were one of the most common distribution types to which a sample distribution was fitted, require a scale and location parameter. These parameters were also required inputs for describing other commonly fitted distribution types such as gamma distributions, log-logistic distributions, and Weibull distributions.

The location parameter produced by @Risk is a measure of the minimum value in the fitted distribution. Regardless of the location parameter value generated, it was assumed for input in to WAM that the location parameter was never less than 1.0 since the minimum component processing time duration that can be recorded in LPMS is 1 minute. When a location parameter is the minimum value of the distribution than it is specifically called a shift parameter. Shift parameters are often applied to processing time distribution due to their having a lower bound.

The scale parameter measures how spread out a distribution is. Increasing the scale parameter for a probability density function will widen its corresponding curve and flatten the curve's peak (i.e., lengthen its tails). The scale parameter for a standard normal probability distribution is equal to its standard deviation. A scale parameter of one will result in the probability density function remaining unchanged. A scale parameter of greater than one horizontally stretches out a probability density function in both directions; whereas as a scale parameter that is a fraction will compress the probability density curve's width.

Another parameter needed for some distribution types is the shape parameter, which is any parameter that is not a scale or location parameter and affects the shape of the probability density curve. The shape can be estimated in terms of the skewness and (or) kurtosis of the distribution.

2.2.2 Random Minor Downtimes

Locks experience periods of time when traffic is unable to transit through the facility. These periods are referred to as downtime. This study addresses downtime by segregating these events into two groups, random minor and major maintenance. This section discusses random minor downtimes.
Random minor downtimes are short duration, less than 1 day, unscheduled chamber closures. They are caused by various things such as the weather, mechanical breakdowns, river conditions, lock conditions, and other circumstances. For Brandon Road Lock analysis random minor downtime files were developed based on 2009 through 2013 LPMS data and are summarized in Table 9.
.

Table 9 Brandon Road Lock Historic LPMS Random Minor Stalls and WAM Downtime [a]

Disruption Description	Number of Occurrences	Average Duration (Minutes)	Minimum Duration (Minutes)	Maximum Duration (Minutes)
Bridge or other structure (i.e. railway, pontoon, swing, etc.)	7	54	24	114
Debris in lock recess or lock chamber	1	62	62	62
Fog	1	60	60	60
Ice on lock or lock equipment	1	66	66	66
Lightning	1	79	79	79
Lock hardware or equipment malfunction	4	97	56	124
Lock OK; Unused for other reasons (i.e. River closing etc.)	2	114	21	206
Maintaining Lock or Lock Equipment	526	53	13	321
Other	4	28	7	47
Repairing Lock or Hardware	2	60	4	115
[a] Source: Lock Performance Monitoring System (LPMS)				

2.2.3 **Fleet**

The fleet is the sum total of all vessels that use the lock. This includes commercial tows, Light-boats, and recreation craft. The fleet is fed to WAM as an external event file known as the WAM shipment list. The shipment list is generated based on historic LPMS and WCSC data, and may contain several thousand records. Each record, which represents a shipment, has a unique arrival time and vessel description. When taken in total, a WAM shipment list closely matches the overall characteristics of the actual fleet.

A typical shipment can be characterized three ways; by type of vessel, by size of vessel, and by time of arrival. WAM simulates three types of vessels, tows, recreation craft, and Light-boats / other vessels. The size of the vessel is dependent on vessel type, and for tows, the number and type barges. Arrival times are based on historic arrival patterns, with each vessel type having its own arrival pattern. The actual arrival time in any one given WAM shipment list is variable. The shipment list drives what happens at the lock during the simulation. Therefore, a great deal of effort is expended to ensure that the "what and when" of the WAM fleet closely match the "what and when" of the actual fleet.

2.2.4 **Vessel Types**

Vessels are grouped into one three types in this study. Tows are commercial towboats pushing one or more barges. Light-boats are commercial towboats without barges. Recreation craft are non-commercial, usually small, vessels. Commercial-passenger vessels, government vessels, and other vessel types are counted and included in the Light-boats group. Table 10 shows the number of vessels, by vessel type, for the 2013 Brandon Road fleet.

Table 10 Brandon Road Lock Number of Vessels by Type [a]

Vessel Type Classification	Vessel Count
Tows	2,370
Recreation	555
Light/Other	707
Source: Lock Performance Monitoring System (LPMS)	

2.2.5 Towboat Types

Towboats were categorized into 8 groups based on horsepower. Table 11 lists the towboat types, horsepower, prevalence, and dimensions used in this study.

Table 11 Brandon Road Lock Towboat Types, Horsepower, and Dimension Assumptions [a]

Horsepower Class	Percent of Population	Length (Feet)	Width (Feet)
< 1,000	28.8	82	24
> 1,000	3.5	98	29
> 1,500	10.7	115	30
> 1,900	21.4	131	31
> 2,300	18.1	141	35
> 3,100	6.1	151	40
> 4,200	8.5	162	42
> 5,500	3.0	185	53
[a] Source: Lock Performance Monitoring System (LPMS)			

2.2.6 Barge Types

Tow size is a key input determinant when estimating lock capacity. Tow size is determined by the type and number of barges being pushed. This study models 12 barge types which are typical on the inland navigation system. Table 12 shows the barge types, barge dimensions, number of barges, percent of total barges by type, and barges per tow in the 2013 Brandon Road Lock fleet.

Table 12 Brandon Road Lock Barge Data [a]

Barge Type	Length (Feet)	Width (Feet)	Percent of Total	Total Barges Per Tow
Sand Flat	135	27	0.24	2.2
Regular	175	26	0.01	1.0
Stumbo	195	26	0.00	-
Jumbo	195	35	35.66	4.6
Covered Jumbo	195	35	41.47	6.5
Super Jumbo	245	35	9.77	2.8
Giant Jumbo	260	52	0.01	1.0
Jumbo Tanker	195	35	0.00	-
147 Tanker	147	52	0.39	1.7
175 Tanker	175	54	0.17	1.5
264 Tanker	264	50	0.71	1.6
297 Tanker	297	54	11.57	2.3
Total				4.2
Source: Lock Performance Monitoring System (LPMS)				

2.3 WAM Existing Condition Calibration and Validation

WAM calibration and validation involves first a validation of the shipment list generator and the shipment list that is fed into the WAM simulation. After the shipment list is calibrated, the next step is to validate the WAM simulation itself. The validation process for Brandon Road Lock existing condition consisted of three steps: 1) validation of the shipment list; 2) validation of the processing times by lockage type; and 3) validation of the delay times.

2.3.1 Shipment List Calibration

After the input data is prepared, the next steps in running WAM are running the shipment list, generator and calibrating, and validating the shipment lists. Calibration is a process that fine-tunes the input files so that generated shipment lists closely match the real world fleet. Calibration is necessary for two reasons. First, WAM uses two data sources to create the shipment lists, and the data sources are not perfectly compatible. Second, the shipment list generator generates tows that have only one barge type instead of two or more barge types in a single tow. For a full explanation of how the shipment list generator works, see Section 2.4.5. A detailed description of the calibration process can be found in Section 2.4.6. It should be noted that every shipment list contains the same number of recreational craft and light-boats as measured by LPMS at Brandon Road in 2013 (707 light-boats and other vessels types, and 555 recreation craft).

Table 11 shows the statistics used when calibrating the shipment list. The target values for tons / loaded barge were taken directly from WCSC data. The target values for number of tows, number of barges were taken directly from LPMS data. The other remaining values were calculated based on the values taken directly from WCSC and LPMS. The values shown in the WAM Runs column are the averages of ten different WAM shipment lists. Calibration is considered complete when the WAM Runs are within 3% of the Target values for all statistics.

Table 13 Brandon Road Lock Shipment List Calibration [a]

	Target	WAM Runs	% Difference
Tonnage (Thousands)	10,536.79	10,438.00	-0.94%
Tows	2,370.00	2,400.00	1.27%
Tons per Tow	4,445.90	4,349.17	-2.18%
Barges	10,063.00	9,969.00	-0.93%
Percent Empty	38%	37%	-1.07%
Tons per Loaded Barge	1,701.40	1,672.22	-1.72%
Barges per Tow	4.25	4.15	-2.17%
Source: Lock Performance Monitoring System (LPMS) and Waterborne Commerce Statistics Center (WCSC)			

2.3.2 Processing Time & Delay Validation

After the shipment list is calibrated, the next step is to validate the WAM simulation itself. Validation ensures that WAM results reasonably reproduce actual base year processing and delay times. Target processing and delay times, taken directly from LPMS, were used to validate WAM. Fifty WAM runs were made at base year traffic levels with the First-In First-Out (FIFO) lockage policy, discussed in Section 2.4.1. The average processing and delay times for those runs is then compared to actual data.

Table 14 shows how well WAM reproduces the target processing and delay times. WAM reproduces processing times at Brandon Road Lock by 4.74%, but underestimates delay times by 3.02%.

Table 14 Brandon Road Lock Processing Time Validation [a]

Year	Minutes					
	Average Processing Time	WAM Processing	Average Delay	WAM Delay	Average Transit	WAM Transit
2009	67.10		55.29		122.39	
2010	60.67		31.82		92.48	
2011	60.27		38.20		98.47	
2012	59.68		31.18		90.85	
2013	64.19		45.35		109.54	
5-Year Average	62.30	65.40	40.18	39.00	102.48	104.40
Note: All times are expressed in terms of minutes per tow [a] Source: Lock Performance Monitoring System (LPMS)						

2.4 Existing / Without-Project Condition Capacity Analysis

Capacity is a useful number when making simple comparisons between locks. However, navigation economic studies do not use the capacity number. Instead, the economic analysis uses capacity curves, or tonnage-transit curves. The tonnage-transit curves are used because they define the relationship between tonnages processed and expected transit time over a range of tonnage levels. This way, the economic model can determine expected transit time for any given tonnage between zero and capacity.

2.4.1 Identification of Optimal Lockage Policy

After input preparation, shipment list calibration, and processing and delay time validation, the next step is to determine the most efficient lockage policy. This is done to satisfy Corps regulation ER-1105-2-100 section II, E-9.c.a which states in part "Assume that all reasonably expected non-structural practices …. Including … lockage policies are implemented at the appropriate time." Two lockage policies are typically evaluated: First-In First-Out (FIFO); and n-up / n-down service policy.

Often to determine the best or "optimal" lockage policy, simulation runs are made at high project utilization levels for each lockage policy. The 'optimal' lockage policy is the policy that results in the highest tonnage level with the lowest transit time at maximum lock utilization. With the n-up / n-down service policy in WAM, FIFO is practiced until the n-up / n-down policy becomes optimal. The n-up / n-down policy is typically optimal at high utilization levels as it minimizes chamber turn-back operations.

Factors that can contribute to the optimal lockage policy include historical patterns of vessel arrivals, vessel loading patterns, directional fleet characteristics, project geography, and turnback time for the lock chamber. Test runs were performed for the existing / without-project condition to determine the best operating policy, with FIFO yielding a higher capacity at the maximum utilization levels after multiple variations of the tests were performed. Test results were conclusive and point to the directional loading characteristics as being a determinant for the optimal lockage policy. Approximately 66% of tonnage transiting Brandon Road moves up bound. Efficiencies can be gained overall by an n-up / n-down service policy, but these efficiencies do not contribute to more tonnage transiting the lock, which is the primary goal of a capacity analysis. Therefore FIFO was used for modeling throughout the analysis.

2.4.2 Without-Project Condition Capacity Results

For the economic analysis, a full-operations and two service disruption curves were developed. The processing time and capacity for the curves with a single main chamber operating for the entire year with only random minor downtimes is shown in Table 15 along with the processing times and capacities for the two service disruption events.

Table 15 Brandon Road Lock Existing / WOPC Capacity and Transit Times

Simulated Event Name	Tonnage at Capacity	Average Transit Time (Hours)	Average Processing Time (Hours)
Full Operation	27,958,690	200.00	1.09
120-Hour 24-Hour/Day Emergency ANS Response	27,388,788	200.00	1.09
720-Hour 24 Hour/Day Work Item Event	22,260,366	200.00	1.09

2.4.3 **Full-Operations Tonnage-Transit Curves**

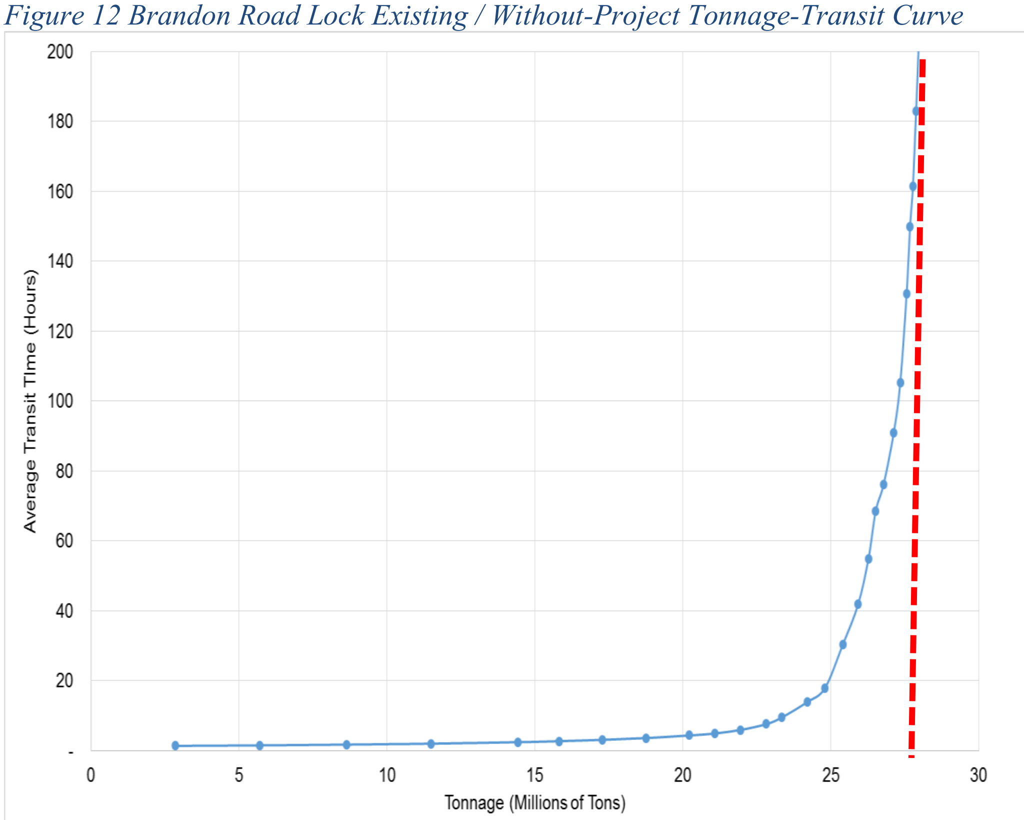
Full capacity curves were developed for the Full Operation (no closure) at Brandon Road Lock.

Figure 12 shows the capacity curve and other information for Brandon Road Lock, Without-Project Condition, Full-Operation Scenario. This capacity curve is used to represent a year where only random downtime occurs. The curve is developed by running WAM at 27 different traffic levels, 125 different runs per level. Therefore, 3,375 WAM runs were made to create one curve. The curve connects the averages at each tonnage level.

Figure 12 also shows a vertical dashed line where the curve goes asymptotic. This value is the capacity shown in For the economic analysis, a full-operations and two service disruption curves were developed. The processing time and capacity for the curves with a single main chamber operating for the entire year with only random minor downtimes is shown in Table 15 along with the processing times and capacities for the two service disruption events.

Table 15 as 27,958,690 tons. The capacity is the tonnage that corresponds with a transit time of 200 hours. The 200 hour transit time is an arbitrary value. In this reach of the curve, the different in tonnage between say, 150 hours and 300 hours is very small.

Figure 12 Brandon Road Lock Existing / Without-Project Tonnage-Transit Curve



2.4.4 Service Disruption Tonnage-Transit Curves

For the economic analysis of the without-project condition two service disruption curves were also needed and developed. The service disruption events are summarized below.

2.4.4.1 720-Hour 24-Hour/Day Scheduled Work Item Event

The tonnage-transit curve simulations for the 720-hour 24-hour/day service disruption event assumes a consecutive 30-day closure of the lock. This service disruption event was defined for dewatering & monitoring, major repair, and gate work item event. This event will be a scheduled work item and therefore traffic during this event was rescheduled in the model to pre and post ship, half in the month before and half in the month after. This reflects that tows are not going to try to transit the lock during the closure, but the need for the shipments will lead to high demand, and thus congestion, before and after the event. This conservative assumption was made given the information received from the 2011 UT CTR surveys, which highlighted the lack of storage and stockpiling capacity for shippers utilizing Brandon Road lock.

2.4.4.2 120-Hour 24-Hour/Day Unscheduled ANS Emergency Response Event

The tonnage-transit curve simulations for the 120-hour 24-hour/day service disruption event assumed an emergency unscheduled closure of 5 consecutive days to support emergency ANS response actions. This service disruption event serves as a proxy for response impacts, based upon review of previous events and estimates of what future events may entail. This event is unscheduled, and thus traffic is not rescheduled around the closure. This is reflected in the tonnage transit curve as the curve has a higher starting point on the y-axis than even the 720-hour event. The relatively small number of tows at the low utilization levels still have a high average delay given the vessels caught during this event.

2.4.5 The Family of Brandon Road Lock Tonnage-Transit Curves

Figure 13 shows the service disruption tonnage-transit curves mapped against the full-operations tonnage-transit curve. The capacity value at 200 hours of average transit time for each curve is displayed in For the economic analysis, a full-operations and two service disruption curves were developed. The processing time and capacity for the curves with a single main chamber operating for the entire year with only random minor downtimes is shown in Table 15 along with the processing times and capacities for the two service disruption events.

Table 15. Care is taken to insure that curves do not cross, as this is usually indicative of an error, as a project with less availability should have less capacity. This is generally the case when curves represent similar events. In Figure 12 however, the curve representing the 120-Hour emergency ANS response event can be seen crossing the 720-hour curve. This curve represents a complete unscheduled closure, while the other curve represents a scheduled closure with traffic pre and post shipping due to the event. Without this mechanism for rescheduling traffic during event, the base average transit time for the 120-Hour unscheduled emergency ANS response event is relatively higher given the small number of tows at the low utilization levels and tows being caught for the duration of the 120-hour event, thus the curve begins higher on the y-axis.

Figure 14 displays the relevant range of tonnage for the existing without-project condition in order to display the characteristics of the curves in relation to historic tonnages.

Figure 13 Brandon Road Lock Existing / Without-Project Tonnage-Transit Curve Family

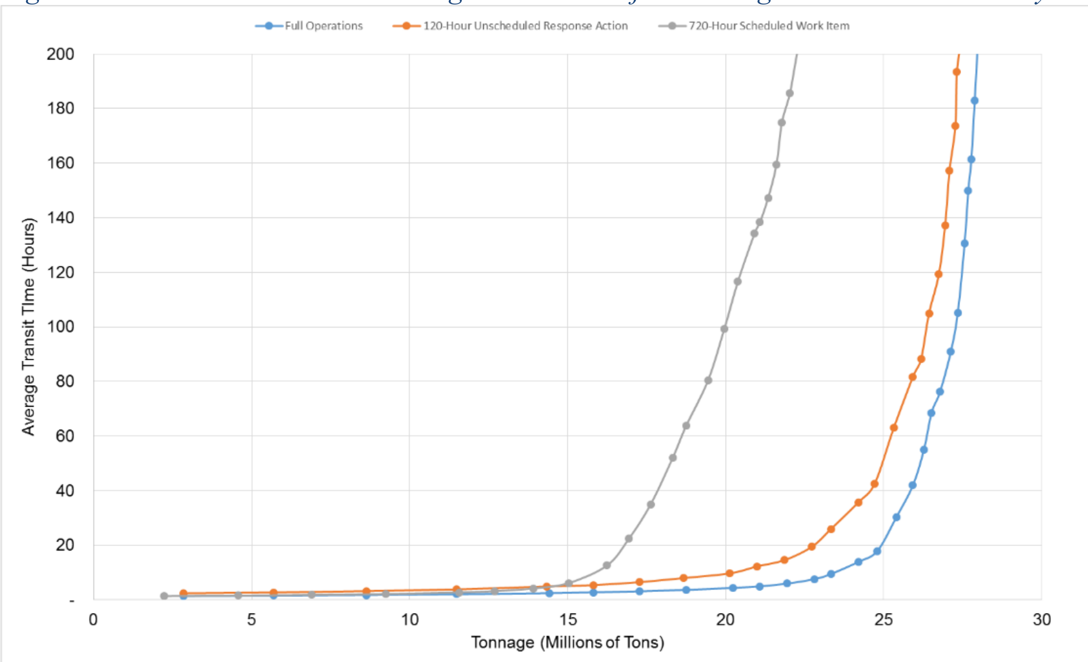
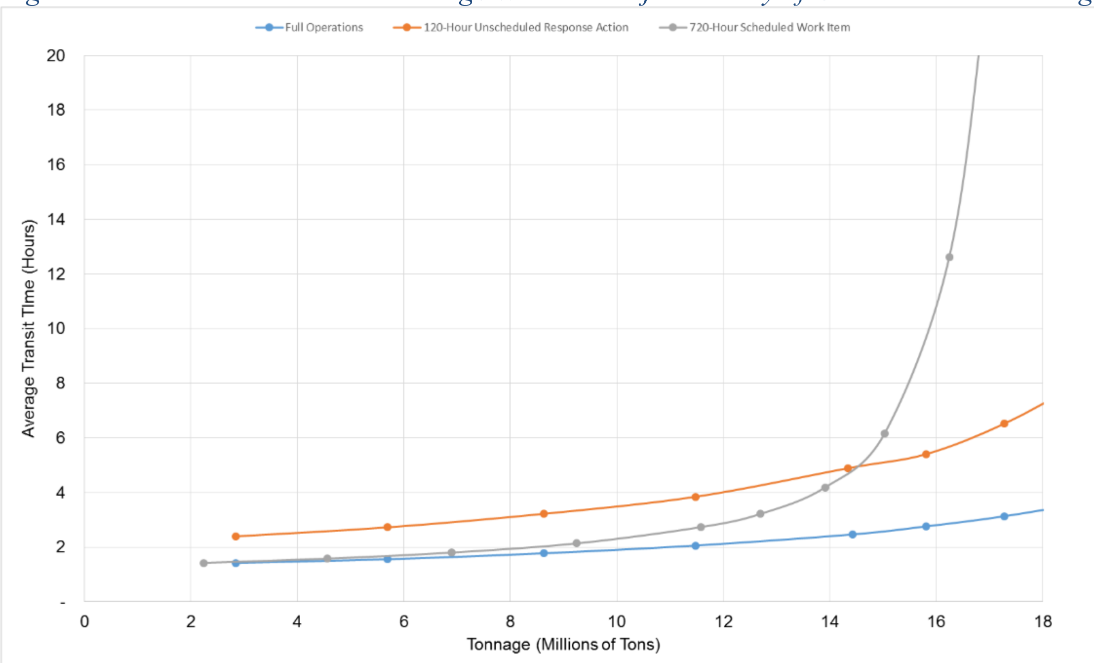


Figure 14: Brandon Road Lock Existing / Without-Project Family of Curves - Relevant Range



3 Brandon Road Lock With-Project Condition Capacity Analysis

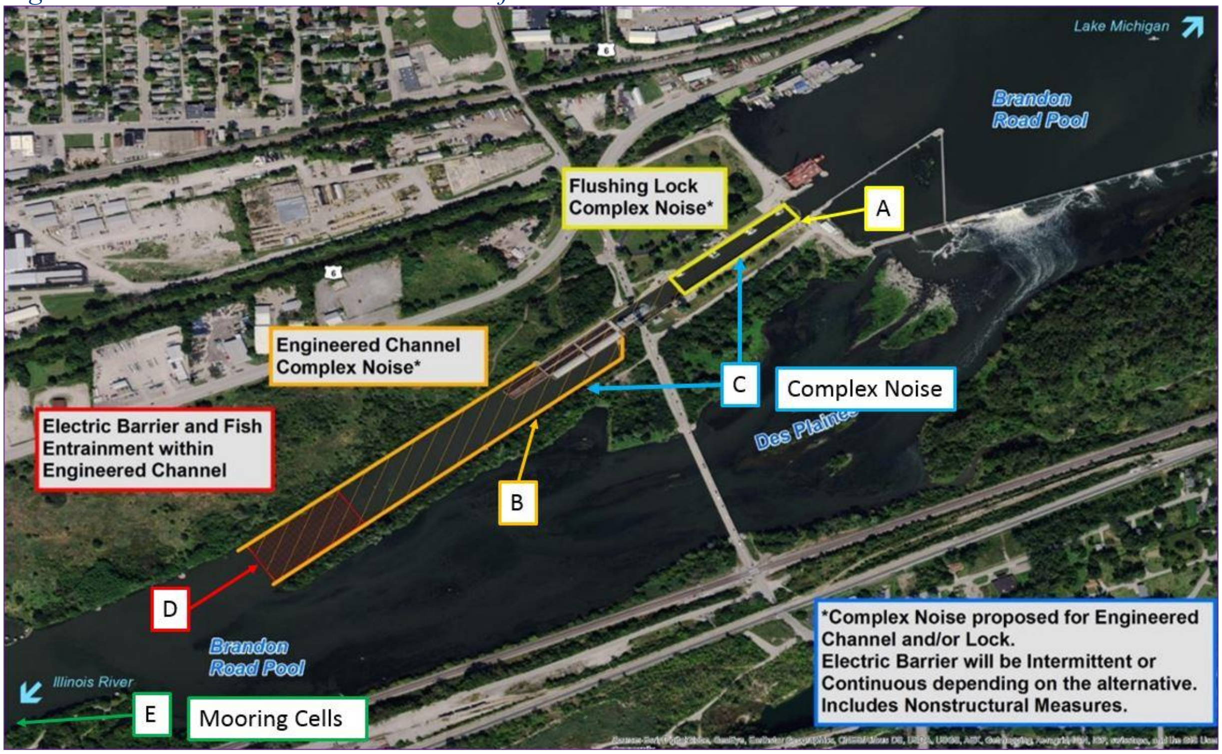
The Brandon Road with-project condition capacity analysis is focused around various ANS control measures proposed for implementation at Brandon Road. Table 16 displays the final array of alternatives considered in the GLMRIS-BR, along with the ANS control measures that they include.

Table 16 ANS Control Measures Included in GLMRIS-BR Alternative Plans

GLMRIS-BR Alternative	ANS Control Measures/Features									
	Sustained Current Activities	Nonstructural	Boat Launches	Flushing Lock	Engineered Channel	Water Jets	Complex Noise	Electric Barrier	Mooring Cells	Lock Closure
No New Federal Action	×									
Nonstructural Alternative	×	×	×							
Technology Alternative – Electric Barrier	×	×	×	×	×	×		×	×	
Technology Alternative – Complex Noise	×	×	×	×	×	×	×			
Technology Alternative – Complex Noise with Electric Barrier	×	×	×	×	×	×	×	×	×	
Lock Closure	×	×	×							×

The features under consideration at Brandon Road Lock are to be constructed within the existing project profile, using the existing and largely unmodified lock chamber. The measures captured in the capacity analysis include a flushing lock, complex noise, an engineered channel, an electric barrier, and mooring cells. Mooring cells are not an ANS response measure, but an element of the study which represents a navigation operation change at the project. Figure 15 displays an aerial view of Brandon Road Lock with outlines of the proposed measure locations. The details of these features are discussed in the *GLMRIS-BR Appendix D – Economic Analysis*. The details of these features are discussed below in terms of their impacts on navigation.

Figure 15 Brandon Road Lock – With-Project Condition Features



Nonstructural Measures

Nonstructural measures above those expected to occur in the No New Federal Action alternative are included as a part of all alternatives. Nonstructural controls do not require the construction of a permanent feature in the waterway and can generally be implemented fairly quickly. Examples include but are not limited to electrofishing and netting. These additional nonstructural measures are not anticipated to have any effects on navigation at BRLD.

Flushing Lock

Navigation Considerations During Construction of Flushing Lock. Construction of the flushing lock would occur at the beginning of the construction period and take approximately 40 days to completely construct. Construction entails reengineering the filling and emptying ports to successfully facilitate the flushing process. These 40 days of construction require a complete, scheduled lock closure.

Navigation Considerations for Operation of Flushing Lock. Operations of the flushing lock entail performing a flushing operation whenever an upbound (moving north from the Dresden Island pool into the Brandon Road pool) vessel approaches the lock. Additionally the second iteration of a consecutive downbound operation, whether it be the second of a multi cut tow or a downbound tow right after another downbound tow, will require a flushing operation. The frequency of this operation is subject to further refinement through physical modeling and dependent upon the availability of water in the Brandon Road pool sufficient to perform the operation, but this analysis assumes every upbound operation and the second consecutive downbound operation is subject to the flushing operation.

The reconfiguration of the filling and emptying ports is beneficial for the lockage process as it is expected to allow the lock to be filled and emptied more quickly and efficiently. This reduction in chambering time slightly reduces the magnitude of the impact from the overall flushing process. The assumed flushing process requires that vessels approaching the lock wishing to pass from the Dresden Island pool to the Brandon Road pool will approach the lock as usual, tie off to the long wall on the right-descending bank, and wait for the lock chamber to flush. Once the flushing process has completed, the vessel will untie from the wall and enter the chamber to process normally.

Navigation Considerations for MRR&R of Flushing Lock. The flushing lock is not expected to require additional MRR&R.

Engineered Channel

Navigation Considerations during Construction of the Engineered Channel. The engineered channel is the main construction item of the technology alternatives evaluated in this analysis. The construction begins concurrently with the flushing lock and takes approximately 909 days to complete. Concurrent with the 960-hour (40 day) closure for flushing lock implementation, construction crews will be constructing the section of the engineered channel closest to the lock chamber to minimize the impact to navigation once the lock reopens. After this 960-hour (40 day) closure, the lock will be unavailable 12 hours per day for the next 30 days, or 360-hours, so that construction crews can complete the engineered channel near the lock to the point that the remainder of the construction can be completed with minimal navigation impacts. Given the intermittent nature of the closure and its proximity to the 960-hour (40 day) closure, traffic is not rescheduled for this event.

Navigation Considerations for Operation of the Engineered Channel. Post implementation of the engineered channel, there are no operational changes identified from operating the engineered channel in and of itself.

Navigation Considerations for MRR&R of the Engineered Channel. The engineered channel is not expected to require additional MRR&R.

Complex Noise

Navigation Considerations During Construction of Complex Noise System. Construction of the complex noise system is assumed to be the final construction activity for alternatives where complex noise is the alternative's only fish deterrent. For alternatives including the speaker system, installation is expected to take approximately 45 calendar days to complete. During this implementation phase, the lock will be closed for approximately 8 hours per day, 5 days a week. For partial closures, navigation is not assumed to reschedule shipments around the closures. For alternatives utilizing both complex noise and electric barrier as swimmer controls, implementation of these measures is anticipated to occur concurrently.

Navigation Considerations for Operation of Complex Noise System. The complex noise system, once implemented, is not anticipated to have an impact on navigation through Brandon Road Lock.

Navigation Considerations for MRR&R of Complex Noise System. The speakers will require periodic replacement, but this is not expected to impact navigation.

Electric Barrier

Navigation Considerations during Construction of Electric Barrier. Implementation of the electric barrier requires work by divers to complete electrode and parasitic placement. This work requires the lock to be shut down for 8 hours per day, 5 days per week for a construction period of approximately 22 calendar days. In alternatives with both an electric barrier (D) and a complex noise system (C), the implementation of the measures are assumed to occur concurrently.

Navigation Considerations for Operation of Electric Barrier.

Two operating parameters were are considered for the electric barrier, intermittent and continuous operating parameters. See Chapter 6 of Main Report for more information regarding operating parameters.

Intermittently Operated Electric Barrier. For alternatives that include two swimmer controls, electric barrier and complex noise, the electric barrier was assumed to be turned off while vessels were approaching the downstream channel, while they were in the channel, and while they were in the lock. The second swimmer control would be available when the electric barrier was off. By shutting off the electric barrier in the presence of vessels, the navigation restrictions for a continuous electric barrier are assumed to be avoided, and navigation is assumed to not be appreciably altered.

Continuously Operated Electric Barrier. A continuously operated barrier is included in the alternative that has one swimmer control. As noted above, assumptions regarding operating parameters were developed with the intention of being protective of life safety. If an alternative is implemented, USACE and USCG would test and evaluate measures included in the alternative to address site-specific operating considerations that cannot be addressed until after construction. These assumptions may or may not be a more restrictive than what would actually be imposed.

Vessel operators will sometimes approach lock chambers with flotillas that do not fit inside the lock chamber as they are configured. Sometimes this requires tows to make multiple cuts to transit a lock, a process by which a portion of the flotilla is placed within the chamber, the rest backs away, and mechanical tow-haulage units or other tows will extract the preceding portion after it completes the process. This will be repeated until the entire tow has transited. In other scenarios, it may be more efficient for a flotilla to move in a tow that exceeds the locks length, counting the towboat, but not the locks width. In these instances, the towboat will disconnect from the rest of the flotilla after placing it in the chamber, and pull alongside to fill the remaining width, allowing the long tow to transit in a single cut.

These operations all require workers to be out on deck disassembling tows or reconfiguring them. These operations put workers at higher risk for falling overboard. To facilitate the evaluation of this measure within the context of the navigation analyses, it is assumed that these operations would no longer be allowed in the vicinity of the engineered channel or lock. The only time this restriction is assumed to be in place is in the immediate area of the lock and the engineered channel. Thus, for commercial cargo navigation, this limits tows transiting the lock to 550 feet by 110 feet, as discussed above in the reconfiguration restriction section.

These changes are included in WAM by adjusting the input files such that no combination of towboat size and length and barge size and length contained tows of this size, and redistributing statistics for the now oversize tows to the largest possible tow combinations of towboats and barges by that size. Table 17 displays the maximum number of barges per tow, given corresponding towboat size, for a 550 feet by 110 feet tow-size restrictions.

Table 17 Brandon Road Lock Continuous Electric Barrier Maximum Barges per Tow by Towboat Size

Towboat Size Classifications (Feet)	Maximum Barges per Tow Given a 550 Feet by 110 Feet Maximum Size											
	Barge Size Classifications (Feet)											
Length x Width	135' x27'	175' x26'	195' x26'	195' x35'	195' x35'	245' x35'	260' x52'	195' x35'	147' x52'	175' x54'	264' x50'	297' x54'
82' x 24'	9	6	6	6	6	3	2	6	6	4	2	2
98' x 29'	9	6	6	6	6	3	2	6	6	4	2	2
115' x 30'	9	6	6	6	6	3	2	6	4	4	2	2
131' x 31'	9	6	6	6	6	3	2	6	4	4	2	2
141' x 35'	9	6	6	6	6	3	2	6	4	4	2	2
151' x 40'	6	6	6	6	6	3	2	6	4	4	2	2
162' x 42'	6	6	6	6	6	3	2	6	4	4	2	2
185' x 53'	6	6	3	3	3	3	2	3	4	4	2	2

It is assumed that the electric barrier would increase the time for upbound vessels to transit the lock due to the inability of tows to wait in the vicinity of the downstream channel, and for any precautions they made need to take to insure they transit the lock safely. The actual increase in time is unknown. However, to account for this unknown time increase for upbound tows making a long approach, a 10-minute increase was used as a proxy. Accounting for this additional time allowed for more accurate estimate of the navigation impacts.

Navigation Considerations for MRR&R of Electric Barrier. The electric barrier is projected to have a design life of approximately 25 years, therefore this analysis assumes the system will have to be rehabilitated every 25 years throughout the planning horizon. This rehabilitation is projected to require the same downtime period as the implementation, so the rehabilitation is considered to occur within 22 calendar days and require 8 hour per day closures, 5 days per week.

Fish Entrainment Mitigation (Water Jets)

Water jets would be attached to the channel bottom and be used to remove or dislodge fish from up-bound tows to contend with vessel-induced motion that transports fish along with the vessel.

Navigation Considerations During Construction of Water Jets. Water jets are included in the construction of the engineered channel, and do not impose a unique set of restrictions during construction, and do not impose restrictions on navigation during their post-construction operation.

Navigation Considerations for Operation of Water Jets. The water jets are not anticipated to have an impact on navigation through Brandon Road Lock.

Navigation Considerations for MRR&R of Water Jets. The pumps for the water jets will require periodic replacement, but this is not expected to impact navigation.

Mooring Cells for Downstream Approach Channel

The addition of four mooring cells downstream of the lock is not a measure to address ANS, but is under consideration to facilitate the ease of navigation through the project and allow crews to make sure their tow is safe to transit the project.

Navigation Considerations During Construction of Mooring Cells. These mooring cells are projected for construction south of the lock away from the main approach area. They are not predicted to have any impact on navigation during construction.

Navigation Considerations for Operation of Mooring Cells. To capture the potential benefits of the mooring cells, the proxy time of 10 minutes that was assumed for upbound tows making a long approach due to the continuous electric barrier was removed in the model runs that included the new mooring area.

Navigation Considerations for MRR&R of Mooring Cells. The mooring cells will require a 1-time dredging event 25 years after they are constructed. This is not expected to impact navigation.

Boat Launches for Downstream Approach Channel

The downstream launch into Dresden Island Pool would be built at one of two locations, depending on the alternative. For the Nonstructural Alternative, the launch would be constructed on the isthmus of land adjacent to the approach channel. A gravel road with secure gate access would lead from Brandon Road to a parking area, and a boat launch into the approach channel. For the technology alternatives, the boat launch would be built further downstream, just south of the approach channel outlet. The access road to the electric barrier and/or complex noise control buildings would extend to a parking and launch area.

Navigation Considerations During Construction of Boat Launches. Construction of the boat launches are not expected to have any impact on navigation.

Navigation Considerations for Operation of Boat Launches. The boat launches are not anticipated to have an impact on navigation through Brandon Road Lock.

Navigation Considerations for MRR&R of Boat Launches. The boat launches are not expected to require additional MRR&R.

Permanent Lock Closure

Permanent lock closure involves the removal of the upstream operational gates from the Brandon Road Lock and replaces them with a permanent concrete wall that ties into the existing concrete gate sill and existing lock walls to structurally separate the upper pool from the lower pool. Permanent lock closure is solely included in the Lock Closure alternative.

3.1 With-Project Condition Input Data

The with-project condition data was built off the without-project condition data.

Processing Times. The WPC tonnage-transit curves were simulated in WAM based on adjustments made to the location parameter of the different WOPC component processing time distributions. The location parameter is shifted up by the amount by which the mean time increases for a specific processing component. This increase in the mean is in turn based on assumptions made about how changes to measures at Brandon Road Lock will impact processing times. Therefore the shape and distribution type will not change for a specific component processing time distribution, but its location may shift if the average time for the distribution is expected to change from the WOPC to the WPC. The probability density curve will still have the same height, skewness, and kurtosis, with the only change being the curve is shifted to the right along the horizontal access to indicate a uniform increase in the processing time for every observation within that distribution. Table 18 displays the component processing times for Brandon Road Lock that are subject to change given the proposed measures.

Table 18 Component Processing Time Changes by Measure [a]

	Processing Time Component	2009-2013 Average		Features [b]					
				Flushing Lock (A)		Continuous Electric Barrier (D)		Mooring Cells (E)	
		Up Bound	Down Bound	Up Bound	Down Bound	Up Bound	Down Bound	Up Bound	Down Bound
1-Cut Tows	Long Approach	11.88	9.36	21.5	0.0	10.0	0.0	-10.0	0.0
	Short Approach	8.01	5.92	18.0	18.0	0.0	0.0	0.0	0.0
	Chambering	24.29	17.32	-7.0	-7.0	0.0	0.0	0.0	0.0
2-Cut Tows	Long Approach	19.79	14.33	43.0	0	Assumed No-Multi Cut Tows		0.0	0.0
	Short Approach	10.69	9.25	36.0	36.0	Assumed No-Multi Cut Tows		0.0	0.0
	Chambering	108.28	96.37	-14.0	-14.0	Assumed No-Multi Cut Tows		0.0	0.0

[a] Source: Lock Performance Monitoring System (LPMS)
[b] Timing changes associated with each feature are expressed in minutes of additional or reduced time associated with the operation of the feature. As features are added to alternatives the times expressed are added to the processing time component designated here.

Processing Times. The random minor downtimes were assumed the same as under the without-project condition for all WPC alternatives (Table 9).

Fleet. The fleet was not expected to change under any of the WPC alternatives aside from the Technology Alternative – Electric Barrier and Technology Alternative – Electric Barrier with Complex Noise. The WOPC vessel, towboat, and barge types were assumed for all with-project condition alternatives, excluding the Technology Alternative – Electric Barrier and Technology Alternative – Electric Barrier with Complex Noise. Fleet assumptions for the continuously operating electric barrier are discussed in Section 3.3.3.2.

3.2 WAM With-Project Condition Calibration and Validation

Given that the fleet is not assumed to change under the with-project condition alternatives, excluding the continuously operating electric barrier, no WAM calibration and validation was required. The fleet assumptions for the continuously operating electric barrier are discussed in Section 3.3.3.2.

3.3 With-Project Condition Capacity Analysis

Table 16 displays the final array of alternatives considered in the GLMRIS-BR, along with the ANS control measures that they include. The final array includes No New Federal Action, the Nonstructural Alternative, Technology Alternative – Complex Noise, Technology Alternative – Electric Barrier, Technology Alternative – Complex Noise with Electric Barrier, and Lock Closure.

For the purposes of the capacity analysis, No New Federal Action and Nonstructural alternatives have no projected long term changes to the lock or lock performance, and therefore are identical to the Future-Without Project Condition. The Lock Closure alternative would result in the permanent closure of Brandon Road Lock once authorized by Congress; therefore, this alternate is not analyzed in the capacity analysis. The details of the remaining technology alternatives in relation to the capacity analysis are discussed below.

3.3.1 Technology Alternative – Complex Noise

The Technology Alternative – Complex Noise under consideration at Brandon Road includes the following ANS controls, nonstructural measures, flushing lock, engineered channel, and complex noise system. The capacity curves used for analyzing this alternative include the years of construction, a long-term operation curve, a curve representing emergency ANS response actions, and a curve representing a major rehabilitation operation of the lock chamber. All of the post-construction curves assume an operating flushing lock, an engineered channel, and a complex noise system.

3.3.1.1 Full-Operations Tonnage-Transit Curve

Full-operation tonnage-transit curves were developed for the Technology Alternative – Complex Noise. The processing time and capacity for the new single main chamber operating for the entire year with only random minor downtimes is shown in Table 19. The processing time and capacity values for each stage of construction as well as information pertaining to post-construction service disruptions. Note that average processing times are lower and the tonnage at capacity is higher during construction than for full operation. While construction is associated with closures, the operating policies post-construction result in higher average processing times and lower overall capacity.

Table 19 Capacity and Transit Times (Brandon Road Lock) for Technology Alternative - Complex Noise

Simulated Event Name	Tonnage at Capacity	Average Transit Time (Hours)	Average Processing Time (Hours)
Full Operation	17,576,152	200.00	1.27
120-Hour 24-Hour/Day Emergency ANS Response Event	16,916,999	200.00	1.27
720-Hour 24 Hour/Day Major Rehabilitation Event	13,365,483	200.00	1.27
1st Year Construction	21,085,269	200.00	1.09
2nd Year Construction	26,904,704	200.00	1.09
3rd Year Construction	21,537,544	200.00	1.20

3.3.1.2 Tonnage-Transit Curves Families for Technology Alternative – Complex Noise

Figure 16 shows the tonnage-transit curve family for the construction period of the Complex Noise alternative. The full-operations curve and two service disruption curves are displayed in Figure 17. The relevant range for the Operation Family of Curves is shown in

Figure 18. Similar to the 120-Hour event in the WPC, the 120-Hour event in the Technology Alternative – Complex Noise, at low utilization levels, the unscheduled emergency response event crosses the 720-Hour event given the rescheduling assumptions associated with the 720-Hour Event.

Figure 16 Construction Tonnage-Transit Curve Family (Brandon Road Lock) for Technology Alternative - Complex Noise

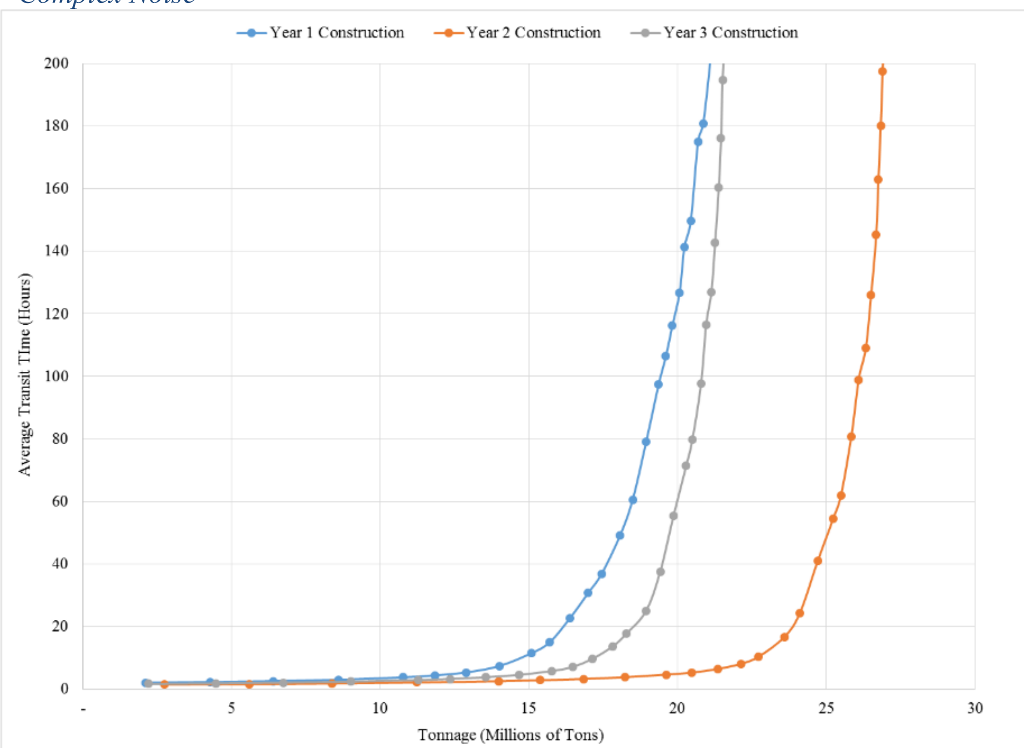


Figure 17 Operation Family of Curves (Brandon Road Lock) for Technology Alternative - Complex Noise

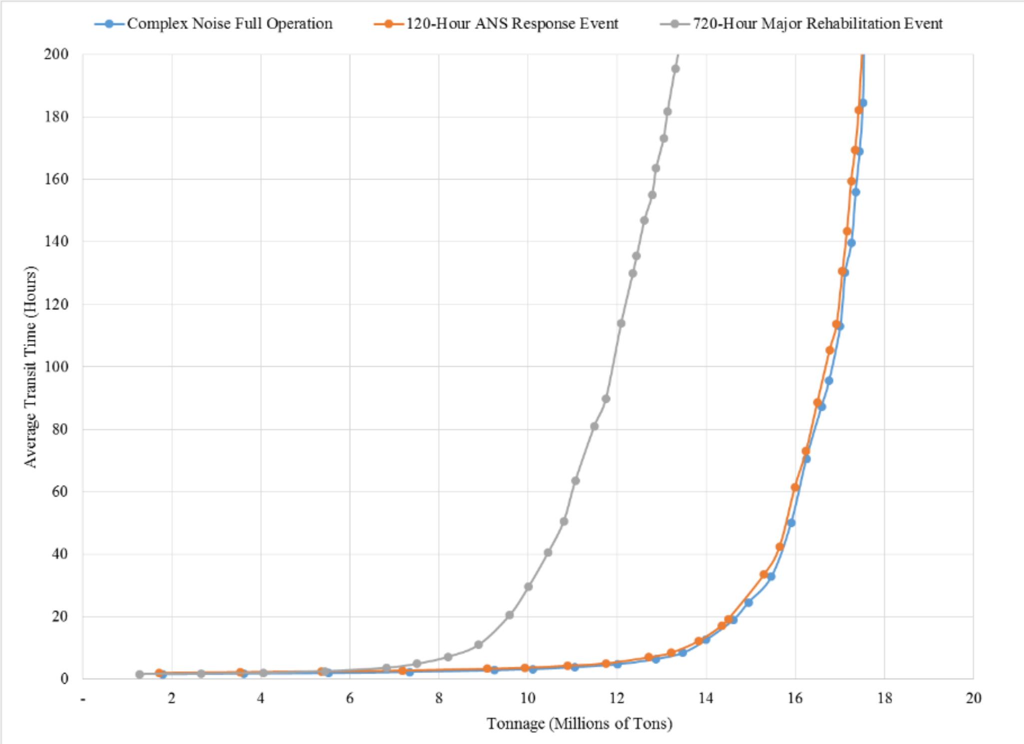
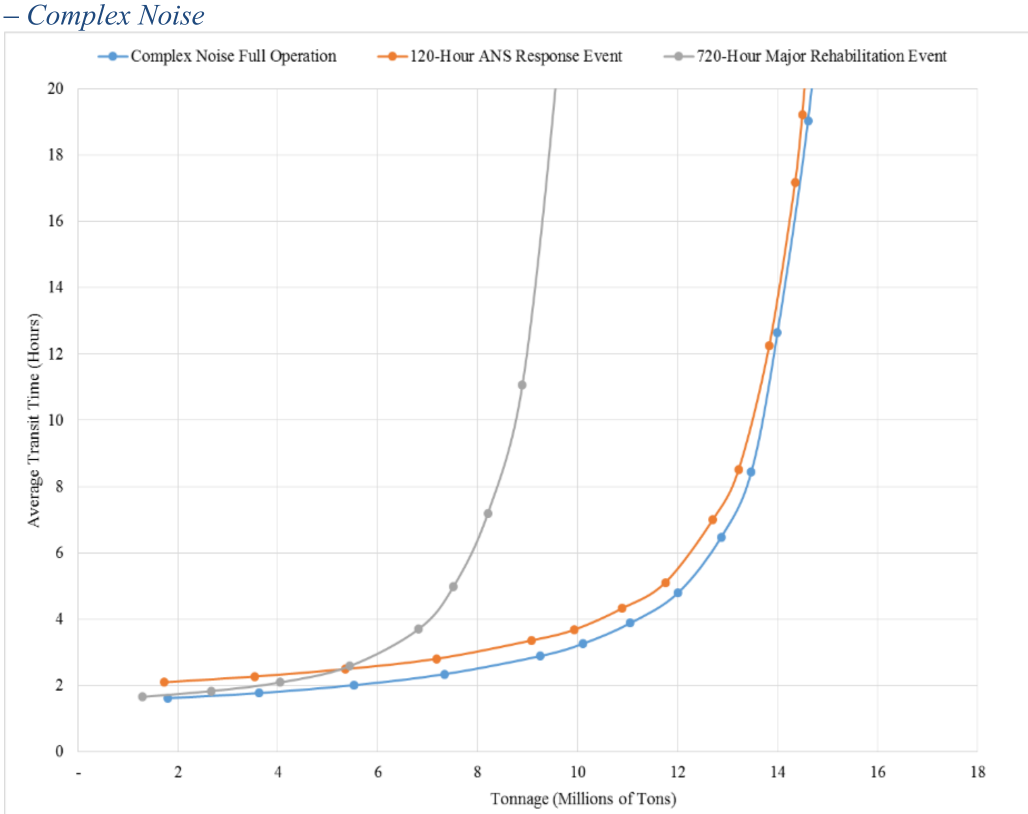


Figure 18 Operation Family of Curves – Relevant Range (Brandon Road Lock) for Technology Alternative – Complex Noise



3.3.2 Technology Alternative – Complex Noise with Intermittent Electric Barrier

The Technology Alternative – Complex Noise with Intermittent Electric Barrier under consideration at Brandon Road includes the following ANS controls: nonstructural measures, flushing lock, engineered channel, a complex noise system, and an electric barrier that operates when there are no vessels immediately downstream of the engineered channel, in the engineered channel and within the lock. The capacity curves used for analyzing this alternative include the years of construction, a long-term operation curve, a curve representing emergency ANS response actions, a curve representing a major rehabilitation operation of the lock chamber, and a curve for a scheduled replacement of the electric barrier system. All of the post-construction curves assume an operating flushing lock, an engineered channel, a complex noise system, and an intermittently operated electric barrier.

3.3.2.1 Full-Operations Tonnage-Transit Curve

Full-operation tonnage-transit curves were developed for the Technology Alternative – Complex Noise with Intermittent Electric Barrier. The processing time and capacity for the new single main chamber operating for the entire year with only random minor downtimes is shown in Table 20. The processing time and capacity values for each stage of construction as well as information pertaining to post-construction service disruptions. Aside from the electric barrier replacement work item, the operations of the intermittent electric barrier in terms of navigation impacts are identical to the Technology Alternative – Complex Noise. Note that average processing times are lower and the tonnage at capacity is higher during construction than for full operation. While construction is associated with closures, the operating policies post-construction result in higher average processing times and lower overall capacity.

Table 20 Capacity and Transit Times (Brandon Road Lock) for Technology Alternative – Complex Noise with Intermittent Electric Barrier

Simulated Event Name	Tonnage at Capacity	Average Transit Time (Hours)	Average Processing Time (Hours)
Full Operation	17,576,152	200.00	1.27
120-Hour 24-Hour/Day Emergency ANS Response Event	16,916,999	200.00	1.27
720-Hour 24 Hour/Day Major Rehabilitation Event	13,365,483	200.00	1.27
176-Hour 8 Hour/Day 5 Day/Week Electric Barrier Rehabilitation Event	16,327,768	200.00	1.27
1st Year Construction	21,085,269	200.00	1.09
2nd Year Construction	26,904,704	200.00	1.09
3rd Year Construction	21,537,544	200.00	1.20

3.3.2.2 Tonnage-Transit Curves Families for Technology Alternative – Complex Noise with Intermittent Electric Barrier

Figure 19 shows the tonnage-transit curve family for the construction period of the Intermittent Electric Barrier with Complex Noise alternative. The full-operations curve and three service disruption curves are displayed in
Figure *20*. The relevant range for the Operation Family of Curves is shown in

Figure 21. Similar to the 120-Hour event in the WOPC, the 120-Hour event in the Technology Alternative – Complex Noise with Intermittent Electric Barrier, at low utilization levels, the unscheduled emergency response event crosses the 720-Hour event given the rescheduling assumptions associated

with the 720-Hour Event, and the 176-Hour intermittent closure event for electric barrier replacement given the intermittent nature of the closure for the work item.

Figure 19 Construction Tonnage-Transit Curve Family (Brandon Road Lock) for Technology Alternative – Complex Noise with Intermittent Electric Barrier

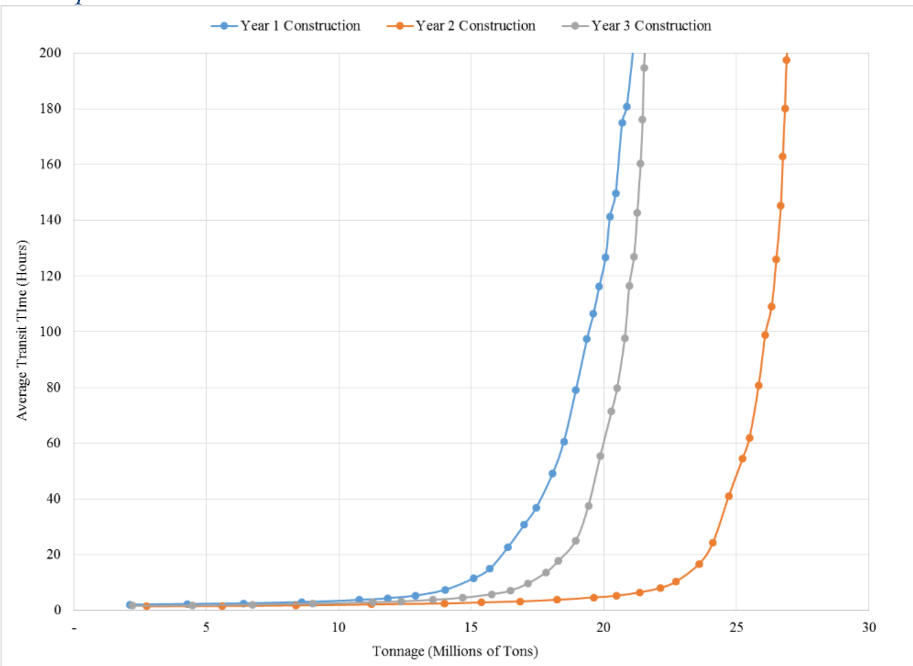


Figure 20 Operation Family of Curves (Brandon Road Lock) for Technology Alternative – Complex Noise with Intermittent Electric Barrier

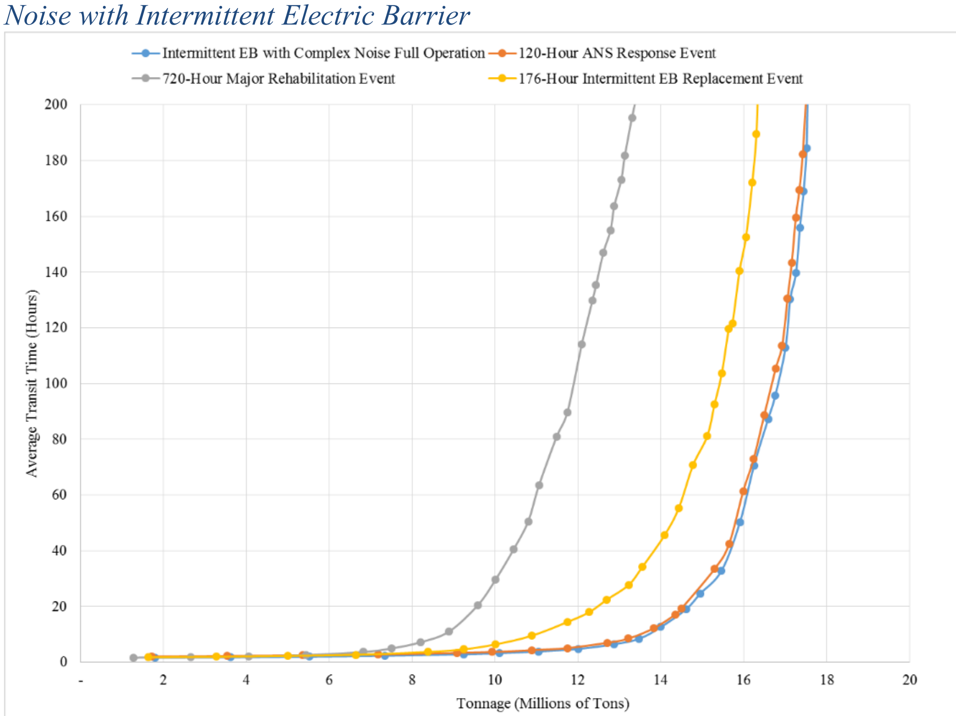
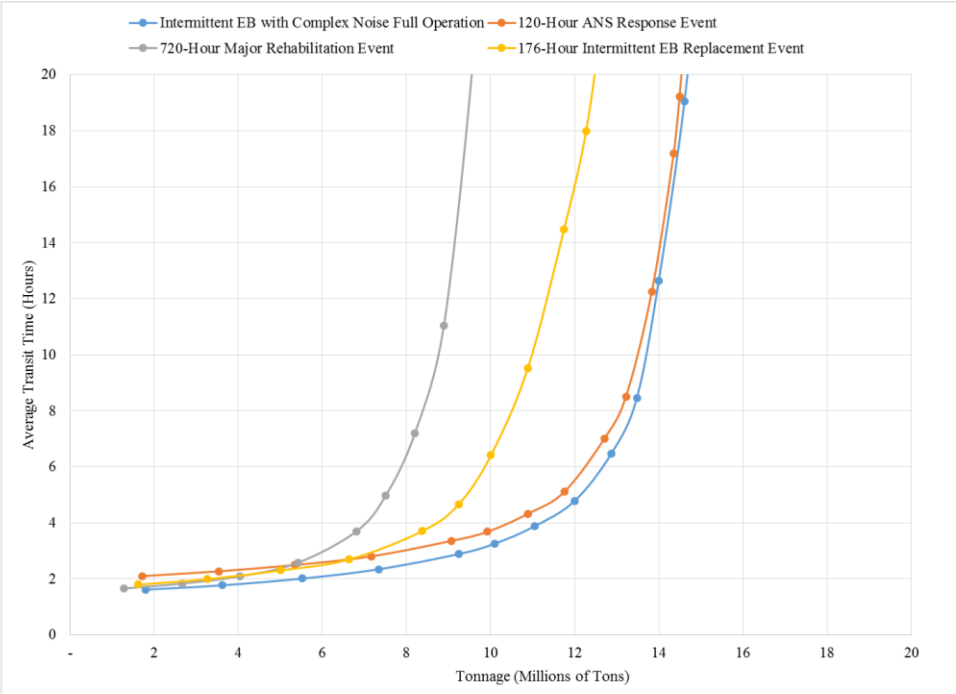


Figure 21 Operation Family of Curves – Relevant Range for Technology Alternative – Complex Noise with Intermittent Electric Barrier (Brandon Road Lock)



3.3.3 Technology Alternative - Electric Barrier

This analysis was conducted as a sensitivity analysis to estimated the navigation impacts if the electric barrier measure of the Technology Alternative – Complex Noise with Electric Barrier was operated continuously. The Technology Alternative – Complex Noise with Continuous Electric Barrier alternative under consideration at Brandon Road includes the following ANS controls: nonstructural measures, a flushing lock, engineered channel, complex noise, and an electric barrier that operates continuously. This alternative also includes mooring cells located below the lock. The capacity curves used for analyzing this alternative include the years of construction, a long-term operation curve, a curve representing emergency ANS response actions, a curve representing a major rehabilitation operation of the lock chamber, and a curve for a scheduled replacement of the electric barrier system. All of the post-construction curves assume nonstructural measures, an operating flushing lock, an engineered channel, and a continuously operated electric barrier with mooring cells.

3.3.3.1 Full-Operations Tonnage-Transit Curve

Full-operation tonnage-transit curves were developed for the Brandon Road Lock under the Technology Alternative – Electric Barrier. The processing time and capacity for the new single main chamber operating for the entire year with only random minor downtimes is shown in Table 21

The processing time and capacity values for each stage of construction as well as information pertaining to post-construction service disruptions. Note that average processing times are lower and the tonnage at capacity is higher during construction than for full operation. While construction is associated with closures, the operating policies post-construction result in higher average processing times and lower overall capacity.

Table 21 Capacity and Transit Times (Brandon Road Lock) for Technology Alternative – Electric Barrier

Simulated Event Name	Tonnage at Capacity	Average Transit Time (Hours)	Average Processing Time (Hours)
Full Operation	16,891,716	200.00	1.22
120-Hour 24-Hour/Day Emergency ANS Response Event	16,406,764	200.00	1.22
720-Hour 24 Hour/Day Major Rehabilitation Event	12,493,682	200.00	1.22
176-Hour 8 Hour/Day 5 Day/Week Electric Barrier Rehabilitation Event	15,699,230	200.00	1.22
1st Year Construction	21,085,269	200.00	1.09
2nd Year Construction	26,904,704	200.00	1.09
3rd Year Construction	20,648,314	200.00	1.18

3.3.3.2 **Tonnage-Transit Curves Families for Technology Alternative – Electric Barrier**

Figure 22 shows the tonnage-transit curve family for the construction period of the Technology Alternative – Electric Barrier. The full-operations curve and three service disruption curves are displayed in Figure 23. The relevant range for the Operation Family of Curves is shown in Figure 24. Similar to the 120-Hour event in the WOPC, the 120-Hour event in the Technology Alternative – Electric Barrier, at low utilization levels, the unscheduled emergency response event crosses the 720-Hour event given the rescheduling assumptions associated with the 720-Hour Event, and the 176-Hour intermittent closure event for electric barrier replacement given the intermittent nature of the closure for the work item. In Figure 22, the curve for the first year of construction can be seen crossing the curve for the third year of construction. This is due to the change in operating policy in the third year of construction for the implementation of the continuous electric barrier assumption.

Figure 22 Construction Tonnage-Transit Curve Family for Technology Alternative – Electric Barrier (Brandon Road Lock)

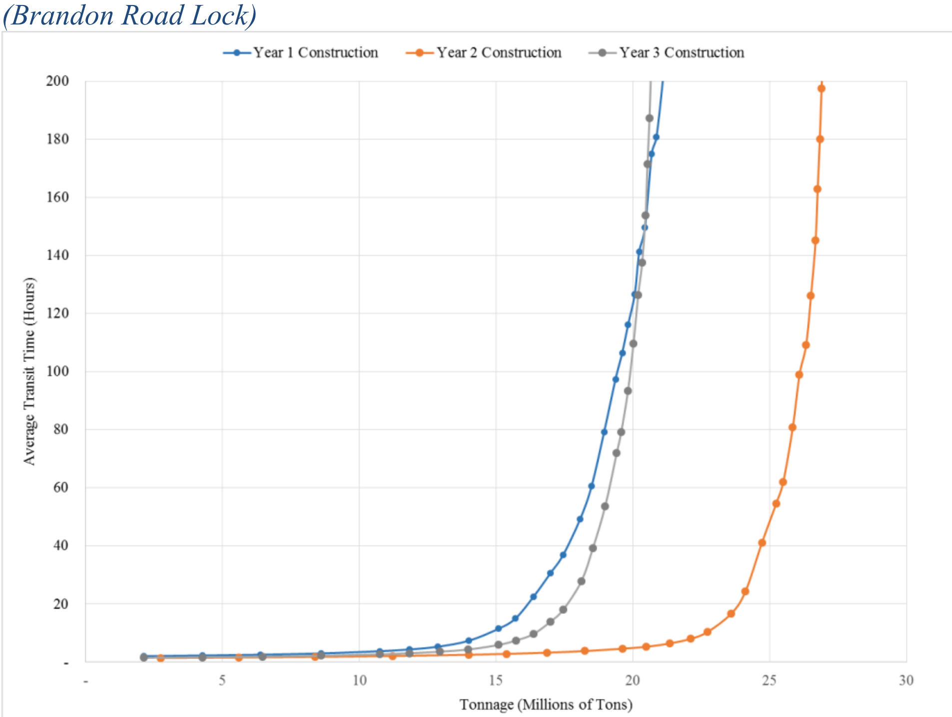


Figure 23 Operation Family of Curves (Brandon Road Lock) for Technology Alternative – Electric Barrier

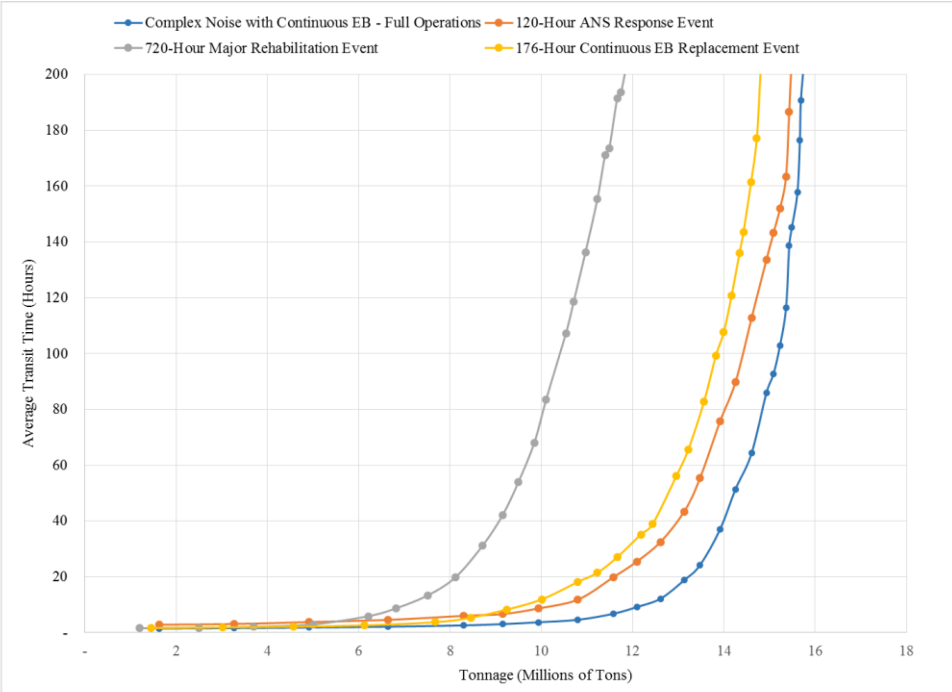
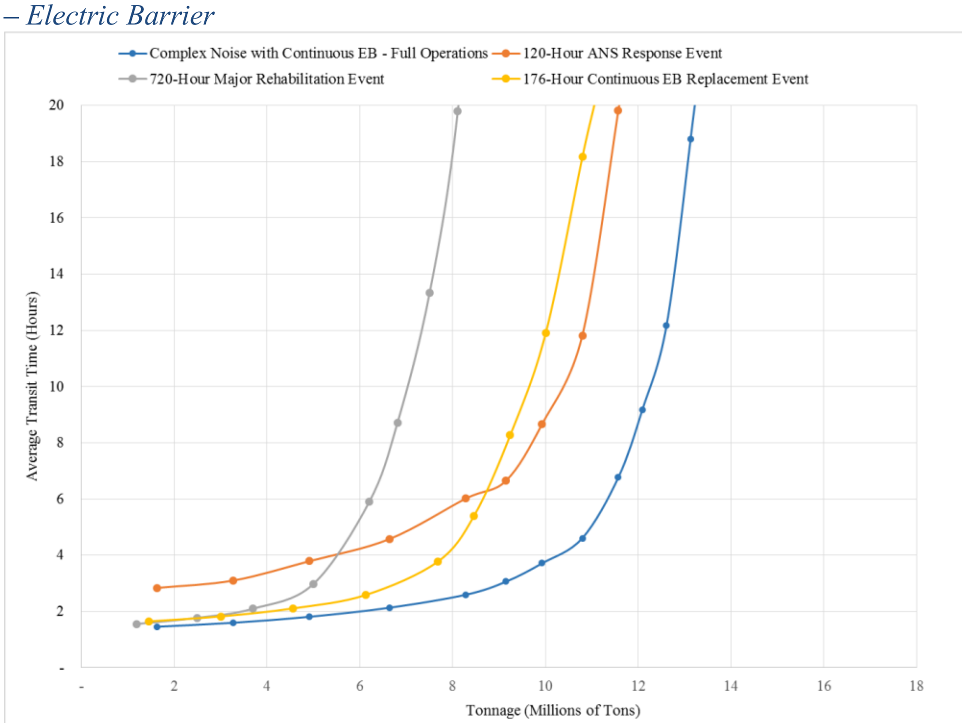


Figure 24 Operation Family of Curves– Relevant Range (Brandon Road Lock) for Technology Alternative – Electric Barrier



3.3.4 Technology Alternative – Complex Noise with Continuous Electric Barrier

The Technology Alternative – Complex Noise with Electric Barrier alternative under consideration at Brandon Road includes the flushing lock, engineered channel, complex noise, and an electric fish barrier that operates in the continuously without regard for vessels within the vicinity of the lock. This alternative also includes mooring cells located below the lock. The capacity curves used for analyzing this alternative include the years of construction, a long-term operation curve, a curve representing emergency ANS response actions, a curve representing a major rehabilitation operation of the lock chamber, and a curve for a scheduled replacement of the electric barrier system. All of the post-construction curves assume an operating flushing lock, an engineered channel, and a continuously operated electric barrier with mooring cells.

3.3.4.1 Full-Operations Tonnage-Transit Curve

Full-operation tonnage-transit curves were developed for the Brandon Road Lock under the Technology Alternative – Electric Barrier. The processing time and capacity for the new single main chamber operating for the entire year with only random minor downtimes is shown in Table 22. The processing time and capacity values for each stage of construction as well as information pertaining to post-construction service disruptions. Note that average processing times are lower and the tonnage at capacity is higher during construction than for full operation. While construction is associated with closures, the operating policies post-construction result in higher average processing times and lower overall capacity. Table 22 also shows a slightly higher capacity for the 3rd year of construction when compared to

Table 21, despite having a longer construction period for the implementation of the complex noise. Despite this increased construction duration, it effectively increases the amount of time the project operates without the flushing lock and other navigation restrictions, so it is a slight increase in overall project capacity.

Table 22 Capacity and Transit Times (Brandon Road Lock) for Technology Alternative – Complex Noise with Continuous Electric Barrier

Simulated Event Name	Tonnage at Capacity	Average Transit Time (Hours)	Average Processing Time (Hours)
Full Operation	16,891,716	200.00	1.22
120-Hour 24-Hour/Day Emergency ANS Response Event	16,406,764	200.00	1.22
720-Hour 24 Hour/Day Major Rehabilitation Event	12,493,682	200.00	1.22
176-Hour 8 Hour/Day 5 Day/Week Electric Barrier Rehabilitation Event	15,699,230	200.00	1.22
1st Year Construction	21,085,269	200.00	1.09
2nd Year Construction	26,904,704	200.00	1.09
3rd Year Construction	21,235,604	200.00	1.16

3.3.4.2 Tonnage-Transit Curves Families for Technology Alternative – Complex Noise with Continuous Electric Barrier

Figure 25 shows the tonnage-transit curve family for the construction period of the Technology Alternative – Complex Noise with Electric Barrier. The full-operations curve and three service disruption curves are displayed in Figure 26. The relevant range for the Operation Family of Curves is shown in Figure 27. Figures 26 and 27 are identical to Figures 23 and 24, because the only difference in capacity between the alternatives is the slightly longer closure duration in the third year of construction for Technology Alternative – Complex Noise with Electric Barrier. Similar to the 120-Hour event in the WOPC, the 120-Hour event in the Technology Alternative – Complex Noise with Electric Barrier, at low utilization levels, the unscheduled emergency response event crosses the 720-Hour event given the rescheduling assumptions associated with the 720-Hour Event, and the 176-Hour intermittent closure event for electric barrier replacement given the intermittent nature of the closure for the work item. In Figure 25, the curve for the first year of construction can be seen crossing the curve for the third year of construction. This is due to the change in operating policy in the third year of construction for the implementation of the continuous electric barrier assumption.

Figure 25 Construction Tonnage-Transit Curve Family for Technology Alternative – Complex Noise with Continuous Electric Barrier (Brandon Road Lock)

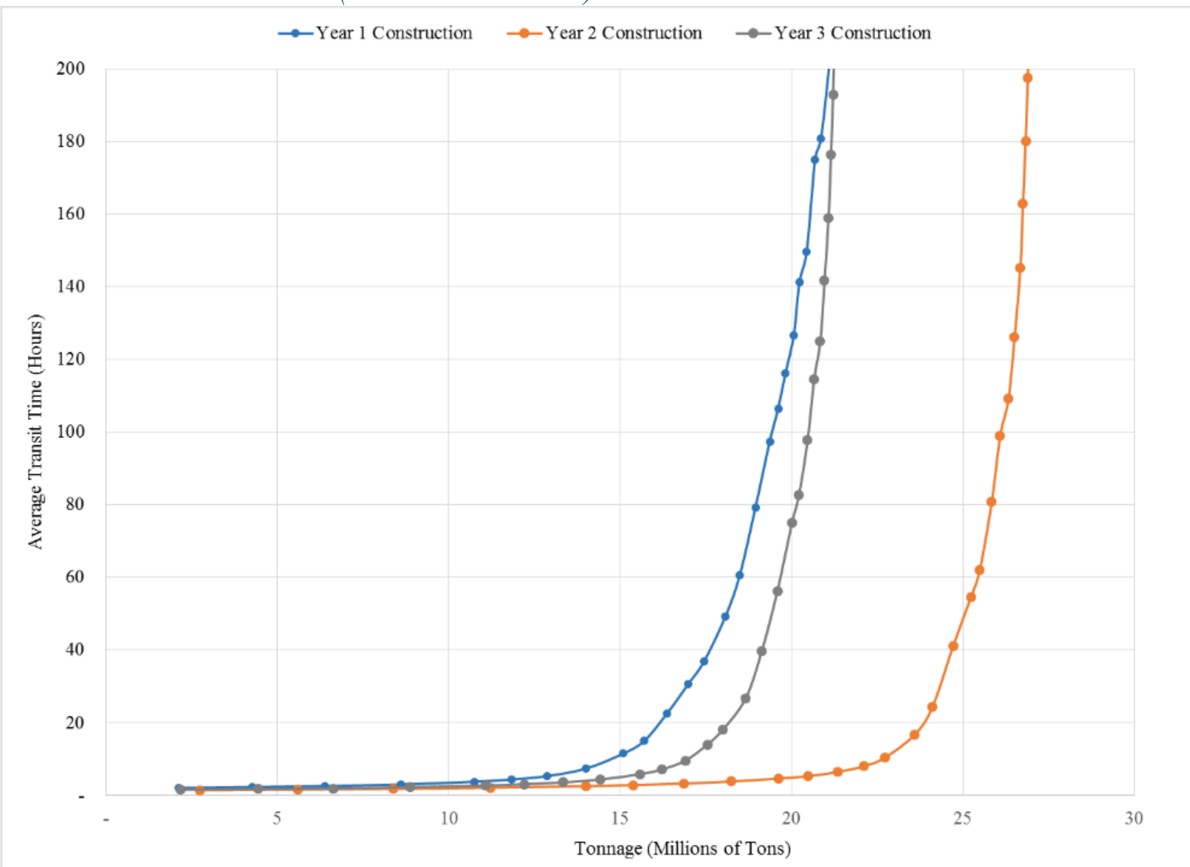


Figure 26 Operation Family of Curves (Brandon Road Lock) for Technology Alternative – Complex Noise with Continuous Electric Barrier

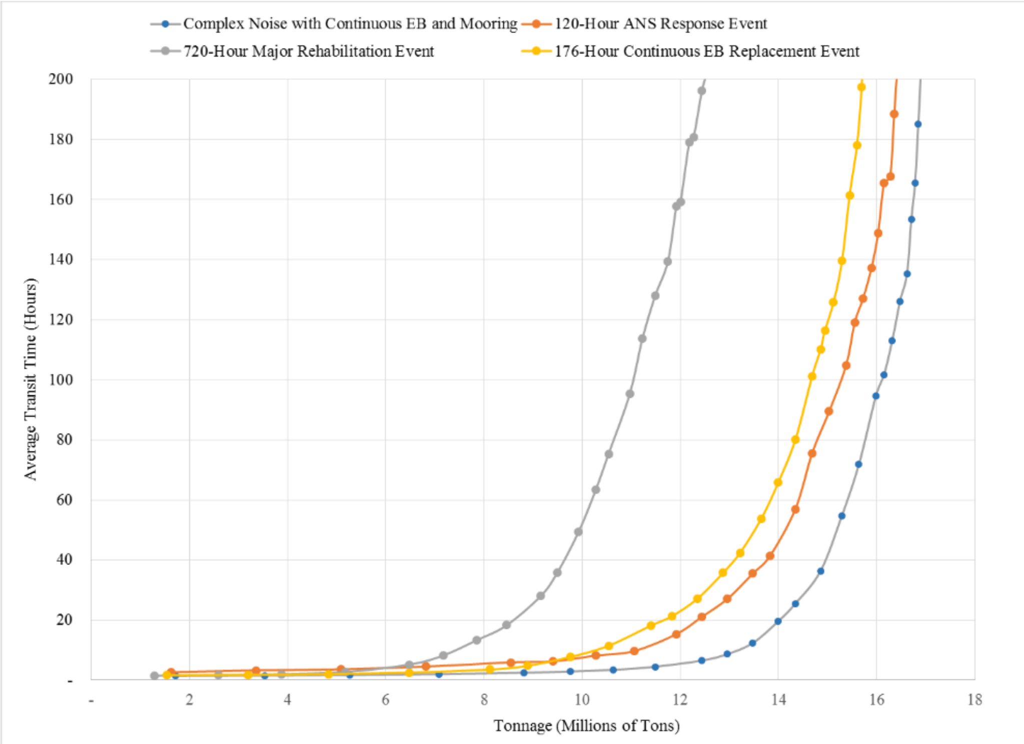
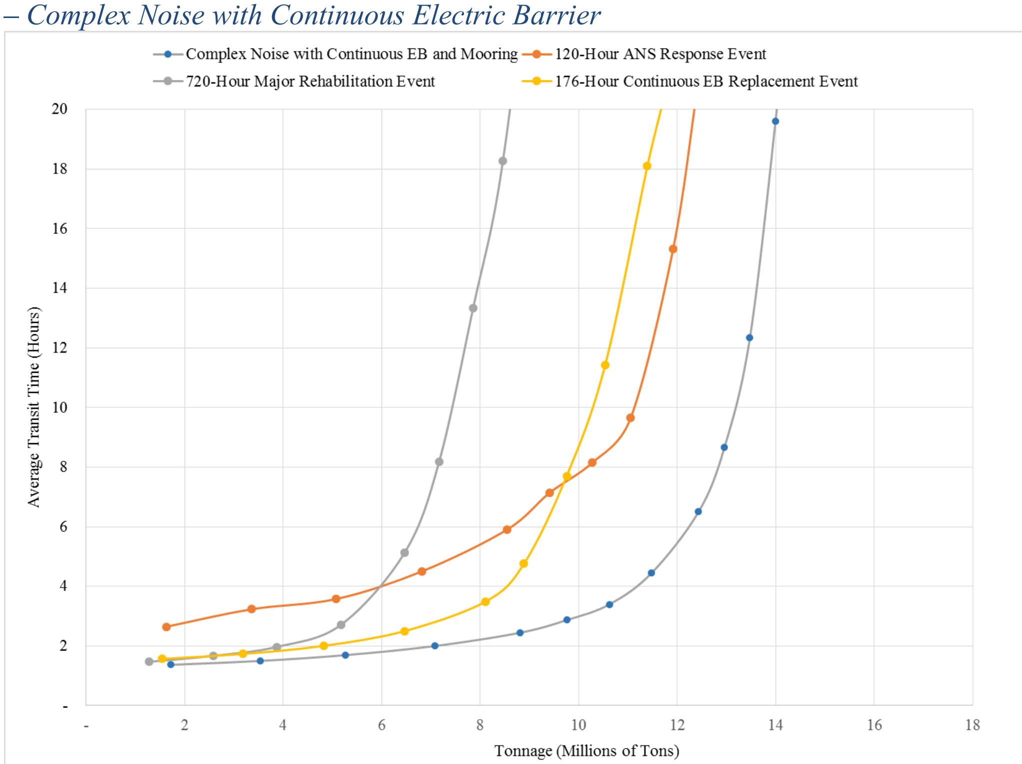


Figure 27 Operation Family of Curves– Relevant Range (Brandon Road Lock) for Technology Alternative – Complex Noise with Continuous Electric Barrier



3.3.5 **Sensitivity Analysis – Mooring Cells**

A sensitivity analysis was performed during the capacity analysis stage to identify the potential benefits of the proposed mooring cells. In a capacity analysis, these benefits are shown strictly in the terms of capacity and transit time changes. The mooring cells present other benefits that cannot be calculated strictly through a capacity analysis, and these are left to the equilibrium modeling. The capacity analysis was used to screen the mooring cells as to whether or not to carry them forward for the equilibrium modeling. For the purposes of this analysis, the mooring cells were projected to decrease processing time by the 10 minutes imposed by the presence of the electric barrier in the upbound approach channel. Without physical modeling, these times are assumptions used as proxies to assess potential impacts.

Figure 27shows the Full Operations curves for Brandon Road Lock for the Complex Noise with Continuous Electric Barrier Alternatives with and without mooring cells. At full capacity with 200 hours of average transit time, the addition of the mooring cells is projected to yield approximately 1 million more tons of capacity. Figure 29shows the relevant range for the same curves, where it is possible to see that the addition of mooring cells translates to a decrease in average transit time, the benefits of which increase as project tonnage increases. At historical traffic levels the addition of mooring cells yields an approximate 1.2 hour reduction in average transit time.

Figure 28 Full Operation Curves (Brandon Road Lock) - Complex Noise with Continuous EB With and Without Mooring Cells

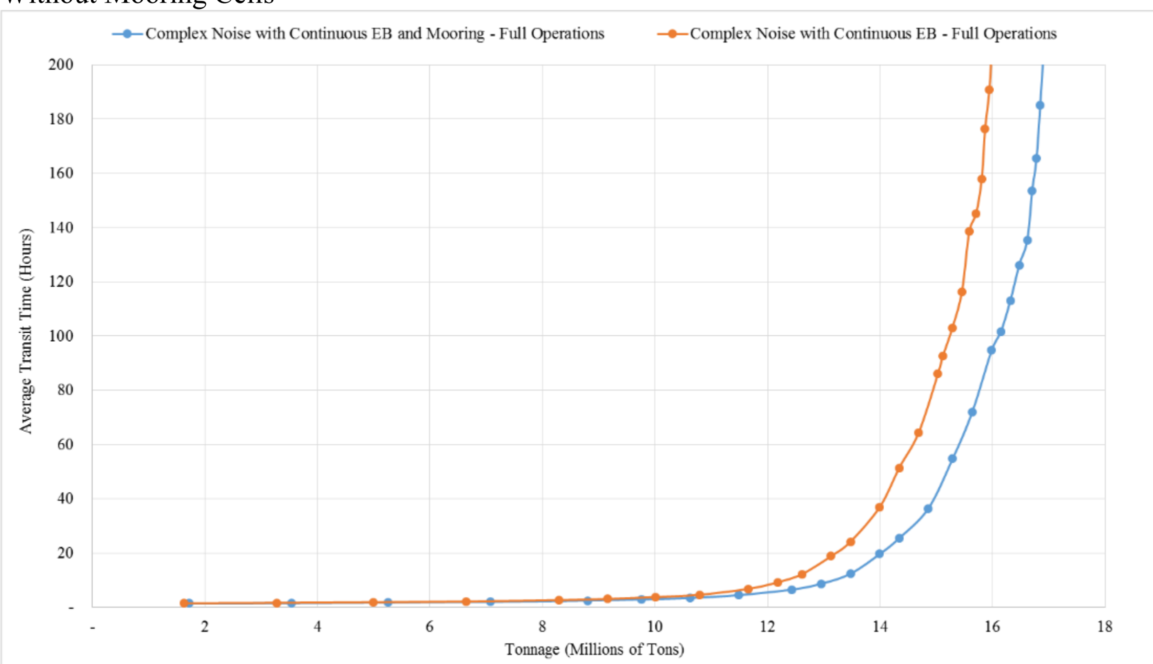
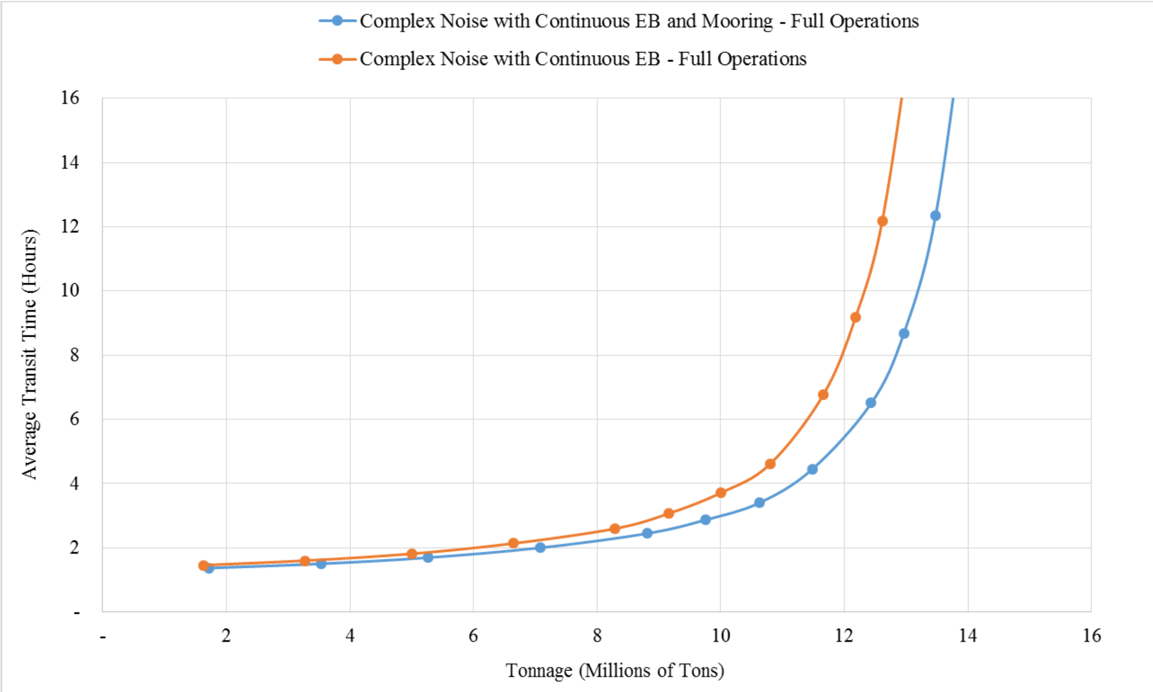


Figure 29 Full Operation Curves – Relevant Range (Brandon Road Lock) for Complex Noise with Continuous Electric Barrier With and Without Mooring Cells



Great Lakes and Mississippi River Interbasin Study (GLMRIS) - Brandon Road

Appendix D - Economics

Attachment 2 - Waterway Traffic Demand Projections

Table of Contents

1 Introduction **5**

1.1 Geographic Scope *5*

1.2 Project Setting *6*

1.3 Analytic Scope *6*

1.4 Sources *7*

1.5 BASE YEAR *9*

2 COMMODITIES **11**

2.1 Steel and Scrap *11*

2.2 Iron Ore *16*

2.2.1 Pig Iron 16

2.3 Petroleum Products *17*

2.3.1 Petroleum Coke and Asphalt 18

2.3.2 Other Petroleum Fuels 18

2.4 Crude *18*

2.5 Agriculture *19*

2.6 Chemicals *20*

2.6.1 Caustic Soda 20

2.6.2 Ethanol 20

2.6.3 Antifreeze/Deicer 20

2.7 Aggregates *20*

2.8 Others *21*

2.9 Not Elsewhere Classified *21*

3 RESULTS **22**

4 REFERENCES **23**

Table of Tables

TABLE 1: COMMODITY INDEX SUMMARY....7
TABLE 2: TARGET, WCS, AND LPMS TONNAGES IN BASE YEARS....9
TABLE 3: TARGET TONNAGE ESCALATION FACTOR BY COMMODITY GROUP 10
TABLE 4 - COMPOSITE POPULATION FORECAST 21

Table of Figures

FIGURE 1: BRANDON ROAD LOCK AND DAM GEOGRAPHICAL SETTING....6
FIGURE 2: HISTORICAL BRANDON ROAD TONNAGE AND COMMODITY PERCENTAGES 11
FIGURE 3 STEEL PLANTS IN THE CHICAGO REGION 12
FIGURE 4 APPARENT U.S. STEEL CONSUMPTION VS. RIVERBORNE SHIPMENTS OF FINISHED STEEL 13
FIGURE 5: APPARENT ANNUAL DOMESTIC STEEL CONSUMPTION BY METRIC TONS....14
FIGURE 6: DOMESTIC ANNUAL STEEL PRODUCTION FORECAST....15
FIGURE 7: ANNUAL U.S. STEEL AND PIG IRON PRODUCTION FROM 1975 – PRESENTED WITH LINEAR TREND16
FIGURE 8: U.S. WATERWAYS FOR PETROLEUM SHIPMENTS....17
FIGURE 9: COMPARISON OF U.S. REFINERY RECEIPTS OF DOMESTIC CRUDE BY MODE....19
FIGURE 10: BRANDON ROAD HISTORICAL TONNAGE AND MOST-LIKELY PROJECTED DEMAND....22

1 Introduction

This attachment documents the data sources, methods and results for updating the Chicago Area Waterway System (CAWS) traffic demand forecasts that were originally developed in support of the U.S. Army Corps of Engineers (USACE) Great Lakes and Mississippi River Interbasin Study (GLMRIS). These updated traffic demand forecasts were completed in support of the GLMRIS at Brandon Road (GLMRIS-BR) commercial cargo navigation national economic development (NED) analysis. This attachment is not intended to serve as a stand-alone document, but rather, is a complement to the GLMRIS-BR Report: Appendix D – Economic Analysis.
Updated traffic demand forecasts since the initial GLMRIS effort were necessitated by changes in the dynamics of petroleum products moving on the CAWS. In addition to refining the outlooks these commodities, the GLMRIS-BR traffic forecasts focused on changes in the iron and steel industry. Increased granularity in the forecasts for this GLMRIS-BR effort included:

1. Forecasts at the individual commodity level, rather than commodity group levels;
2. Forecasts at the individual dock level; and
3. Analyzing more specific growth indicators.

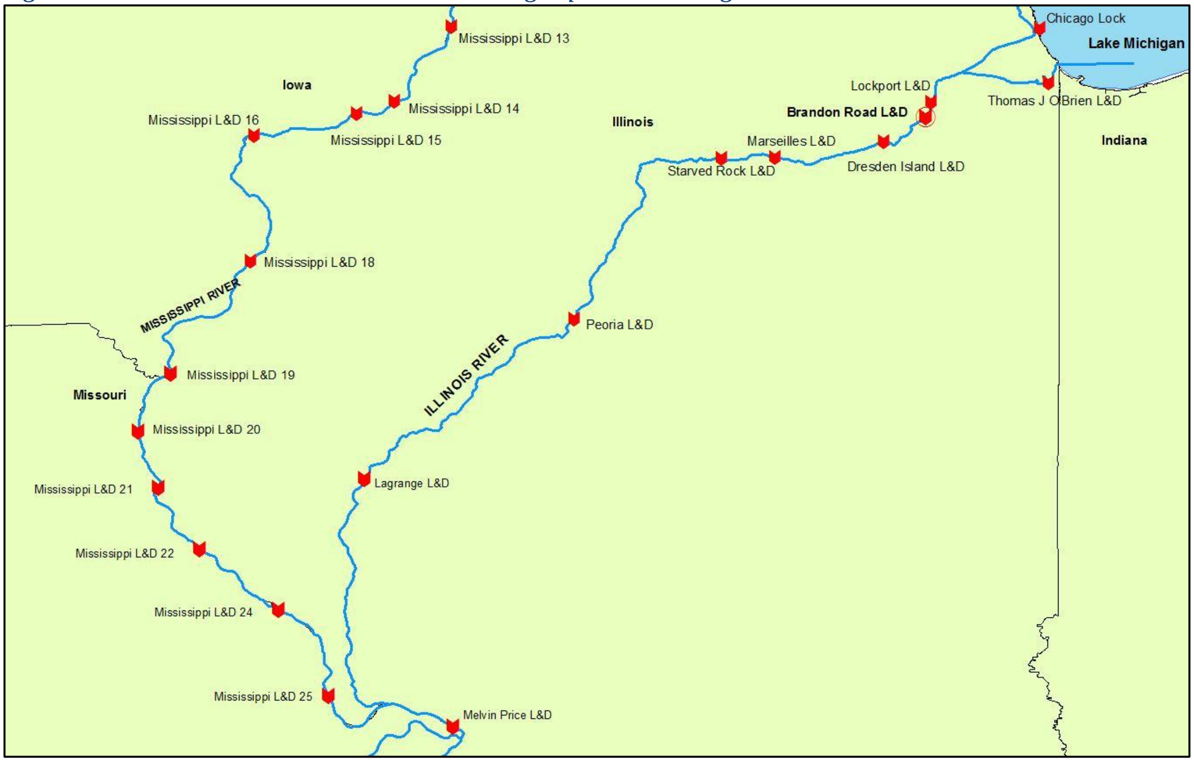
Fluctuations in traffic within the vicinity of Brandon Road Lock and Dam (BRLD) have been most recently dictated by the petroleum and iron & steel industries. These industries and their respective inputs/outputs are among the most volatile of bulk commodities. The industries as a whole have experienced swift changes due to the advents of hydraulic fracturing and horizontal drilling producing large influxes of shale and Canadian crude oil. The iron and steel industry faces its own unique challenges with changes in the competitiveness of the U.S. dollar and low-priced imports. Although there are several other bulk commodities moving on the CAWS, changes in the aforementioned industries were the central focus of the GLMRIS-BR traffic demand forecasts. Other commodities were included but forecasted with less detail due to their milder and more predictable traffic flows.

The traffic projections presented in this document are the most-likely traffic projections, and serve as the base traffic demands in the GLMRIS-BR navigation economic analysis.

1.1 Geographic Scope

Brandon Road Lock and Dam is located on the Illinois River at mile 286 near Joliet and Rockdale, IL. Brandon Road Lock is located approximated 15 miles upstream from Dresden Island Lock and Dam and approximately 5 miles downstream from Lockport Lock.

Figure 1: Brandon Road Lock and Dam Geographical Setting



1.2 Project Setting

The Illinois Waterway is a system of rivers which connect Lake Michigan at the mouth of the Calumet River to the mouth of the Illinois River as it flows into the Mississippi River in Grafton, Illinois. The system encompasses the Calumet River, the Chicago Sanitary Ship Canal (CSSC), the Illinois River, and a short navigable section of the Des Plaines River. USACE manages eight lock projects on the system, which include Thomas J. O'Brien on the Calumet River, Lockport and Brandon Road on the Des Plaines River, and Dresden Island, Starved Rock, Peoria, and Lagrange on the Illinois River. The Illinois Waterway serves as the sole commercially navigable inland link between the Great Lakes and the Mississippi River Basin. The waterway is not only important to American commerce, it supports a variety of other public purposes, including flood control, waterside commercial development, effluent discharge, and water-based recreational activities.

1.3 Analytic Scope

The waterway transportation network is includes both demanders and suppliers. Demanders of waterway transportation tend to be commercial firms that provide and/or receive a product on the waterway (i.e. shippers). These demanders may or may not be located on the waterway and they may or may not have modal or market alternatives (e.g. rail, truck, alternate origin/destination). Suppliers are barge companies that have a fleet of tow boats and barges that are allocated over the market (i.e. operators). Waterway transportation demands are an intermediate product and are derived demands. As such, they depend on linkages to input markets as well as output markets. For example, the demand for the transportation of coal from one location to an electric utility plant depends on the coal market as well as the power market. Understanding the complex interactions between demanders of waterway transportation and the factors that influence their behavior is paramount in forecasting the use of the inland waterway system.

Traffic demand forecasts are an integral part of the Corps modeling process for inland navigation studies. Base year (observed) traffic flows are forecasted into the future assuming the base year transportation prices (land and water). Then through a waterway transportation partial equilibrium process, expected traffic levels are estimated for the without and with-project conditions given their performance characteristics (e.g. operating conditions of each GLMRIS-BR alternative). Forecasts developed are of waterway traffic demand only, meaning they will not consider transportation system constraints. Both the waterway and overland transportation systems will be considered to be reliable and efficient, and capable of handling future overland traffic demands. Transportation system constraints are accounted for during the equilibrium modeling process of the Navigation Investment Model (NIM), of which forecasted traffic demands are an input.

For USACE, potential navigation projects are typically evaluated using a 50-year period of analysis, which is considerably beyond the forecasting horizon of most forecasting models. For this forecasting effort, projected demand beyond 2040 is held constant, since credible indices for traffic forecasting were not available beyond 2040.

1.4 Sources

A variety of potential forecasting sources for estimation of future waterborne tonnage flows were explored. Some of the sources used were "off-the-shelf" indices that are direct substitutes for the goods that move on the waterway. Some reputable indices were utilized at escalated or deescalated rates to emphasize the projected effect that the commodity growth would have on barge demand, rather than just the commodity in general. In cases where the Waterborne Commerce Statistics (WCS) data represented a basket of goods, a composite or series of indices were used to reflect the diversity of that commodity group. Conversely, certain indices that reflected a series of goods may have been used on multiple specific waterborne commodities. In total, specific or combination indices that can be traced directly back to a reputable source represent 82 percent of total waterborne traffic between 2012 and 2014. The remainder of commodities were forecasted using regional population growth, since reputable sources indicating the direction of commodity growth and respective demand for waterway transportation were not available.

The sources in **Error! Reference source not found.** are a summary of the indices that were applied to specific commodities, and a general description of the source. Other reference materials used to guide the direction of developing or choosing growth rates can be found in the commodities write-ups and bibliography. Some of these sources are proprietary in nature and for official use only.

Table 1: Commodity Index Summary

Commodity		Source	Index Used	End Year
Steel, Scrap, and Residuals				
	Flat-Rolled Products of Iron & Steel,Not Clad,Pltd	USACE I&S Profile	Domestic Steel Production	2025
	Slag, Dross, Scalings & Waste of Iron or Steel	USACE I&S Profile	Domestic Steel Production	2025
	Ingots and Other Primary Forms of Iron or Steel	USACE I&S Profile	Domestic Steel Production	2025
	Primary Iron and Steel Products, NEC	USACE I&S Profile	Domestic Steel Production	2025
	Granulated Slar from the Manufacture of Iron/Steel	USACE I&S Profile	Domestic Steel Production	2025

Commodity	Source	Index Used	End Year
Iron and Steel Bars,Rods,Angles,Shapes & Sections	USACE I&S Profile	Domestic Steel Production	2025
Ferrous Waste & Scrap;Remelting Ingots of Iron/Stl	World Steel Association	1% annual	2030
Wire of Iron or Steel	World Steel Association	1% annual	2030
Other Ferro-Alloys (Exc Radioactive Ferro-Alloys)	World Steel Association	1% annual	2030
Manufactures of Metals, NEC	World Steel Association	1% annual	2030
Tubes, Pipes, Hollow Profiles of Iron or Steel	World Steel Association	1% annual	2030
Pig Iron and Iron Ore			
Pig Iron & Spiegeleisen,in Pigs,Blocks, Other Form	USACE	-1.25% annual	2030
Iron Ore and Concentrates	USACE I&S Profile	Domestic Movement of Iron Ore	2025
Coke & Asphalt			
Petro.Bitumen,Petro.Coke,Asphalt,Butumen mixes NEC	USDOE	Fuels - Other	2040
Coke, Semi-Coke of Coal, of Lignite or of Peat	USACE I&S Profile	Domestic Movement of Iron Ore	2025
Petroleum Fuels			
Other Light Oils from Petroleum & Bitum Minerals	USDOE	Distillate Fuel Oil	2040
Fuel Oils, NEC	USDOE	Fuels - Other	2040
Gas Oils	USDOE	Liquefied Petroleum Gases and Other	2040
Other Medium Oils from Petroleum & Bitum Minerals	USDOE	Residual Fuel Oil	2040
Gasoline Including Aviation (Except Jet)	USDOE	Motor Gasoline	2040
Jet Fuel (Gasoline Type)	USDOE	Jet Fuel	2040
Crude			
Petroleum Oils/Oils from Bituminous Minerals,Crude	USDOE	50% Crude Production	2040
Agriculture			
Wheat (Including Spelt) and Meslin, Unmilled	USDA	50% Wheat Exports	2025
Soya Beans	USDA	Soyean Exports	2025
Chemicals			
Ethyl Alcohol (Not Denatured) 80% or More Alcohol	USDOE	E85 - Capped	2020
Sodium Hydroxide Aqueous Soln(Soda Lye,Liq Soda)	CMAP/IDPH	Population - Composite	2040
Ethylene Glycol (Ethanedoil)	CMAP/IDPH	Population - Composite	2040
Aggregates			
Portland, Aluminous, Slag, or Supersulfate Cement	Criton Corp	Cement	2019

Commodity		Source	Index Used	End Year
	Sands, Natural, of all Kinds (Exc Silica & Quartz)	Criton Corp	Sand/Gravel	2019
	Pebbles, Gravel, Crushed Stone (Specialized Use)	Criton Corp	Sand/Gravel	2019
Others				
	Sodium Chloride,Pure & Common Salt(Incl Sea Water)	Criton Corp	Salt	2019
	Wood in Chips or Particles	Criton Corp	Wood Chips	2019
	Manganese Ores and Concentrates	Criton Corp	Manganese Ores	2019
	Urea Fertilizers	Criton Corp	Fertilizers	2019
	Mineral or Chemical Fertilizers, Nitrogenous,NEC	Criton Corp	Fertilizers	2019
	Ammonium Sulfate Fertilizers	Criton Corp	Fertilizers	2019
	Mineral or Chemical Fertilizers, Potassic, NEC	Criton Corp	Fertilizers	2019
	Fertilizers, NEC	Criton Corp	Fertilizers	2019
	Aluminum Ores & Concentrates (Including Alumina)	Criton Corp	Aluminum Ores	2019
	Gypsum and Anhydrite	Criton Corp	Gypsum	2019
	Limestone Flux & Calcareous Stone Used in Lime Mfg	Criton Corp	Lime	2019

1.5 BASE YEAR

The base year of traffic used for the GLMRIS-BR traffic demand forecast is an average of traffic from the years 2012 through 2014. This update was completed to include more recent developments in traffic patterns and tonnages since 2011, which was the base year of traffic used in the GLMRIS Report (2011). An average of years is used to help moderate any significant fluctuations and reflect consistency. The specific sources for the base year tonnage was both WCS and the Lock Performance Monitoring System (LPMS). A target tonnage was developed that utilized the most reliable aspects of both databases. A known limitation of the WCS database is the possibility of underreported or non-reported tonnages. However, using vessel level data from WCS provides a very accurate estimation of the average barge loading rates (tons per barge) by individual commodities and their respective equipment types. Conversely, the LPMS database provides a general estimation of tonnage as recorded by lock operators at each project. However, the barge counts for individual vessels within each flotilla are discretely recorded. Using both sets of data, the average barge loading by commodity group from WCS were multiplied by the number of loaded barges by commodity group to develop a target tonnage. The results are displayed in Table 2: Target, WCS, and LPMS Tonnages in Base Years and Table 3: Target Tonnage Escalation Factor by Commodity Group.

Table 2: Target, WCS, and LPMS Tonnages in Base Years

Year	Target Tons[1]	LPMS Actual	WCS Actual
2014	12,923,133	12,588,435	11,455,030
2013	10,338,088	10,427,098	8,848,073
2012	11,232,183	11,089,065	9,803,265

[1] Developed using loaded rate from WCS (tons/trips) and number of loaded barges from LPMS

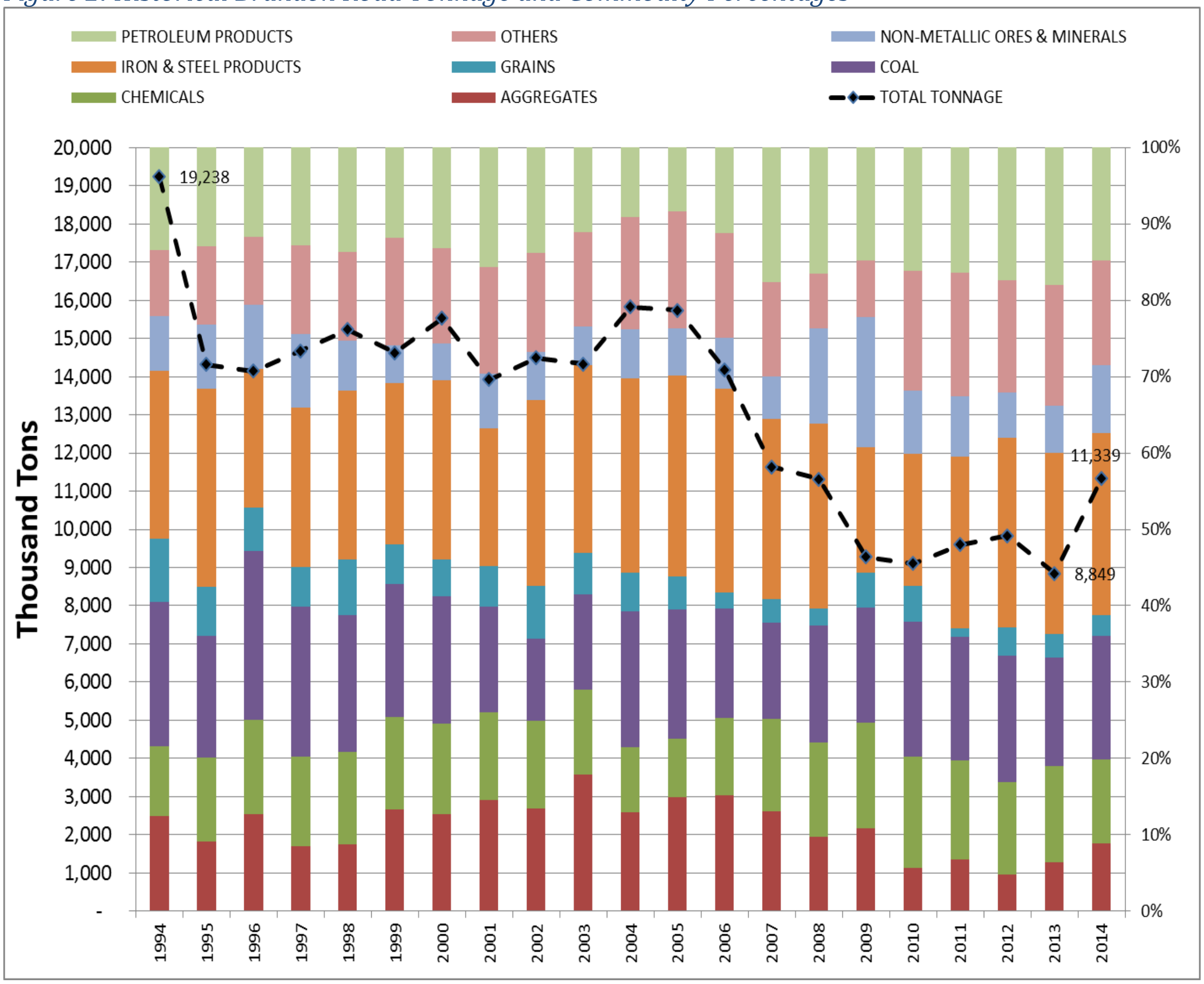
Table 3: Target Tonnage Escalation Factor by Commodity Group

Commodity Group	2012-2014 Average Tons (WCS)	Target Escalation Factor	2012-2014 Average Tons (Target)
Coal and Coke	1,536,660	1.127663246	1,732,835
Petroleum Products	1,628,866	0.99839697	1,626,255
Crude Petroleum	195,405	2.147527023	419,638
Aggregates	673,692	2.091956298	1,409,335
Grain	311,514	1.272299162	396,339
Chemicals	1,164,585	1.145900432	1,334,498
Ores and Minerals	706,085	1.057879081	746,952
Iron and Steel	2,373,569	0.998912172	2,370,987
All Others	1,445,079	1.010990352	1,460,961

2 COMMODITIES

Since the equilibrium traffic modeling using the Navigation Investment Model (NIM) requires origin-to-destination commodities flows, the traffic identified in the base year is escalated by the respective growth rate at the individual 5-digit commodity code level. Since the NIM model requires some level of homogenized aggregation, theses projected demands are ultimate grouped into a nine commodity groups. A display of the groups and their respective historical tonnages can be seen in Figure 2: Historical Brandon Road Tonnage and Commodity Percentages. Crude petroleum could not be displayed since there were not a sufficient amount of operators in some years.

Figure 2: Historical Brandon Road Tonnage and Commodity Percentages



2.1 Steel and Scrap

Historically, steel businesses located in the Great Lakes region, New York, Pennsylvania, Ohio, Illinois, Indiana and Michigan have been the dominant producers in the United States. Cities located on the Great Lakes provided centralized access to the great iron ore deposits of Minnesota, Wisconsin and Michigan's peninsula while also providing access to coal mines in the Appalachians. Additionally, the Northeast housed the largest population centers which drew the greatest demand for iron and steel. Figure 3 Steel Plants in the Chicago Region displays the primary facilities in the Chicago area. The larger-scale facilities receiving waterborne tonnage are integrated steel mills, with the exception of the Electric Arc Furnace (EAF) operated by ArcelorMittal at Indiana Harbor.

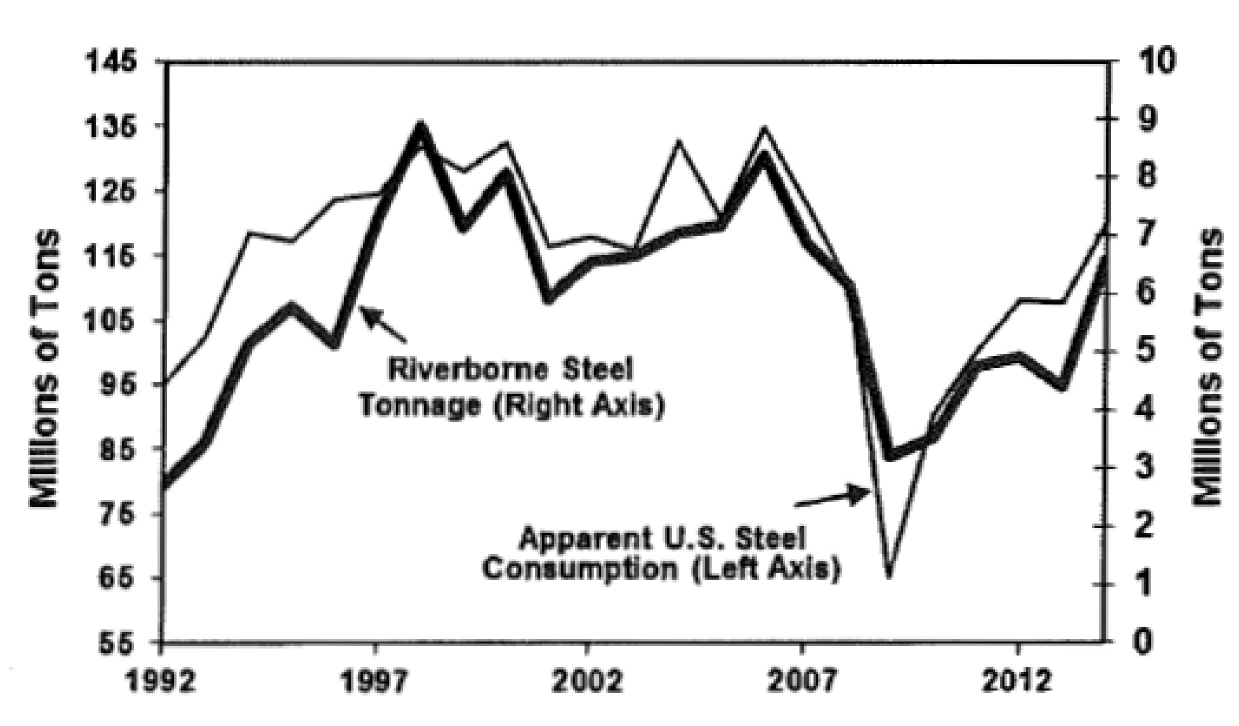
Figure 3 Steel Plants in the Chicago Region

Reference	Facility Type	Company	Location
1A	EAF	A Finkl & Sons Co	Chicago
4J	BOF	ArcellorMittal	Riverdale, IL
4H	BOF / EAF	ArcellorMittal	Indiana Harbor
4C	BOF	ArcellorMittal	Burns Harbor
19C	BOF	U.S. Steel	Gary, IN
36	EAF	NLMK Indiana (Beta Steel)	Portage, IN
Source: AIM Market Research			

In the United States, the Great Lakes and Mid-Atlantic region support the vast majority of steel production, accounting for 44.5% of U.S. steel production. Almost all of the blast furnace (BF) and basic oxygen furnace (BOF) production continues to be performed in this area of the country for the same historical reasons (Pfisterer, 2015). Due to the vast influence that the Great Lakes region has upon total U.S. Steel production, forecasts of total U.S. production serve as a good indication of the activity in the Chicago region. This is consistent with the rationale provided in the GLMRIS Report, which utilized a Steel Industry

Outlook presented by ArcelorMittal to the Federal Reserve Bank of Chicago. An updated version of this report was also analyzed for the Brandon Road effort, which suggests a soft domestic steel market supported by the automotive industry and competing heavily with low priced imports (DiCianni, 2015). This is also verified by Criton Corporation's 2015 forecast for steel which holds the position that riverborne shipment of finished steel fluctuate with the fortunes of the U.S. steel industry (Criton Corporation, 2015). This is emphasized by

Figure 4 Apparent U.S. Steel Consumption vs. Riverborne Shipments of Finished Steel



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It is important to note that production is not the same as consumption, the latter of which accounts for imports and exports. This can be seen in Figure 5: Apparent Annual Domestic Steel Consumption by Metric Tons. The total demand for steel in the U.S. is driven by several key factors. These include domestic and global economic growth, global production capacity, cost of imports and exports, policy, regulations, tariffs, the strength of the U.S. Dollar, the cost of alternatives to steel, and others.

Figure 4 Apparent U.S. Steel Consumption vs. Riverborne Shipments of Finished Steel

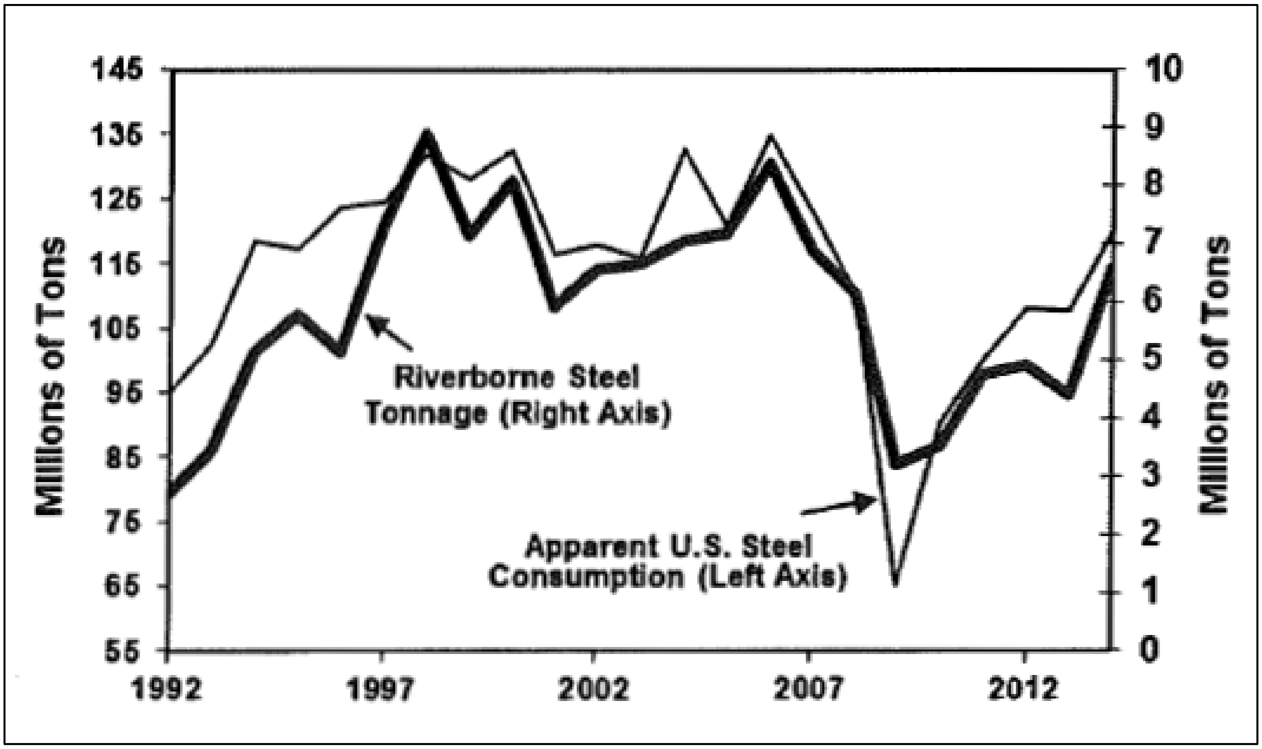
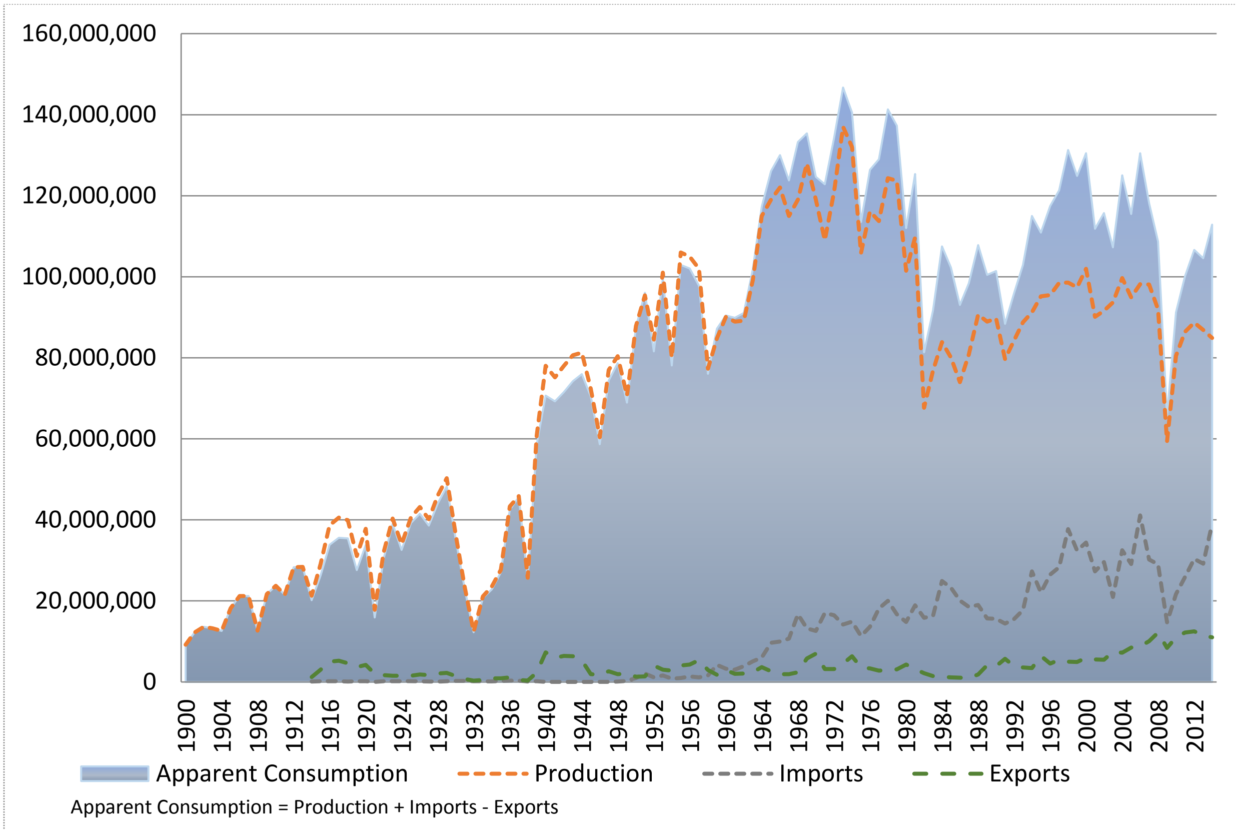


Figure 5: Apparent Annual Domestic Steel Consumption by Metric Tons



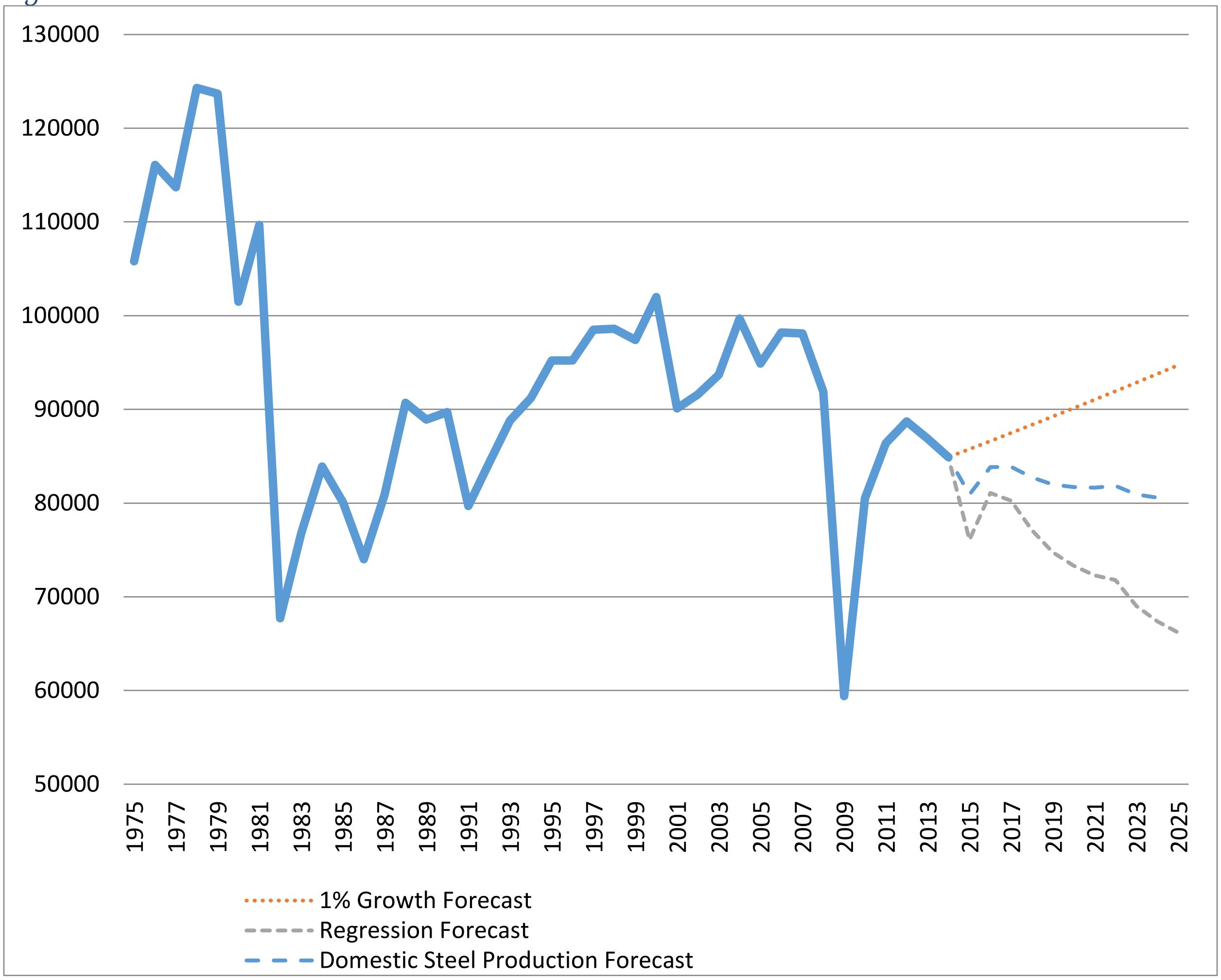
In terms of short-term fluctuations (1-3 years), recessions are the key driver in consumption changes. The economic decline in 2008-09 was the worst since the great depression in terms of percentage of production. Steel demand has rebounded to over 100 million due to the need to replace aging infrastructure, recovery in the automotive industry, and the oil and gas boom from new domestic discoveries.

However, as steel demand recovers, it still lags behind historic levels. The U.S. economy continues to grow at a modest rate of 2% which is below historic post recovery levels. Increased national debt and growing non-discretionary budget constraints have limited funds for infrastructure at the Federal, State and Local government level. Business fixed investment is down as businesses have focused on increasing shareholder value through dividend payments and share buybacks. This has limited steel demand. As a result, steel demand is likely to continue to increase but at a diminishing rate over the back half of the decade (Pfisterer, 2015).

Forecasted growth in steel products for the GLMRIS-BR reference case are based upon a composite forecast. This composite forecast includes the two approaches highlighted in

Figure 6: Domestic Annual Steel Production Forecast.

Figure 6: Domestic Annual Steel Production Forecast



The first is based upon a 1% annual growth as predicted by the World Steel Association. Scrap steel was given the World Steel Association 1% annual growth rate since they are typically inputs into the EAF facilities, which have a more profitable outlook. This growth rate was also applied to tubular steel due to a foreseen need for pipeline capacity. In addition, this growth rate was used for a few specialized metal products like radioactive ferro-alloys that are not as easily substituted by foreign imports. This rate of growth is held constant through 2030.

The second forecast was determined using a Microsoft Excel Forecast Formula. The forecast function returns the predicted value of the dependent variable for the specific value, x, of the independent variable by using a best fit (least squares) linear regression to predict y values from x values. In this case the dependent variable is future domestic steel production and the independent variable is historical annual domestic steel production. This is a time series forecast that uses actual historical results to predict future results. Historical domestic annual steel production levels were calculated by the USGS and all data is the actual levels up through 2014. The regression uses the trailing 7 years to determine the specific independent year's forecast. It should be noted that the forecast for 2016 only utilized the trailing 6 years data. This was done to avoid an outlier effect from the 2008-2009 financial crash which caused steel production to plummet to its lowest level in 65 years.

The composite forecast mentioned above was a blending of the two aforementioned forecasts into a third forecast, with an equal weighting which is represented by Domestic Steel Production Forecast line. Under this forecast, steel production is seen to decline at approximately 0.5% annually from the level seen in 2014. As a result, total annual steel production is expected to decline to approximately 80MT by 2025 (Pfisterer, 2015). Traffic demand was held constant beyond 2025 due to the volatility of iron and steel products.

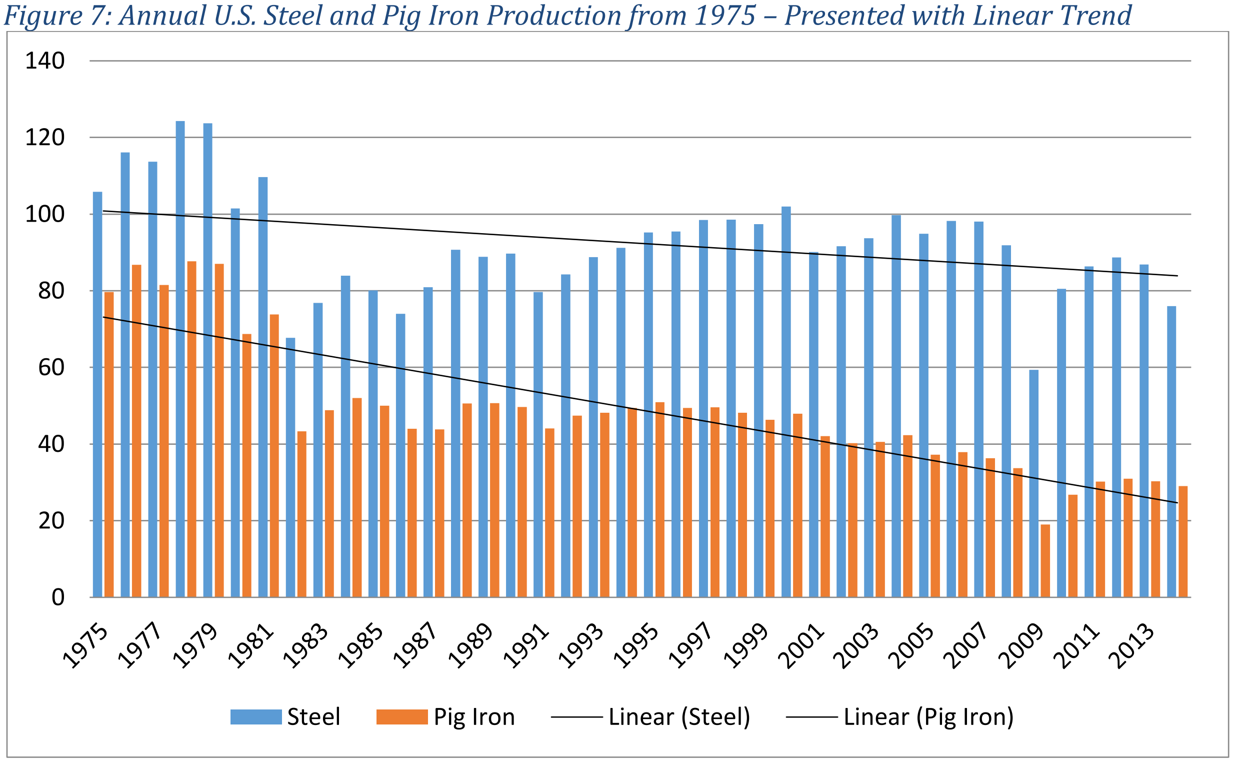
Other than using broad U.S. projections for steel products, the demand forecasts for traffic using Brandon Road are also supplemented by projections that are specific at the dock level. As an example, public research indicated that the U.S. Steel Gary Works facility has been experiencing low production volumes at both their flat rolled and tubular segments due to high levels of imports, supply chain inventories, rapidly falling spot prices, and rig counts (Pete, 2015). This dock was given a traffic projection escalated at 1.5 times the rate of the Domestic Steel Production Forecast.

2.2 Iron Ore

2.2.1 Pig Iron

The decline in pig iron production is more relevant in terms of iron ore demand. A decline in pig iron production would represent a decline in BF/BOF facilities that utilize iron ore. Since 1975, pig iron production has fallen over 60%. Pig iron production has been falling approximately 2.5% annually over the same period of time. Based on this decline, it is likely pig iron production in the U.S. will continue to trend down over the coming decades.

Figure 7: Annual U.S. Steel and Pig Iron Production from 1975 – Presented with Linear Trend



Commerce in this sector in the Chicago Region is dominated by Maryland Pig Services, who handles a significant amount of pig iron and hot briquetted iron (HBI) shipped to foundries to various locations from Wisconsin to Michigan. Firms like Maryland Pig Services were given a trend projected decline of half the historic annual rate of decline over the course of the forecast horizon. The U.S. average annual rate of

decline was halved to 1.25%, mostly due to the static levels of pig iron production since the early 1980's. This trend is expected to continue to 2030, at which point production level remain relatively static.
The initial more precipitous decline in pig iron seen in the late 1970's and early 1980's was the result of over production in the global market as well as economic crisis. Slowing demand from the post-war boom, cheap imports and rising pension costs put pressure on American producers. Companies like Youngstown Sheet and Tube, Republic Steel and Bethlehem Steel all completely closed or shuttered considerable facilities during this time (Pfisterer, 2015).

2.3 Petroleum Products

The Inland Marine Transportation System affords the Chicago region the diversity to interact with a number of significant petroleum refining regions across the country. Since the refinement of petroleum involves many different products and byproducts, the dynamics of the barge movements relevant to petroleum refining can often change significantly. The traditional interactions between these regions can been seen in Figure 8: U.S. Waterways for Petroleum Shipments.

Figure 8: U.S. Waterways for Petroleum Shipments

Due to increased production of crude from the Williston Basin, waterway traffic in the Chicago region has been increasing. The ExxonMobil Joliet refinery, BP Whiting refinery, and Citgo Lemont refinery contribute the majority of the waterborne shipments of petroleum related products through the Brandon Road. The Exxon refinery is equipped to handle 250,000 barrels of crude (predominantly Canadian) per day that is pipelined to the facility (ExxonMobil, 2016). The Citgo refinery is the smallest of the three with a crude processing capacity of 167,000 barrels of crude per day (CITGO, 2016). The largest of the three is the BP refinery, which recently underwent a modernization project in 2013 to expand its production capacity to 430,000 barrels per day making it the sixth largest in the U.S. (BP, 2016).

2.3.1 Petroleum Coke and Asphalt

Petroleum coke and asphalt are significant commodities moving through BRL, mostly due to local refineries producing products such as gasoline and distillate fuels. Since pet coke and asphalt are heavier, residual products of the crude oil refining process, they are well suited for barge transportation. Production volumes of pet coke and asphalt are not heavily influenced by their overall demand. Rather, they are mostly driven by the profitability of refining the respective fuels that they are derived from.

Petroleum coke moving through BRLD has increased in recent years due to increased processing of crude oil. Long-term growth in petroleum coke for the reference case is expected to mirror the growth in the petroleum and crude products it is derived from, which shows positive growth through 2040 at a rate of approximately 3% annually. The specific index used is the U.S. Department of Energy's Annual Energy Outlook 2015 reference case growth in "other" petroleum fuels, which explicitly includes growth in pet coke and asphalt along with other miscellaneous petroleum products.

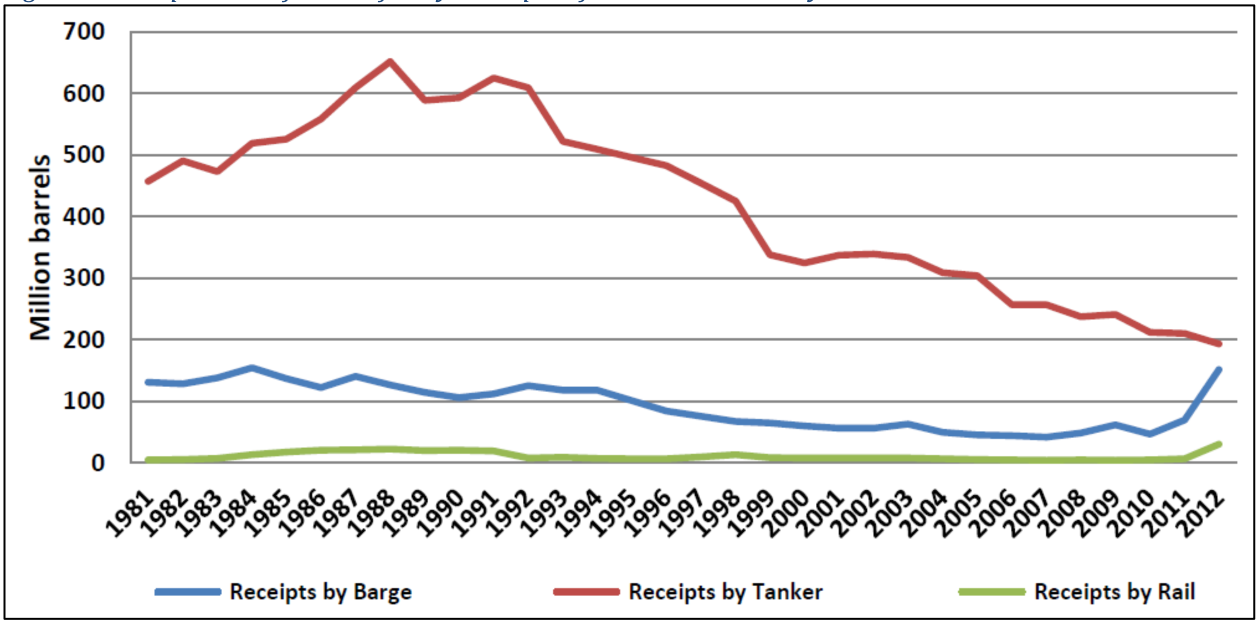
2.3.2 Other Petroleum Fuels

The refineries around BRLD are also responsible for waterborne shipments of the distilled fuel products. Table 1: Commodity Index Summary summarizes the individual commodities that were forecasted within this group and the respective growth indices that were applied.

2.4 Crude

In general, the production of crude petroleum from the Bakken region has been outpacing increases in pipeline capacity, which is typically the preferred method of delivery. Due to these constraints, the barge market is often seen as a low-cost alternative. The system has so far adapted via an expansion in crude-by-rail shipments, pipeline modifications to increase throughput and reverse flow direction from northward to southward, as well as some repurposing of natural gas pipelines. Barge shipments of crude oil to refineries have also grown rapidly, while tanker shipments continues to decline, reflecting a decrease of crude imports into the United States. Major new pipelines projects are in the works, though large pipeline projects typically require several years of planning, financing, permitting and construction (Staff, 2014).

Figure 9: Comparison of U.S. Refinery Receipts of Domestic Crude by Mode



Source: Energy Information Administration

Currently, crude not refined in Chicago is exported by barge to the Gulf Coast. The primary shipper of crude petroleum through BRL is the CITGO Lemont refinery, who receives their crude by pipeline. Growth in waterborne crude traffic is projected to continue to trend upwards, even beyond current levels. In the short-run, the inability to construct the Keystone XL pipeline will continue to hamper TransCanada's ability to export large quantities of its crude production (KOB-TV, 2016). However, the barge market is projected to receive a reduced share of continued crude production growth as pipelines are expected to increase their capital expenditures and expand their capacity in the long-term. The chosen growth rate for forecasting is EIA's outlook for domestic crude production through 2040. Due to the likelihood that the barge market will receive a smaller share of this growth, the year over growth was halved. This assumption is supported by Sandor Toth of River Transport News who acknowledged that barge shipments are contingent on limited pipeline capacity (Toth, 2014).

2.5 Agriculture

Agricultural products moving on the CAWS are highly variable, with a mix of commodities and shipment volumes that depend on day-to-day global market outcomes (Dager, Bray, & Burton, 2012). Barge demand is also influenced by other macro-level factors. These include exchange rate fluctuations, changes in ocean freight markets, and macro-level changes in agricultural, energy and tax policies (Criton Corporation, 2015). Most of the agriculture products moving through Brandon road consist of soybeans and wheat, and are primarily export bound. The majority are shipments are between Cargill facilities at Burns Harbor and grain elevators below Brandon Road. Cargill ships outbound wheat via rail, barge and lake vessel and receives wheat by truck and barge (Dager, Bray, & Burton, 2012). Traffic for these commodities is expected to grow at the pace set by the U.S. Department of Agriculture (USDA) for the respective commodities, which considers changes in the global market. The specific indices used were for export, however the projected growth for wheat was deescalated by 50% since the barge market typically sees a smaller modal share of this growth, and downbound movements from the Chicago region to the Gulf Coast and Lower Mississippi are some of the longest in the country.

2.6 Chemicals

Although there is a substantial variety of chemicals moving through BRL, three commodities contribute the most significant amount of tonnage through the lock, including: caustic soda, ethanol, and antifreeze/deicer.

2.6.1 Caustic Soda

Sodium Hydroxide dominates the flow of barged delivered chemicals through BRLD. Two firms are responsible for the shipment of this good; International-Matex Tank Terminals (IMTT) and Olin Corporation (PR Newswire, 2012), both located in Lemont. The two firms receive sodium hydroxide from plants on the Lower Mississippi and mix the caustic soda with chlorine to produce bleach. The bleach is then distributed outbound from the plants to customers by truck (Dager, Bray, & Burton, 2012). Since the output is primarily used for water and wastewater treatment, growth is projected to track steadily with the regional population.

2.6.2 Ethanol

Ethyl Alcohol moving through Brandon Road is primarily handled and shipped north to south by Kinder Morgan to a variety of locations, including the Gulf Coast region and Tennessee. The shipping terminal is located on the CSSC and handles a variety of chemicals, in addition to petroleum and residual fuel oils, has a total storage capacity of 2,493,108 bbls, and access to rail, truck and barge service (Kinder Morgan Terminals, 2016). Growth in barge delivered ethanol is projected to trend with EIA's projections for E85 fuel through 2020, after which the growth is held constant. Additional growth is not forecasted beyond 2020 due to the following uncertainties: (1) the extent to which ethanol's projected growth will play in the demand for waterway transportation; and (2) the anticipated need for expanded terminal capacity to accommodate the projected increase in EIA's forecast beyond 2020.

2.6.3 Antifreeze/Deicer

Although not as substantial in terms of tonnage as the two aforementioned commodities, ethylene glycol is an important good moving through BRL. It is used for the creation of antifreeze for the automobile industry, and deicing at O'Hare International Airport. Two firms receive the majority of ethylene glycol by barge through BRLD; IMTT and CCI Illinois Manufacturing, both in Lemont. Growth for this commodity is expected to follow regional population trends, since changes in population will likely yield increased activity at the airport and roadways in the long-run.

2.7 Aggregates

Aggregates being moved through BRLD primarily consist of cement, sands, and gravel. The aggregates moving in the Chicago region play an important role in the production of ready-mix concrete, and some facilities are located in the downtown area. Loss of barge transportation would result in further truck congestion in an already heavily populated area. The shipment of these products also affect growth in the Cincinnati area, who benefit from backhaul shipments from Chicago. Low-cost waterway transport also allows Holcim to process residual blast furnace slag into a cement additive, a marginal but usefully purposed residual product that would otherwise not be profitable by other modes of transportation.

Since these commodities typically serve the construction industry, they are among the most highly impacted of barged commodities in times of recession. This is exemplified in Figure 2: Historical Brandon Road

Tonnage and Commodity Percentages. Barge shipments of aggregates have begun to slowly increase since reaching a historic 20-year low (1994-2014 period), and are projected to modestly increase as the economy recovers and more construction materials are demanded. Specifically, the Citron Corp forecast used cites the recent increase in river borne shipments of cement as compared to demand from the 13 states bordering the inland river system.

2.8 Others

Brandon Road Lock serves supports the transport of several other useful commodities. One such commodity is salt, which is used for deicing, water softening, and in the food industry. Companies rely on salt shipments moving through BRL to ensure they can blend various salts to produce a mixture that is demanded by their customers. Other commodities include forestry products, fertilizers, and even oversized cargo that would be problematic to move via an overland mode. The majority of commodities in the "All Others" category of commodities were projected using growth indices provided by Criton Corporation as seen in Table 1: Commodity Index Summary.

2.9 Not Elsewhere Classified

As mentioned in Section 1.4, reputable growth indices could not be found for 18% of the commodities moving through Brandon Road. For these goods, a composite population forecast was developed that utilizes regional growth forecasted from two different sources. The first is a *2040 Forecast of Population, Households and Employment* done by Chicago Metropolitan Agency for Planning (CMAP). The primary purpose of the data is to serve as an input into transportation modeling (CMAP, 2016). The second population forecast is prepared by the Illinois Department of Public Health (IDPH, 2016). The IDPH forecast projects population growth to 2025, whereas CMAP forecasts to 2040. Growth in the eight counties that form the metropolitan area were used from both sources. Since the lengths of each forecast vary, each was converted into an average annual value, and then equally weighted together to create a composite growth value. This value was then applied to the remaining 18% of commodities.

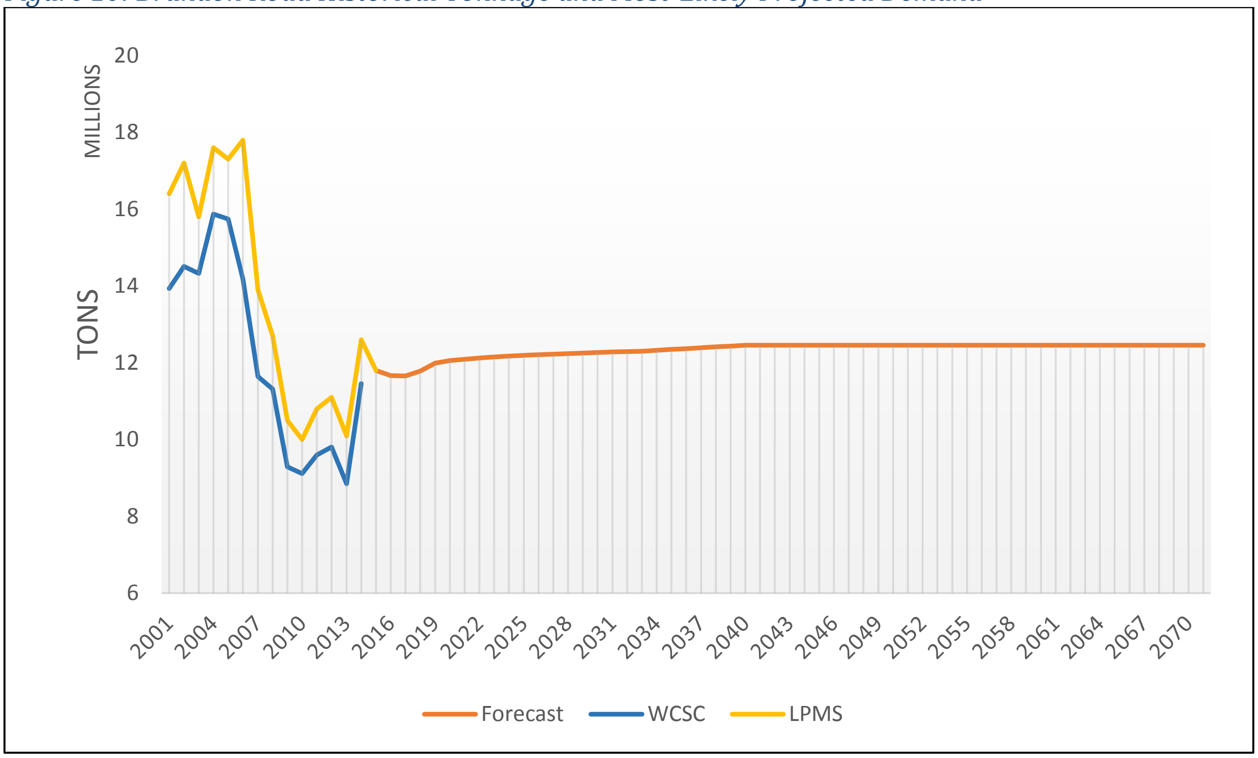
Table 4 - Composite Population Forecast

IDPH Average Annual Population Growth	
2010 to 2015	0.34%
2015 to 2020	0.30%
2020 to 2025	0.27%
Average	0.30%
CMAP Average Annual Population Growth	
2010 to 2040	0.95%
Composite Average Annual Population Growth	
	0.63%

3 RESULTS

The specific growth in each commodity results in several offsetting factors that yield a rather static waterway traffic demand forecast. Primarily, the anticipated negative growth in the iron and steel industry results in a short-run decline in traffic to 2017, totaling approximately 11.65 million tons. Growth in other commodities causes demand to rebound by 2020 to 12.05 million tons, working in an opposing direction of iron and steel decline. By 2030, demand increases to 12.2 million tons, and to 12.4 million tons by 2040. Demand is assumed to be constant beyond 2040 to 2070, which is the end of the planning analysis period.

Figure 10: Brandon Road Historical Tonnage and Most-Likely Projected Demand



4 REFERENCES

BP. (2016). *BP Energy Outlook - 2016 edition.* BP. Retrieved from http://www.bp.com/en/global/corporate/energy-economics/energy-outlook-2035/energy-outlook-downloads.html

BP. (2016, March 30). *What we do > Refining > Whiting, Indiana*. Retrieved from BP United States: http://www.bp.com/en_us/bp-us/what-we-do/refining/whiting.html

CITGO. (2016, March 30). *About Us: CITGO Lemont*. Retrieved from CITGO: http://www.citgorefining.com/lemont/about-us

CMAP. (2016, April). *Population Forecast*. Retrieved from Chicago Metropolitan Agency for Planning: http://www.cmap.illinois.gov/data/demographics/population-forecast

Criton Corporation. (2015). *Prospects for the Dry Cargo Inland Barge Market through 2019.* Silver Spring, MD: Criton Corporation.

Dager, C., Bray, L., & Burton, M. (2012). *Industry and Freight Profiles for Traffic Moving in the Chicago Area Waterway System.* Knoxville: University of Tennessee Center for Transportation Research.

DiCianni, R. J. (2015). Steel Market Outlook. *Twenty-Ninth Annual Economic Outlook Symposium* (pp. 1-30). Chicago: ArcelorMittal for The Federal Reserve Bank of Chicago. Retrieved from https://www.chicagofed.org/~/media/others/events/2015/economic-outlook-symposium/dicianni-120415.pdf.

ExxonMobil. (2016, March 29). *Joliet Refinery*. Retrieved from ExxonMobil Corporate: http://corporate.exxonmobil.com/en/company/worldwide-operations/locations/united-states/us-refineries/joliet

ExxonMobil. (2016). *The Outlook for Energy: A View to 2040.* ExxonMobil. Retrieved from http://corporate.exxonmobil.com/en/energy/energy-outlook

IDPH. (2016, April). *State of Illinois Data Portal*. Retrieved from IDPH Population Projections 2014 Edition: https://data.illinois.gov/dataset/IDPH-Population-Projections-2014-Edition/6u8g-w2b6/data

Kinder Morgan Terminals. (2016, April 3). *Argo, IL Terminal.* Retrieved from Kinder Morgan: http://www.kindermorgan.com/content/docs/terminalbrochures/mw_Argo.pdf

KOB-TV. (2016, March 2). Keystone XL Pipeline Dead. *KOB-TV Channel 4 Eyewitness News*. Retrieved from http://www.kob.com/article/stories/s4065146.shtml#.Vv6D9-Y5V5L

Pete, J. S. (2015, April 29). *U.S. Steel CEO: Layoff notices nationwide rise to 9,000.* Retrieved from Northwest Indiana Times: http://www.nwitimes.com/business/local/u-s-steel-ceo-layoff-notices-nationwide-rise-to/article_2545ab4b-393d-5462-a4e3-d5f6885f7e93.html

Pfisterer, N. (2015). *A Comprehensive Overview of the U.S. Iron Ore and Steel Industries.* Buffalo: U.S. Army Corps of Engineers.

PR Newswire. (2012). Olin Corporation Completes Acquisition of K. A. Steel Chemicals Inc. *PR Newswire*, 1. Retrieved from http://www.prnewswire.com/news-releases/olin-corporation-completes-acquisition-of-k-a-steel-chemicals-inc-167092705.html

Staff, Q. E. (2014). Memorandum For Record. *QER Public Stakeholder Meeting: Rail, Barge, and Truck Transportation* (pp. 1-27). Chicago: U.S. Department of Energy.

Toth, S. (2014). Changing U.S. Petroleum Dynamics and their Impact on River Petroleum Traffic. *U.S. Army Corps of Engineers Planning Associates Program* (pp. 1-21). Huntington, WV: Criton Corporation.

U.S. Environmental Protection Agency. (2016, March 30). *Petroleum Coke on Chicago's South Side*. Retrieved from U.S. Environmental Protection Agency: https://www.epa.gov/petroleum-coke-chicago