Great Lakes Maritime Research Institute

A University of Wisconsin - Superior and University of Minnesota Duluth Consortium

Annual Report October 2006 - October 2007

Provided to the United States Congress and the U.S. Department of Transportation, Maritime Administration

A National Maritime Enhancement Institute

www.glmri.org

Annual Report
to Congress

The Great Lakes Maritime Research Institute

A National Maritime Enhancement Institute
designated by
The U.S. Department of Transportation, Maritime Administration

November 2007

Co-Directors
Richard D. Stewart and James P. Riehl

Program Assistant Director
Carol J. Wolosz

Associate Researcher
Stacey E. Carlson

GLMRI Program Office, 1023 University Drive, 291 Marshall W. Alworth Hall, Duluth, MN 55812
www.glmri.org
(218) 726-7446

Mission Statement

The Great Lakes Maritime Research Institute is dedicated to developing and improving economically and environmentally sustainable maritime commerce on the Great Lakes through applied research.

A National Maritime Enhancement Institute

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The U.S. Department of Transportation, Maritime Administration

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Richard D. Stewart, Ph.D.
James P. Riehl, Ph.D.
Carol J. Wolosz
Stacey E. Carlson
Tab 1: Michael D. Parsons, Ph.D.
Tab 2: Peter Lindquist, Ph.D.
Tab 3: David Singer, Ph.D.
Tab 4: Daniel Pope, Ph.D.
Tab 5: Randall Hicks, Ph.D.
Tab 6: Donn Branstrator, Ph.D.
Tab 7: R. Douglas Ricketts, Ph.D. and Nigel Wattrus, Ph.D.
Tab 8: Joan Chadde
Tab 9: Lynn Corson, Ph.D.</td><td colspan="2">8. Performing Organization Report No.</td></tr>
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The Great Lakes Maritime Research Institute was established to pursue research efforts in marine transportation, logistics, economics, engineering, environmental planning, and port management. The consortium also draws on expertise in a wide range of other areas through affiliations with other Great Lakes universities. This is the second year of funded support. The research agenda was extended to fund nine major projects, while two universities joined GLMRI as affiliate universities. This report details the nine projects while discussing meetings, outreach and education, and other efforts undertaken in support of the mission.</td></tr>
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Research and Outreach Project Reports

Overview and Background

This report provides a compilation of the completed work under the second funded year of the Great Lakes Maritime Research Institute (GLMRI) for the period of October 2006 through October 2007. Funding was provided through the U.S. Department of Transportation (US DOT), Maritime Administration (MARAD) that was appropriated by Congress in the Departments of Transportation, Treasury, and Housing and Urban Development, the Judiciary, District of Columbia, and Independent Agencies Act of 2006. This is the first of two years of effort funded against this specific appropriation totaling $1,980,000.

During March 2004, the University of Minnesota Duluth (UMD) and the University of Wisconsin-Superior (UW-Superior) formed the consortium, the Great Lakes Maritime Research Institute. Federal funding to support the GLMRI was first received in May 2005. The Maritime Administration designated the GLMRI as a National Maritime Enhancement Institute (NMEI) on June 1, 2005.

$750,000 was federally appropriated through the Transportation Act of 2005 (FY 05), specifically for Great Lakes research by an NMEI. This appropriation provided partial funding to support the research objectives in the Coast Guard and Maritime Transportation Act of 2004 authorizing a U.S. designated Great Lakes NMEI. A report detailing the effort funded by this appropriation is available on the GLMRI web site: www.glmri.org.

Consortium Partners

The transportation research centers of the **University of Wisconsin-Superior** and the **University of Minnesota Duluth** have, for several years, jointly pursued transportation and logistics research, public forums, and funding. In March 2004, these universities formally agreed to form a research consortium that would focus on Great Lakes maritime research.

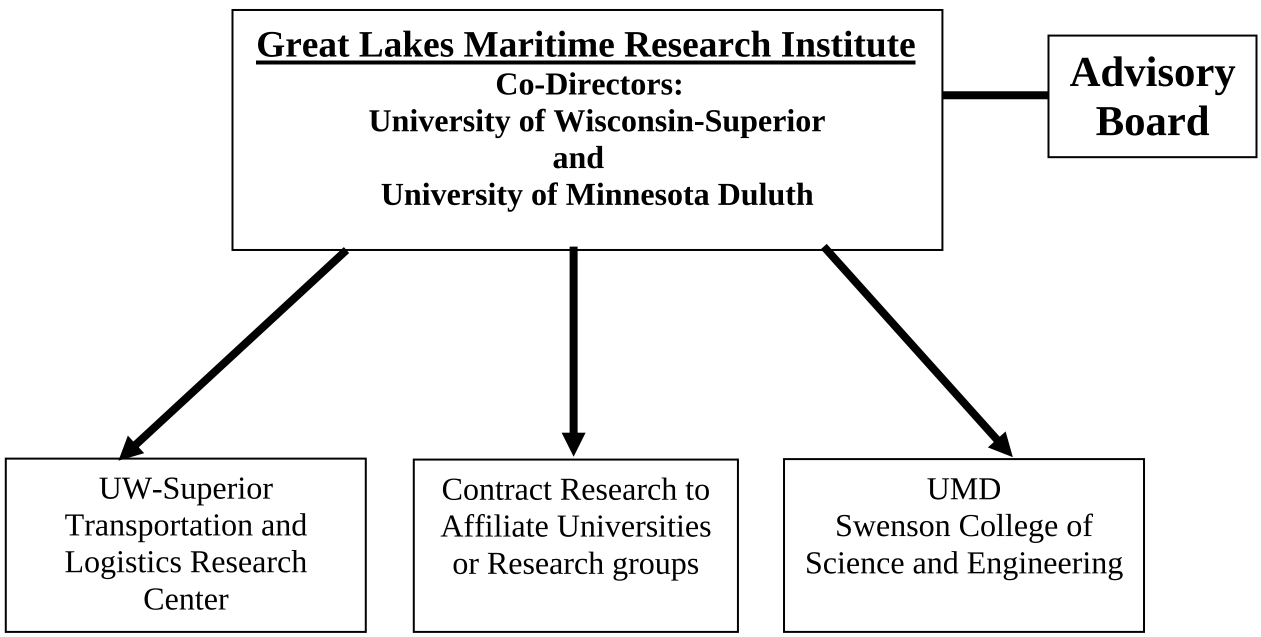
The two universities are located in the largest ports on the Great Lakes, the Twin Ports of Duluth, Minnesota, and Superior, Wisconsin. The communities have been a transportation hub for over 150 years. In addition to the maritime industry, the Twin Ports are serviced by four class 1 railroads, is the terminus of the longest pipeline in North America, is the headquarters to over thirty trucking companies, have an international airport and is home to the largest single engine airplane manufacturer in the U.S. The Twin Ports have a U.S. Coast Guard (USCG) Marine Safety Unit and is the home port for the new USCG Cutter *Alder*. The Twin Ports are also a Port of Entry with the U.S. Customs Office and The Immigration and Naturalization Service.

The Great Lakes Maritime Research Institute combines the strengths of two universities and their academic and research expertise. This dynamic combination provides a program area with tremendous breadth as a National Maritime Enhancement Institute serving the Great Lakes Region. The University of Wisconsin-Superior and the University of Minnesota Duluth have formally joined together to pool the considerable resources available to the two institutions to continue and expand

Great Lakes maritime research. The universities have a history of supporting each other in the area of transportation research.

The consortia that forms the GLMRI draws staff from two universities with experts in marine transportation, logistics, economics, engineering, technology, computer management, management, marine environmental, planning, geography, and port management. The consortium can also draw on expertise in a wide range of other areas including air and rail transportation management, operations research, mathematics, and social sciences. Both universities are members of federally nominated University Transportation Centers: UW-Superior is an affiliate member of the University of Wisconsin-Madison's National Center for Freight and Infrastructure Research and Education; and UMD is an affiliate member of the University of Minnesota's Center for Transportation Studies.

The faculty and administrators of the GLMRI have had a long-term involvement with the maritime industry including shippers, carriers, ports and government agencies. The consortium is committed to improving the maritime system of the Great Lakes and the United States.



Advisory Board

The following organizations make up the GLMRI Advisory Board:

- The Great Lakes Commission
- The St. Lawrence Seaway Development Corporation (SLSDC)
- The Maritime Administration
- The Society of Naval Architects and Marine Engineers (SNAME)
- The American Great Lakes Ports Association
- The U.S. Coast Guard
- The Lake Carriers' Association
- The U.S. Army Corps of Engineers (USACE)

The current representation to the Advisory Board is listed below:

Dr. Thomas Huntley
Commissioner and former Chairman, Great Lakes Commission
Duluth, MN 55812

Mr. Craig Middlebrook
Deputy Administrator, St. Lawrence Seaway Development Corporation
Washington, DC 20590

Ms. Doris J. Bautch
Director, Maritime Administration, Great Lakes Gateway
Schaumberg, IL 60173

Mr. Al Horsmon
Chairman, Society of Naval Architects and Marine Engineers, Great Lakes/Great Rivers Section
Three Rivers, MI 49093

Mr. Adolph Ojard
Chairman, American Great Lakes Ports Association
Duluth, MN 55802

Commander Gary Croot
U.S. Coast Guard, Marine Safety Unit
Duluth, MN 55802

Mr. James H.I. Weakley
President, Lake Carriers' Association
Cleveland, OH 44113

Lieutenant Colonel William Leady
District Engineer, U.S. Army Corps of Engineers, Detroit District
Detroit, MI 48266

The third annual meeting of the Advisory Board was held on September 27, 2007, in Duluth, Minnesota, at the Lake Superior Marine Museum. An update was presented on the current projects and outreach activities, along with announcing the selection of the research projects for the coming year. Each of the Advisory Board members provided an update on maritime issues impacting their organization along with any other factors that would involve or support a team approach to further the research areas under GLMRI.

University Research Affiliations

Universities in the Great Lakes region with expertise in the research focus areas were offered affiliations to partner in applicable areas. Researchers and other relevant affiliate assets from the affiliated universities are included as part of the research portfolio of the GLMRI, and the affiliate may serve as project researchers based on submitted proposals in response to an annual Request for Proposals. Research affiliates are encouraged to leverage GLMRI resources in efforts to secure independent and joint funding opportunities for Great Lakes maritime research. During the past year, two additional universities joined the list of affiliate universities, The University of Findlay (Ohio) and Rochester Institute of Technology (New York). Current affiliates are listed below, along with the assigned university representative.

Great Lakes Maritime Academy
Admiral John Tanner
1701 East Front Street
Traverse City, MI 49686

Michigan Technological University
Dr. William Sproule
Dept. of Civil and Environmental Engineering
1400 Townsend Drive
Houghton, MI 49931

University of Michigan
Dr. Armin Troesch
Dept. of Naval Architecture and Marine Engineering
2600 Draper
Ann Arbor, MI 48109

Purdue University
Mr. Rick Evans
Assistant Director, Industrial/Foundation Administration
Young Hall
302 Wood Street
West Lafayette, IN 47907-2108

Purdue University North Central
Dr. Keith Schwingendorf
Dean, College of Science
1401 S. US Hwy 421
Westville, IN 46391

University of Toledo
Dr. Mark Vonderembse / Mr. Rich Martinko
Director, Intermodal Transportation Institute
2801 W. Bancroft St.
Toledo, OH 43606

University of Wisconsin-Madison
Dr. Teresa M. Adams
Director, National Center for Freight and Infrastructure Research and Education
1415 Engineering Drive, Rm 2205
Madison, Wisconsin 53706

The University of Findlay
Mr. Mark Alliman
School of Environmental and Emergency Management
1000 North Main Street
Findlay, OH 45840

Rochester Institute of Technology
Dr. James J. Winebrake
Department of STS/Public Policy
92 Lomb Memorial Drive
Rochester, NY 14623

The annual meeting of the affiliate universities was held in conjunction with the Advisory Board meeting, on Friday, September 28, 2007, at the Lake Superior Marine Museum in Duluth, Minnesota. In addition to the GLMRI program update, each of the current researchers provided a brief presentation of their ongoing work. The annual meeting provides an opportunity for members of the maritime community along with the current researchers to share ideas and provide input to the projects. This has proven to be a positive venue for technical and resource exchange.

Research Focus for FY 07

The selections for the research and outreach activities for the efforts detailed in this report were completed in the summer and fall of 2006. The call for proposals was released on April 5, 2006, with the proposals due to GLMRI by June 30, 2006. An extended review was completed with award notifications released in October 2006. Eighteen proposals from the affiliated universities and the two host-universities were received requesting over $1.4 million. A review process that included outside reviewers from MARAD made the final selections. The following projects were supported with a detailed report included as a separate tab:

- Part II: Hydrodynamic Optimization Testing of the Ballast-Free Ship Design (University of Michigan) – Tab1
- Phase II of implementing the Great Lakes Maritime Information Delivery System (University of Toledo) – Tab 2
- A review of the Great Lakes shipbuilding and repair capability – Past, present and future (University of Michigan) – Tab 3
- The Effect of Long-Term Cold Storage on Biodiesel Blends (University of Minnesota Duluth) – Tab 4
- Structure of Bacterial Communities Associated with Accelerated Corrosive Loss of Port Transportation Infrastructure (University of Minnesota Duluth) – Tab 5
- Testing Relationships between Propagule Pressure and Colonization Success of Invasive Species (University of Minnesota Duluth and the University of Wisconsin-Superior's Lake Superior Research Institute in cooperation with the Northeast Midwest Institute's Great Ships Initiative) – Tab 6
- Multibeam Bathymetry Survey of the Duluth-Superior Harbor (University of Minnesota Duluth) – Tab 7
- Great Lakes Maritime Transportation K-12 Education Program for Teachers, Students and Communities, Year 2 (Michigan Technological University) – Tab 8

Later in the year, a seed project was awarded to Purdue University to do an initial study toward developing an environmental management system model. An update is provided in Tab 9.

Research Focus for FY 08

The annual call for proposals was released to the consortium and affiliate universities on April 5, 2007, with a due date of June 4, 2007. The review process from proposal receipt to award announcements took two months. We held to a tight agenda, while still including a thorough review involving external expertise.

The FY 2008 suggested research focus topics include:

- Evaluate short sea shipping market opportunities on the Great Lakes
- Evaluate export and import markets for foreign trade between ports on the Great Lakes and foreign ports such as those located in Europe and Africa
- Evaluate the environmental benefits of waterborne transportation in the Great Lakes region and assist in developing sustainable solutions to the environmental effects of maritime transportation and port operations
- Analyze the methods and effects of taxes and fees imposed on Great Lakes shipping
- Evaluate the state of shipbuilding and repair bases on the Great Lakes and the impact to the industry and national security
- Analyze the origin-to-destination flow of freight in the Great Lakes
- Analyze the economic viability of establishing transshipment facilities and intermodal for ocean-going and intra-lake cargoes on the Great Lakes, which may include the evaluation of 12-month operations of the locks and shipping lanes
- Evaluate new vessel designs for domestic and international shipping on the Great Lakes
- Develop new products and technologies to enhance port security and port operations
- Provide education and outreach activities to the public on Great Lakes maritime shipping, port security and intermodal operations
- Identify ways to improve the integration of the Great Lakes Marine Transportation System (MTS) into the national transportation system
- Examine the potential of expanded seasonal operations on the Great Lakes MTS
- Identify ways to include intelligent transportation applications into the Great Lakes MTS
- Analyze the effects and impacts of aging infrastructure and port corrosion on the Great Lakes MTS

- Establish and maintain a model Great Lakes MTS database

- Identify market opportunities for, and impediments to, the use of United States-flag vessels in trade with Canada on the Great Lakes

A total of 20 proposals were received from nine of the eleven consortium and affiliate universities, requesting over $1.3 million. An initial review was performed by the staff and co-directors. External reviewers were selected based on the content of the proposal. Maritime experts participated from the Maritime Administration, U.S. Coast Guard and Great Lakes' Port Authorities. Proposals were prioritized, and a funding plan was developed with the constraints of the available resources. Proposers were notified of the decisions regarding their individual requests, along with a summary of the reviewer feedback. Since many of the projects were offered a lesser dollar amount than their request, the proposers were asked to provide an updated work plan and budget to allow for the reduced funding.

The following projects were awarded during the timeframe of this report:

- Great Lakes Maritime Education Program for K-12 Teachers, Students and Communities (Michigan Technological University)

- Application of an Environmental Management System "Model" to Examine Port and Tenant Operations and Provide a Tool to Small Public Port Authorities for Enhancing Environmental Initiatives (Purdue University)

- Intermodal Freight Transport in the Great Lakes: Development and Application of a Great Lakes Geographic Intermodal Freight Transport Model (Rochester Institute of Technology)

- Further Development and Optimization of the Ballast-Free Ship Design Concept (University of Michigan)

- Erie Pier Process Re-Use Cost and Market Analysis (University of Minnesota Duluth)

- Year 2: Building Sustainable Solutions to the Issues of Ballast Water Treatment: Testing Relationships Between Propagule Pressure and Colonization Success of Invasive Species (University of Minnesota Duluth and University of Wisconsin-Superior with The Great Ships Initiative under the Northeast Midwest Institute)

- Development and Succession of Microbial Communities Associated with Corroding Steel Pilings in the Duluth-Superior Harbor (University of Minnesota Duluth)

- Shipboard Testing of B-20 (University of Minnesota Duluth)

- The Great Lakes Maritime Information Delivery System: A Resource for the Regional Analysis of Intermodal Freight Flows in the Great Lakes Region (Phase III) (University of Toledo)

Special Projects and Other Cooperative Efforts

Finland Cooperative Research Exchange

In June, Dr. Stewart traveled to Finland to meet with researchers at the VTT Technical Research Centre of Finland. He spent time with the research center to exchange ideas and to consider joint research projects. GLMRI is working to bring Finnish researchers to the United States to discuss their research and move toward developing a cooperative research exchange program. Dr. Stewart was also able to tour many of the ports and marine transportation facilities on his visit, to learn about Finland's transportation initiatives. Dr. Stewart provided an update on this visit to members of the Maritime Administration and the St. Lawrence Seaway Development Corporation.

As a part of this initiative, **Dr. Jorma Rytkonen,** research director of maritime and port operations for the Merikotka Research Institute in Kotka, Finland, was the invited speaker for the GLMRI annual fall meetings. He provided a presentation on the work that is being done in Finland and the Baltic region on maritime initiatives. During his visit with GLMRI, Dr. Rytkonen met with the researchers of Great Ships Initiative at the Research Development Testing and Evaluation facility in Superior, Wisconsin, as part of this research exchange. Dr. Rytkonen also spent a day with maritime business leaders from the Port of Duluth-Superior. He also visited one of the GLMRI affiliate universities, Michigan Technological University, as an extension of this research exchange.

GLMRI is planning to expand this research exchange to other public outreach venues, such as the Great Lakes Marine Community Day event in Cleveland, Ohio, in February 2008.

Student Competition

GLMRI is developing an initiative to incorporate students and build an interest in Great Lakes maritime commerce. As a first step for this initiative, we will work with the GLMRI affiliates and Advisory Board members to build an agenda and focus for the competition. We anticipate launching the competition in the fall of 2008. As of the writing of this report, a project is underway to support a senior design project through the University of Michigan's Naval Architecture and Marine Engineering Department, in partnership with the Duluth Seaway Port Authority, to design a vessel to accommodate the potential markets for slab steel from northeastern Minnesota.

Great Lakes Maritime Academy

As an affiliate member of GLMRI, the Great Lakes Maritime Academy (GLMA) has teamed with GLMRI for furthering their training outreach. As in 2006, GLMA incorporated a stop to the Port of Duluth-Superior on their annual cadet training voyage in May 2007. The two organizations co-sponsored a reception and harbor cruise for community and university leaders to expose the participants to the GLMA cadet program. GLMA's training ship the *State of Michigan* was also opened for public tours. GLMRI Assistant Director Carol Wolosz and Associate Researcher Stacey Carlson joined the *State of Michigan* on their voyage from Duluth to Sault Ste. Marie, Michigan.

As a research component to the visit, GLMA was able to take on a biodiesel fuel blend, as a step in utilizing renewable fuels for maritime applications.

Canadian Initiatives

GLMRI staff members met with Canadian government representatives in conjunction with The Trade, Transportation and Asia-Pacific Gateway and Corridor symposium held in Superior, Wisconsin, on April 20, 2007. Representatives from the west coast ports of Prince Rupert and Vancouver provided updates on their development efforts to build the shipping and rail intermodal hubs that would ultimately lead to the Midwest US. Potential opportunities abound for the Great Lakes region in shipping and commerce.

Also, Dr. Stewart and Carol Wolosz are working to develop a research affiliation and exchange with a Canadian Great Lakes university.

Outreach and Education

Advertisements and Marketing Materials

One of the key components to any organization is communication. GLMRI distributes quarterly reports to the stakeholders and sponsors, but we also are looking to expand the interest in GLMRI's research results. Over the past year, GLMRI has advertised in periodicals, such as *Great Lakes/Seaway Review* and *Lake Superior Magazine*; we have prepared materials such as brochures, and hardcopies and CDs of the research reports; and we have expanded our website.

To enhance networking opportunities, GLMRI has participated as a sponsor to many conferences and activities where there is a tie to the GLMRI mission, such as the 2007 Ohio Conference on Freight, and the International Symposium and Workshop on Global Supply Chain, Intermodal Transportation and Logistics.

Extension Education and Outreach Support

Through a cooperative arrangement, Minnesota Sea Grant supported education and outreach efforts for GLMRI. Staff members developed materials, updated brochures, built display boards and redesigned the web site to provide information dissemination and marketing to GLMRI stakeholders. Dale Bergeron, maritime extension educator, worked with researchers and media to develop articles, papers, and presentations. He also served on numerous committees to develop programs and coordinate studies and plans for furthering sustainable maritime commerce on the Great Lakes.

Outreach Events, Presentations and Participation

Over the year, the GLMRI Co-Directors, staff members and researchers participated on behalf of GLMRI and/or have made presentations on the benefits of short-sea shipping and other research projects to various audiences. A list of the key presentations is provided below:

The 2nd Annual GLMRI Advisory Board meeting. Duluth, MN. October 6, 2006

The 2nd Annual GLMRI Affiliate Universities meeting. Duluth, MN. October 7, 2006

Data Workshop II, University of Toledo. Toledo, OH. November 7, 2006

Carol Wolosz provided a GLMRI overview to The Marine Transportation System National Advisory Council (MTSNAC). Jacksonville, FL. December 5-6, 2006

USACE Great Lakes Stakeholders' Meeting. Cincinnati, OH. December 7, 2006

Transportation Research Board (TRB), Marine Committees, and Poster Session (provided sponsorship for the Wisconsin reception). Washington, D.C. January 14-18, 2007

Office visits with MARAD and SLSDC Administrators and Congressional Offices. Washington, D.C. January 15-16, 2007

Presentation on maritime research areas to the Labovitz School of Business and Economics. University of Minnesota Duluth. February 14, 2007

Mississippi Valley Transportation Coalition Meeting. Dearborn, MI. February 26-27, 2007

Great Lakes Marine Community Day. Cleveland, OH. February 27-28, 2007

Dr. Stewart presented two papers at the Society of Naval Architects and Marine Engineers, Great Lakes/Great Rivers Section meeting. Cleveland, OH. March 1, 2007

Carol Wolosz attended the USACE Stakeholders Meeting. Cleveland, OH. April 3, 2007

UW-Superior hosted a seminar on Trade, Transportation and the Asia-Pacific Gateway and Corridor. Superior, WI. April 20, 2007

Dr. Stewart presented a paper on options available to establish more stringent standards of ballast water to the TRB Committee on the St. Lawrence Seaway. Toronto, ON. May 6-7, 2007

Carol Wolosz presented a GLMRI update to MTSNAC. Chicago, IL. May 8-10, 2007

Stacey Carlson attended the TRB Annual Harbor Safety Committee Conference. Chicago, IL. May 9-11, 2007

Stacey Carlson, Dale Bergeron, and Sharon Moen participated in the River Quest educational program coordinated by the Duluth Seaway Port Authority. Duluth, MN. May 16-18, 2007

Dr. Stewart, Dr. Vonderembse (U of Toledo), Dr. Lindquist (U of Toledo), and Ms. Joan Chadde (Michigan Tech) presented their research at the International Association of Great Lakes Research. State College, PA. May 28-31, 2007.

Dr. Stewart presented an update on the Great Lakes Observing System to the Duluth/Superior Harbor Technical Advisory Committee (HTAC). Superior, WI. June 6, 2007

Stacey Carlson attended the TRB Summer Conference. Chicago, IL. July 6-9, 2007

Program updates were presented to congressional offices, the Maritime Administration and the St. Lawrence Seaway Development Corporation. Washington, D.C. July 16-17, 2007

Dr. Stewart took an observation trip on the M/V Edwin Gott from Two Harbors, MN to Gary, IN, July 20-25, 2007

Great Lakes Maritime Transportation Teachers Institute. Duluth, MN/Superior WI. July 30-August 3, 2007

Dr. Stewart made presentations on Great Lakes Shipping and Carbon Tax Credits at the SNAME sectional meeting. Marinette, WI. September 21, 2007

The 3rd Annual GLMRI Advisory Board meeting. Duluth, MN. September 27, 2007

The 3rd Annual GLMRI Affiliate Universities meeting. Duluth, MN. September 28, 2007

Future Plan for GLMRI – Beyond this Grant

In the second year of formal research, GLMRI projects have developed to a level where there are extended results, and an increase to the depth of focus. Over this past year, each of the research efforts was able to include additional outreach initiatives such as articles, presentations, proceedings, and project workshops. We are quickly becoming the model in developing regional maritime research and commerce enhancements through teaming initiatives and partnerships. As we move GLMRI into the future, we are looking to continue to address Great Lakes maritime focused topics, and build our program to develop strategic initiatives with a long range impact on maritime commerce including port activities, marine environmental issues, and intermodal connections. We will continue to seek academic affiliates throughout the entire Great Lakes region, and will strengthen our ties to private industry and government agencies involved in Great Lakes maritime issues.

Great Lakes Maritime Research Institute

A University of Wisconsin - Superior and University of Minnesota Duluth Consortium

Hydrodynamic Optimization Testing of Ballast-Free Ship Design

Final

Michael G. Parsons Arthur F. Thurnau Professor
Professor of Naval Architecture and Marine Engineering
Phone: 734-763-3081; FAX: 734-936-882; e-mail: parsons@umich.edu

Miltiadis Kotinis Assistant Professor, SUNY Maritime College
Phone: 734-709-6425; FAX: 516-767-1063; e-mail: mkotinis@umich.edu

October 30, 2007

Department of Naval Architecture and Marine Engineering
University of Michigan
2600 Draper Road
Ann Arbor, MI 48109-2145

MICHIGAN

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Executive Summary

The initial investigation of the Ballast-Free Ship concept demonstrated the feasibility of the concept though a thorough examination of various design aspects. The effectiveness of the concept, in terms of eliminating the transport of foreign ballast water from ships operating in the ballast condition, was also demonstrated by utilizing Computational Fluid Dynamics (CFD) software to simulate the flow in the double bottom ballast trunks of the vessel. Nevertheless, this initial investigation did not succeed in showing the full cost-effectiveness of the concept. The main reason was a significant fuel penalty that resulted from an increased power requirement found in the initial hydrodynamic testing of a non-optimized discharge configuration on an existing, higher-speed vessel with a non-optimum propeller.

The current phase of this research project focuses on the further hydrodynamic investigation of the Ballast-Free Ship concept; both experimental and numerical. The experimental investigation was performed by utilizing the Seaway-size bulk carrier model that was designed and built as part of the initial phase of this project; also sponsored by the GLMRI. The resistance and propulsion tests were performed in the towing tank of the University of Michigan Marine Hydrodynamic Laboratory in January 2007. The numerical investigation was performed utilizing commercial CFD software, namely FLUENT®.

The computational results were utilized both as guidance for the experimental setup and also to corroborate the experimental results. Specifically, the selection of the trunk flow inlet and outlet locations utilized in the towing tank experiments was guided by the numerical results. The ballast trunk flow inlet was located in the center of the bulbous bow. Two different locations were tested for the water discharge: one at the level of the upper part of the propeller disk close to Station 17 (near the forward engine room bulkhead, full scale) and one lower close to Station 19 (near the aft engine room bulkhead).

The experiments in the towing tank consisted of detailed resistance and propulsion testing with and without the ballast trunk flow. The analysis of the model test data revealed that the experimental results were in good agreement with the numerical results. Overall, discharging water at the stern of the model slightly increases ship resistance, but proper design of the discharging arrangements can overcome this negative effect. Another source of modest ship resistance increase is the trunk inlet at the bow. Given the limited positive-pressure region at the bow of the vessel, an inlet location other than that currently utilized will probably result in a significant reduction in the available pressure differential, without providing a noteworthy benefit in terms of ship resistance.

Nonetheless, the proper water discharge at the stern of the vessel has a favorable effect on the propulsion characteristics for the Seaway-size bulk carrier design investigated. The computed reduction in powering requirements, relative to the initial unmodified design, at an assumed ballast speed of 15.5 knots was 7.3% for water discharge close to Station 17 and 2.1% for water discharge close to Station 19. This gain in propulsive efficiency outweighs the increase in ship resistance. The method utilized for computing the ship propulsive requirement is based on a well-established extrapolation procedure that contains significant levels of uncertainty; therefore, only a full-scale implementation of the concept can provide a precise determination of the actual propulsive gains.

In order to investigate the economic benefit of the aforementioned propulsive improvements, a pragmatic operating scenario for the grain trade to Europe was adopted for the Ballast-Free bulk carrier. The change in the Required Freight Rate (RFR) with respect to an alternative filtration and UV ballast treatment system was calculated. The net savings would be \$0.93 per ton of cargo for the water discharge close to Station 17 and \$0.44 per ton of cargo for the water discharge close to Station 19. The overall ship design would also benefit from placement of the water discharge near the forward engine room bulkhead. A different operating scenario could result in even lower savings. Nevertheless, cost-effectiveness combined with a numerically-demonstrated foreign-ballast-elimination capability confirms the Ballast-Free Ship concept as a viable alternative to more costly ballast treatment systems. Even though the current project focuses on a smaller Seaway-size bulk carrier, the concept should also be applicable to other new-construction ships of different types and sizes.

1. Introduction

The Ballast-Free Ship Concept was invented (US Patent #6,694,908 2004) and initially investigated (Kotinis et al. 2004, Kotinis 2005, *Ballast Water News* 2004) at the University of Michigan as a way to minimize the risk of the further introduction of nonindigenous aquatic species into the Great Lakes and other coastal waters by ships arriving in the ballast condition. Even though the feasibility of the concept was demonstrated, the initial analysis was limited by its required comprehensive research scope and limited associated budget. Thus, it was only feasible to support model testing that utilized an existing model. Although the vessel type of greatest interest for the Great Lakes nonindigenous aquatic species introduction problem is the Seaway-sized bulk carrier, the best available model was of a relatively finer, higher-speed barge-carrying Lighter Aboard Ship (LASH) vessel. This existing model was modified to utilize a more conventional stern, but the model test results were not directly applicable to the Seaway-sized bulk carriers studied in detail in the rest of the research effort.

The first year of GLMRI sponsored research (Parsons and Kotinis 2006) supported the design of a typical Seaway-sized bulk carrier and the construction of a scaled model to be utilized in subsequent towing tank experiments. This model was designed, constructed, and delivered in 2006. The goal was to use this model to optimize the location of the Ballast-Free trunk discharges in order to reduce or eliminate the propulsion power increase observed with the modified LASH model. The experimental and numerical hydrodynamic investigation, combined with an optimization procedure, was expected to lead to a design solution that could offer a net savings in Required Freight Rate (RFR) relative to alternate ballast water treatment methods and approaches.

In the present research, the hydrodynamic aspects of the Ballast-Free Ship concept were further investigated both experimentally and numerically. The initial results of the experimental program were reported in the popular press in January (Parsons 2007). Part of the numerical investigation, including an attempt at discharge location design optimization, was reported in a paper presented at the 9th International Conference on Numerical Ship Hydrodynamics (Kotinis and Parsons 2007a). The experimental hydrodynamic investigation, supported by a CFD analysis and an economic analysis, will be presented at the Annual Society of Naval Architects and Marine Engineers (SNAME) Meeting in Ft. Lauderdale, FL, in November 2007 (Kotinis and Parsons 2007b).

2. Background

The initial Sea Grant supported development of the Ballast-Free Ship Concept was reported in a paper before the Annual Meeting of the Society of Naval Architects and Marine Engineers (SNAME) in Washington, DC, in October 2004 (Kotinis et al. 2004). Overall, the investigation of the Ballast-Free Ship Concept has shown that it provides a viable alternative to the addition of costly ballast water treatment systems in order to meet the evolving performance requirements for ballast water treatment. The concept <u>essentially eliminates the transport of foreign ballast water</u>. This should be more effective than current treatment methods in reducing the potential for the further introduction of nonindigenous aquatic species into the Great Lakes and coastal waters. Furthermore, it should be equally effective as international requirements extend below the 50 micron range (IMO 2004).

The traditional approach to ballast operations, since the introduction of steam machinery, has been the use of water ballast to increase the weight of the vessel in the light cargo condition. A paradigm shift in thinking here views the ballast condition as a change of buoyancy rather than an addition of weight in order to get the vessel to its safe ballast drafts. Such a shift in thinking led to the invention of the Ballast-Free Ship Concept (US Patent #6,694,908 2004).

In this concept, the traditional ballast tanks are replaced by longitudinal, structural ballast trunks that extend beneath the cargo region of the ship <u>below</u> the ballast draft. The arrangement of an equal capacity conventional Seaway-size bulk carrier is shown on the left in Fig. 2.1; the arrangement of a Ballast-Free Ship Concept Seaway-size bulk carrier is shown for comparison on the right. In this example, the three ballast trunks per side are connected to the sea through a plenum at the bow and a second plenum at the stern. Schematic trunk and plenum arrangements at the bow and stern of the vessel are illustrated in Fig. 2.2 and 2.3, respectively. These trunks are flooded with seawater to reduce the buoyancy of the vessel in the ballast condition in order to get the vessel down to its ballast drafts. Since there is a natural hydrodynamic pressure differential created between the bow region and the stern region of a ship due to its motion through the water, a slow flow is induced in these open ballast trunks. This ensures that the ballast trunks are always filled with slowly-moving “local seawater.” This should ensure that there is no transport of nonindigenous aquatic species across the globe. Therefore, the vessel becomes foreign “ballast-free” from the traditional viewpoint.

When the ballast voyage is completed, the ballast trunks can be isolated from the sea by valves and then pumped dry using conventional ballast pumps. The need for costly ballast water treatment equipment or ballast water treatment chemicals would, thus, be eliminated. This approach would also be equally effective for biota smaller than 50 microns. During the full load condition or any condition where ballast is not necessary, the double bottom ballast trunks can be segregated utilizing sluice gate valves. This is needed to provide the vessel adequate damage survivability.

In order to provide adequate intact stability, equivalent damage survivability, equivalent cargo capacity, etc., the entire vessel design needs to be developed to support this concept of ballast operations as illustrated in Fig. 2.1. The ship requires a higher tank top in order to locate enough ballast trunk volume below the ballast draft and requires a greater hull depth in order to maintain the vessel’s capacity to carry light cargos, such as grain. The Ballast-Free Ship Concept also includes features to minimize the buildup of sediment within the ballast trunks and facilitate their required cleaning; i.e., easier to clean 2.4 m high ballast trunks and the elimination of the lower part of the floors next to the shell.

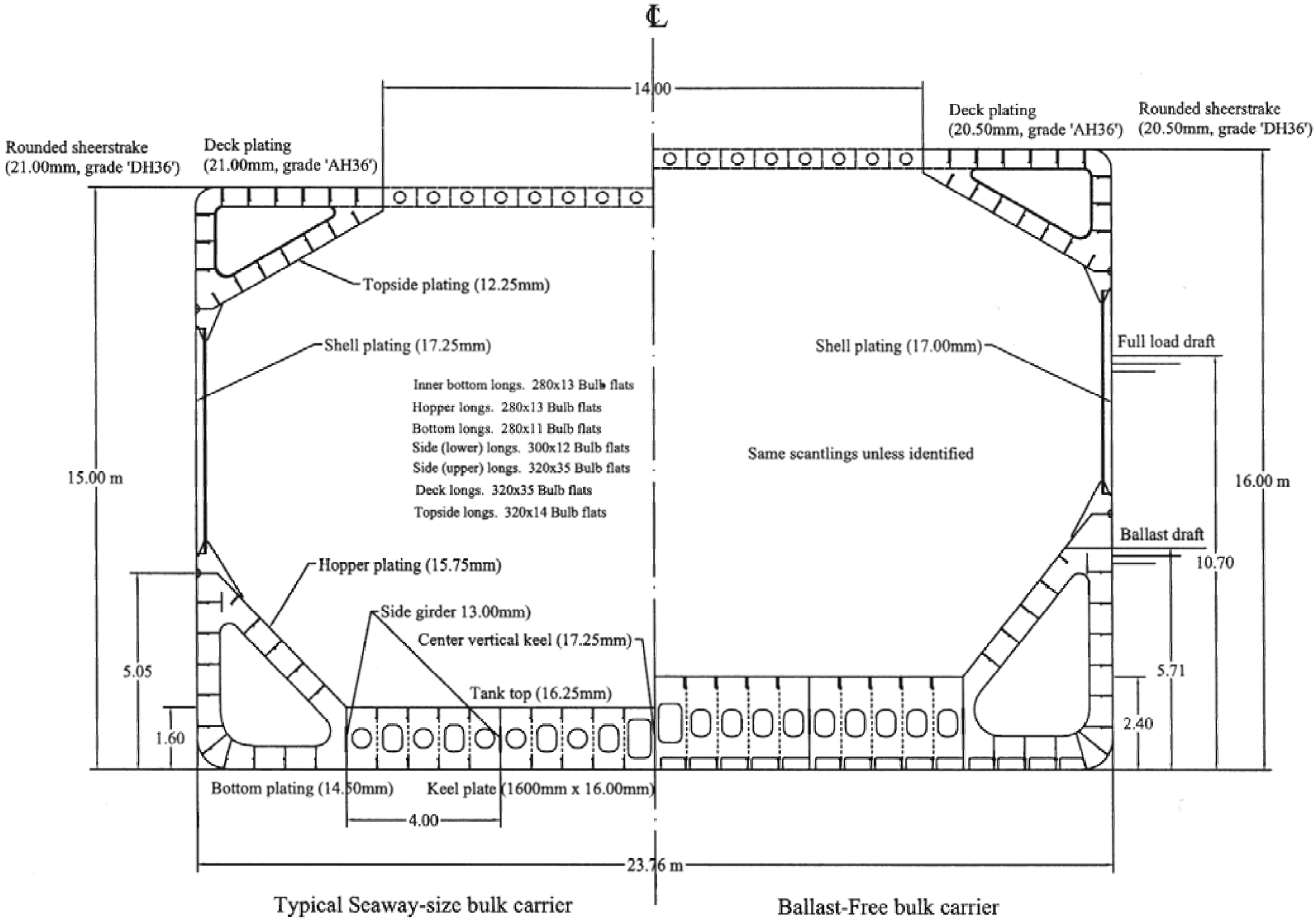

Figure 2.1: Typical Seaway-size Bulk Carrier (left) and Ballast-Free Concept Bulk Carrier (right)

As noted, the initial research on the development of the Ballast-Free Ship Concept was limited by its required comprehensive research scope and limited associated budget. For budgetary reasons, it was only feasible to support model testing that utilized an existing model. Although the vessel type of greatest interest for the Great Lakes nonindigenous aquatic species introduction problem is the Seaway-size bulk carrier, the best available model was of a relatively finer, higher-speed barge-carrying Lighter Aboard Ship (LASH) vessel. This existing model was modified to utilize a more conventional stern, but the model test results were not directly applicable to the Seaway-size bulk carriers studied in detail in the rest of the research effort.

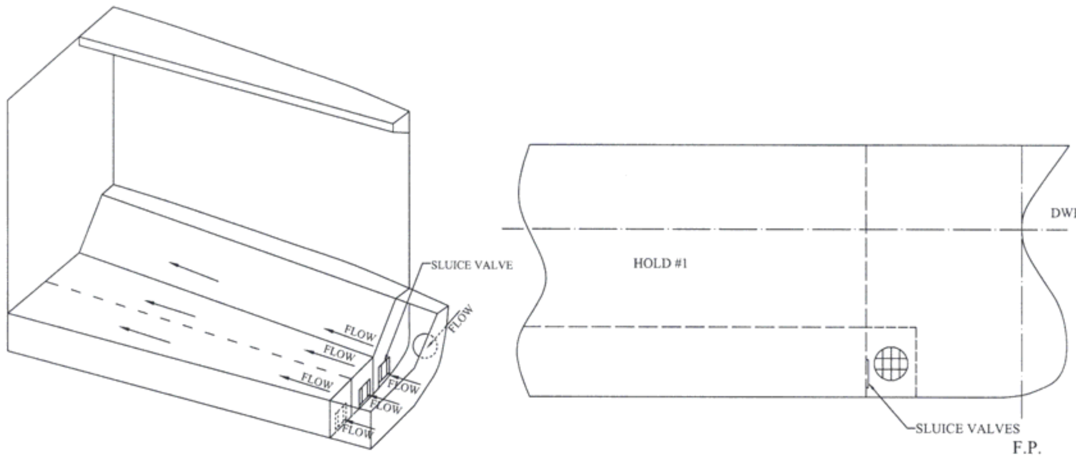

Figure 2.2: Typical Forward Plenum and Collision Bulkhead Arrangement

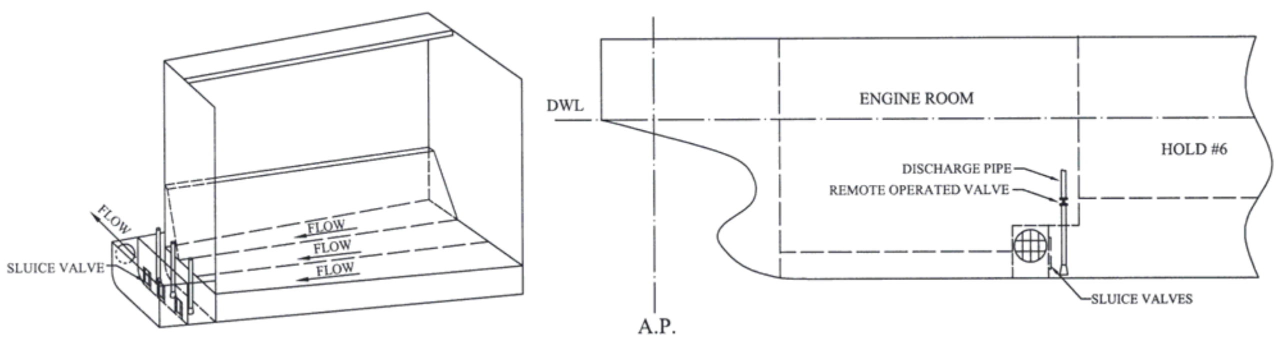

Figure 2.3: Typical Aft Plenum Arrangement

Budget restrictions in the initial investigation phase also required that the model tests be limited to a <u>single system design</u> for the existing model. There was no opportunity to optimize the hydrodynamic design of the system to minimize the economic impact of the Ballast-Free Ship Concept design. Model tests and Computational Fluid Dynamics (CFD) simulations using the modified LASH vessel hull showed that the specific ballast intake and discharge locations and method tested in the initial investigation resulted in a modest 2.2% increase in resistance but a more significant 7.4% increase in the required propulsion power. This specific result assumed a change in the ballast water within the ballast trunks once every two hours, which would meet the environmental intent of the Ballast-Free Ship Concept. The large power increase could result in an undesirable engine size increase and would result in fuel cost penalties. In that investigation, it was concluded that further hydrodynamic optimization could eliminate most, if not all, of this significant added power requirement.

3. Experimental Investigation

The Ballast-Free bulk carrier model, which was designed and built during the initial GLMRI sponsored phase of this project (Parsons and Kotinis 2006), was tested at the University of Michigan Marine Hydrodynamics Laboratory (MHL) in January of 2007. The main particulars of the ship are shown in Table 3.1. The characteristics of the model in the ballast condition are presented in Table 3.2. The bow and the stern of the constructed model are shown in Figs. 3.1 and 3.2, respectively. All the tests were carried out at the ballast drafts at which the Ballast-Free trunks would be in use.

Table 3.1: Main Particulars of the Ballast-Free Bulk Carrier

Waterline length (m)	195.5
Maximum beam (m)	23.76
Depth to main deck (m)	16.00
Full-load draft (m)	10.70
Block coefficient C_B	0.835

Table 3.2: Characteristics of the Ballast-Free Bulk Carrier Model in the Ballast Condition

Geometric scale ratio λ	37.92
Waterline length (m)	5.00
Maximum beam (m)	0.627
F.P. draft @ 40% DWL (m)	0.113
A.P. draft @ 70% DWL (m)	0.198
Wetted surface area (m^2)	5.34

Figure 3.1: Bow View of the Seaway-sized Bulk Carrier Model

Figure 3.2: Stern View of the Seaway-sized Bulk Carrier Model

3.1 Arrangements and Design of Inlet and Outlet Plena

A full-scale diameter of approximately 1 m was chosen for the plena inlet and outlet to ensure a smooth inflow and outflow without imposing severe constraints on the structural arrangements. The corresponding inlet/outlet diameter at model scale is approximately 2.6 cm. The flow rate in the longitudinal trunks was calculated assuming a full-scale volume of ballast water equal to 18,500 m^3. This value was obtained from similar ships, under the assumption of flooding both the normal ballast tanks and a central cargo hold for a heavy weather ballast condition. Assuming an exchange time of 90 min and utilizing Froude scaling, the internal flow rate at model scale is $Q_m = Q_s \lambda^{-5/2} = 3.9 \cdot 10^{-4}$ m^3/s. Using the continuity equation and assuming a symmetrical plenum about the centerplane, the average discharge fluid speed is 0.382 m/s.

The selection of the inlet location was based primarily on providing a pressure differential capable of sustaining a steady trunk (internal) flow. In addition to this, the inlet must be adequately submerged to avoid air ingestion and interaction with the free surface and the bow-generated wave system. An important design constraint is the low forward draft in the ballast condition. It was decided to locate the water inlet right on the face of the bulbous bow in the area around the stagnation point to take advantage of the high positive pressure in this region. Therefore, the centroid of the water inlet was placed at approximately 25% of the design waterline (DWL) above the keel as shown in Fig. 3.3. In this way, the water exchange goal of 99% in less than two hours can be reached, or even exceeded (Kotinis 2005). The fluid exchange at the ballast speed of 15.5 knots (assuming no voluntary speed reduction due to heavy weather) can then be achieved in a distance less than 30 nautical miles.

Figure 3.3: Location of Forward Ballast Trunk Inlet

In order to investigate the effect of the water discharge on the flow at the stern, two different discharge locations were selected; one close to Station 17 and one close to Station 19 as shown in Fig. 3.4. Station 17 is approximately at the location of the forward engineroom bulkhead in the full-scale ship; Station 19 is approximately at the aft engineroom bulkhead. The discharge at Station 17 was located about the 45% DWL and the discharge at Station 19 was located at about the 30% DWL. The flow was discharged at about 10 degrees to the local hull surface. In this way, the effect on the boundary layer flow, as well as the effect on the propeller inflow, could be investigated in a systematic manner.

The choice of the discharge locations investigated was based on the results of a numerical CFD investigation of the stern flow. These results are presented in the next section. If trunk flow rate maximization were the only criterion, the water outlet should be located in an area with high suction pressure to maximize the pressure differential. On the other hand, when the propeller operation is taken into account, the objective is to minimize the power requirement subject to achieving adequate ballast trunk flow.

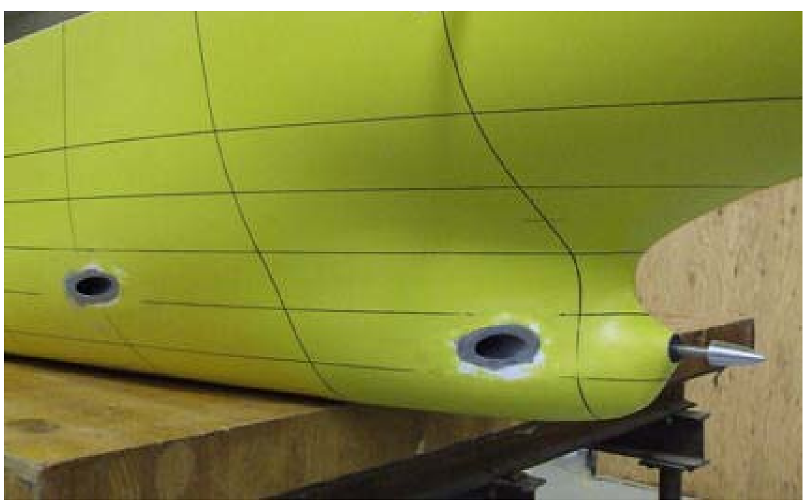

Figure 3.4: Location of Two Ballast Trunk Discharges Investigated

3.2 Experimental Setup

Because the modeling of the internal flow trunks could not be reliably scaled at the small model scale utilized, the scaled total trunk flow was pumped rather than using natural flow. The trunks were modeled by a 1-inch internal diameter pipe that was connected to the water suction at the bow and the water discharge at the stern. The steady internal flow was created and maintained by a flexible-impeller pump. The flow rate was controlled by a high-precision needle valve and monitored by a flow meter. The flow was diverted to the selected discharge location and subsequently split to provide a symmetric water discharge at the stern of the model. Details of the internal flow model are shown in Figs. 3.5 and 3.6.

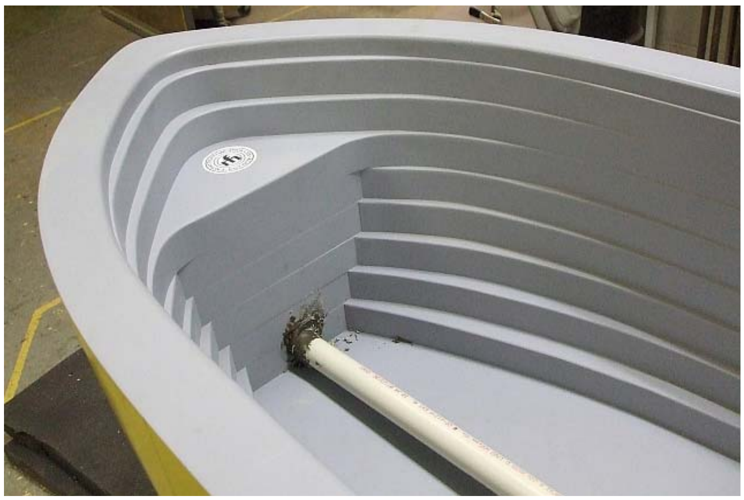

Figure 3.5: Internal Flow Arrangements in the Bow Region

Figure 3.6: Internal Flow Arrangements in the Stern Region – Looking Forward

3.3 Resistance Tests

The experimental test plan for both the resistance and propulsion tests is shown in Table 3.3. It was decided to test a range of speeds spanning a typical ballast condition operating range of bulk carriers of this size. The speed of 15.5 knots is considered as the designed ballast speed for purposes of flow scaling.

Table 3.3: Experimental Test Plan

Test speed	Ship speed (knots)	Model speed (m/s)	Froude number
1	14.50	1.210	0.173
2	15.50	1.295	0.185
3	16.50	1.378	0.197

The resistance of the Ballast-Free bulk carrier model was measured and then extrapolated to full scale using the ITTC-recommended method (ITTC 1978). The results for the full scale resistance and effective power are presented in Figs. 3.7 and 3.8, respectively. For all testing conditions, the results are reported at a standard temperature of 15°C. Prior to the resistance tests, a static calibration test of the load cell was performed. Additional resistance tests were performed at low speeds to derive the form factor used in the extrapolation procedure. Errors related to the static calibration and the form factor derivation were considered as sources of bias error. Four different measurements were obtained at each speed shown in Table 3.3 in order to minimize the precision error. The total uncertainty is calculated as the root sum square of the total bias error and the total precision error. The error bands shown in Figs. 3.7 and 3.8 correspond to the computed uncertainty values, assuming a 95% level of confidence.

The water discharge at the stern has a negative effect on ship resistance in both cases, even though the discharge at Station 17 seems to exacerbate the resistance increase. Even though the resistance curves plotted in Fig. 3.7 show an increase in the average values, the difference with respect to the baseline case is not statistically significant as seen by the overlapping error bands.

3.4 Propulsion Tests

The resistance tests were followed by a series of propulsion tests using the MHL stock model propeller No. 23. The No. 23 stock propeller was the available propeller providing the highest propulsive efficiency and, at the same time, satisfying the hull clearance requirements, assuming a full-scale propeller diameter of 6.0 m. The propeller characteristics for the No. 23 model propeller are shown in Table 3.4. The non-dimensional thrust and torque coefficients plotted versus the coefficient of advance (Kt, Kq – J) of the No. 23 model propeller are shown in Fig. 3.9. The thrust and torque measurements at the self-propulsion condition at each speed were analyzed using the ITTC-recommended method (ITTC 1978). The calculated required delivered power is shown in Fig. 3.10. An uncertainty analysis was also performed for the propulsion test results giving the error bands shown.

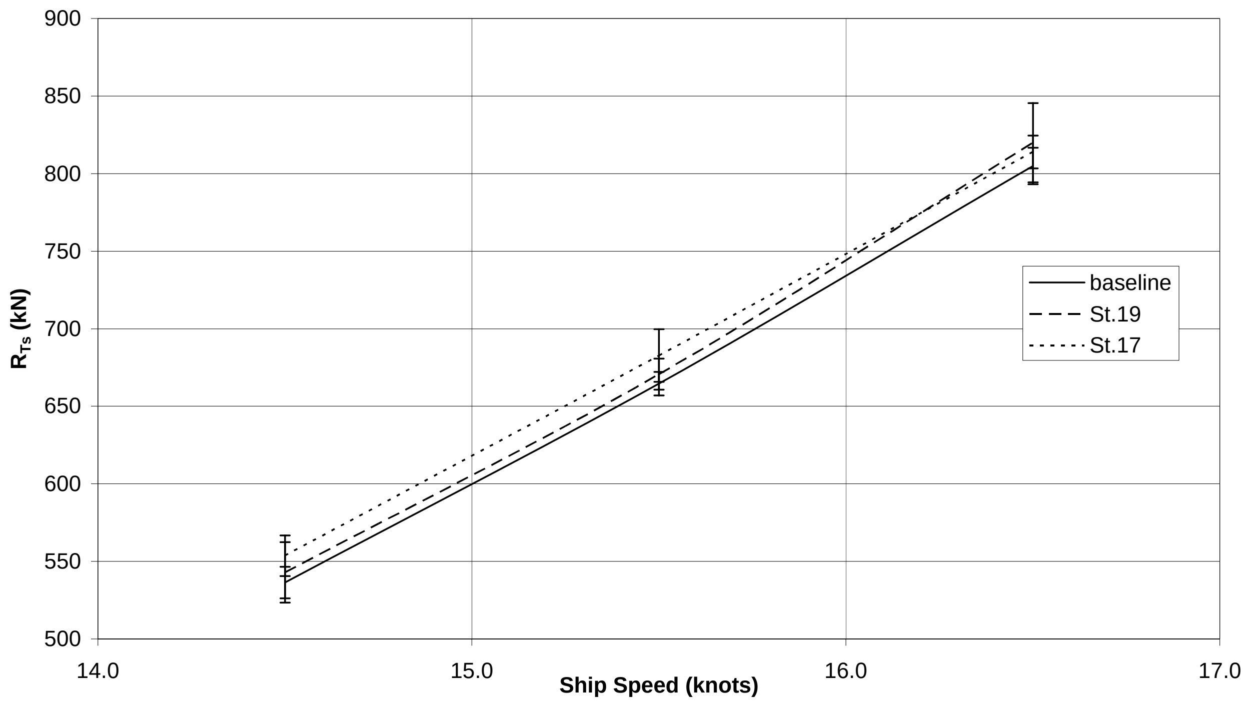

Figure 3.7: Ballast-Free Bulk Carrier Total Resistance

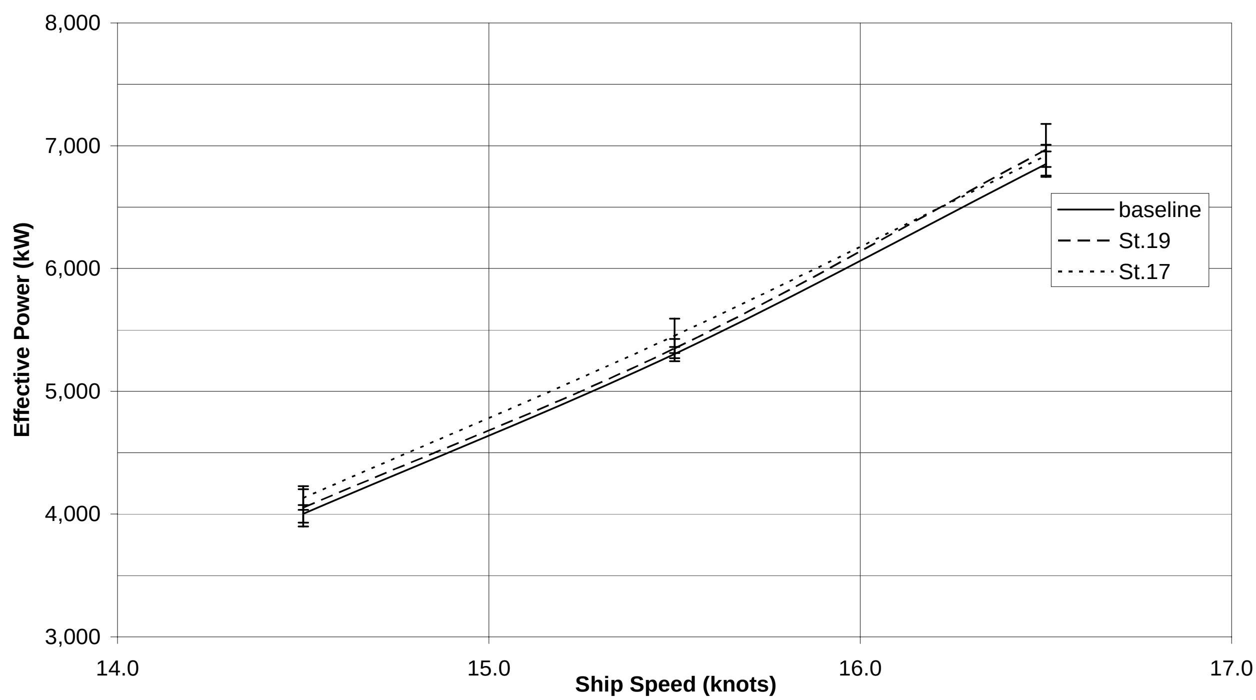

Figure 3.8: Ballast-Free Bulk Carrier Total Effective Power

Table 3.4: Characteristics of the MHL No. 23 Stock Propeller

Number of blades	4
Diameter D_p (m)	0.158
Hub diameter (m)	0.031
Pitch-diameter ratio P/D_p	1.08
Expanded area ratio A_e/A_o	0.55

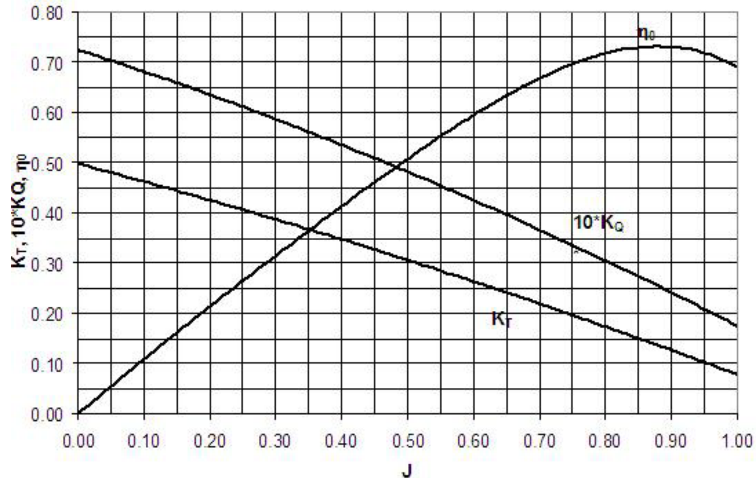

Figure 3.7: Propeller Coefficients versus Advance Coefficient

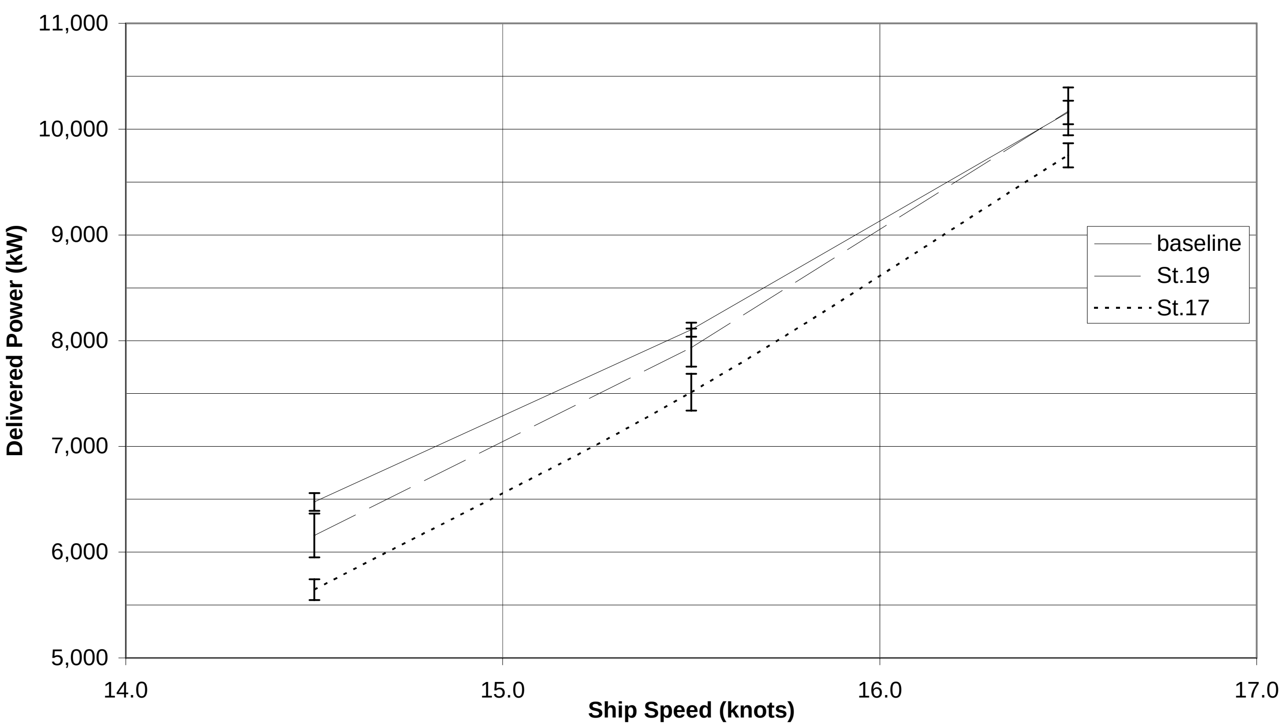

Figure 3.10: Ballast-Free Bulk Carrier Required Delivered Power

The propulsion test results depicted in Fig. 3.10 show a noteworthy reduction in the powering requirements caused by the water discharge at the stern. At a ballast condition speed of 15.5 knots, the reduction in the required delivered power is 7.3% for the discharge close to Station 17 and 2.1% for the discharge close to Station 19. Note that this is compared with a required delivered power increase of 7.4% observed in the initial investigation with the modified LASH vessel and the initial discharge configuration. A physical interpretation of this outcome cannot be fully explained without a detailed analysis of the change in the effective wake entering the propeller with the trunk discharge and its interaction with the detailed propeller design. In the current phase of the project, a qualitative analysis of the results was attempted by utilizing CFD and analyzing the hull nominal wake. This analysis is presented in the next section. An additional advantage of fitting the preferred discharge location near Station 17, at least from an engineroom arrangements perspective, is that the ballast trunks would not have to be carried through the engineroom.

3.5 Propeller Efficiency

Because a stock propeller was used in the experimental investigation, it was unclear to what extent the propulsion power reduction found would actually be realized if an optimum propeller design had been used on the model. The stock propeller utilized in the propulsion tests has characteristics quite similar to those of the standard Wageningen B-Screw Series B4-55 propeller (van Lammeren et al. 1969). Therefore, an attempt was made to find the optimum, in terms of efficiency, standard B-Screw Series propeller and compare its performance with the stock propeller utilized. In this manner, the margin of efficiency improvement of the stock propeller used could be estimated. This could help clarify whether the utilization of an optimum propeller could have benefited as much as the stock propeller from the ballast trunk discharge effect. The results of the analysis for the optimum B-Screw Series propeller the ballast speed of 15.5 knots are shown in Table 3.5.

Table 3.5: Determination of Optimum B4-55 Wageningen B-Screw Series Propeller

P/D_p	η_B	*n (rpm)*	σ	τ_c	*Back Cavitation (%)*	J
0.5	0.510	137	0.368	0.100	0.5	0.321
0.6	0.543	121	0.473	0.131	1.0	0.364
0.7	0.555	108	0.582	0.166	1.5	0.405
0.77	0.558	102	0.659	0.191	2.2	0.433
0.8	0.556	99	0.693	0.202	2.5	0.444
0.9	0.551	92	0.804	0.241	3.5	0.480
1.0	0.541	86	0.915	0.282	4.5	0.513
1.08	0.532	81	1.023	0.324	5.5	0.545
1.2	0.517	77	1.128	0.368	6.5	0.574
1.3	0.506	73	1.231	0.413	7.5	0.601
1.4	0.497	70	1.330	0.460	8.5	0.627

The results in Table 3.5 show that a 4-bladed propeller with a pitch-diameter ratio of 0.77 provides the optimum efficiency $\eta_B = 0.558$ with an acceptable extent (2.2%) of back cavitation.

A comparison of the efficiency of two B-Screw propellers with the model stock propeller in the three test conditions (no ballast trunk flow or baseline and discharge at Stations 17 and 19) is shown in Table 3.6.

Table 3.6: Propeller Efficiency η_B

MHL No.23 Propeller – baseline	0.556
MHL No.23 Propeller – Station 17	0.565
MHL No.23 Propeller – Station 19	0.558
B4-55 (P/D_p = 1.08, same as No. 23)	0.532
Optimum B4-55 (P/D_p = 0.77)	0.558

These results reveal that an improvement in propeller efficiency when operating behind the ship hull of about 4.9% (from 0.532 to 0.558) might be achieved by utilizing an optimum propeller. On the other hand, a different picture is observed when the ballast trunks are discharging at the stern. The propeller efficiency is slightly increased when discharging close to Station 19 and more significantly increased (1.6%) when discharging close to Station 17. Therefore, it can be argued that an optimum propeller will probably not benefit quite as much, in terms of propeller efficiency, as the stock propeller utilized.

However, a significant part of the overall propulsive efficiency improvement can be attributed to the increase of the hull efficiency, as shown in Table 3.7. Thus, it appears that most of the required power improvement (actually a small apparent resistance increase and a 7.3% delivered power reduction) observed would still be realized when an optimum propeller were used.

Table 3.7: Hull Efficiency and Propulsive Efficiency

	Hull Efficiency, η_H	Propulsive Efficiency, $\eta_P = \eta_B{*}\eta_H$
MHL No.23 Propeller – baseline	1.194	0.664
MHL No.23 Propeller – Station 17	1.286	0.727
MHL No.23 Propeller – Station 19	1.214	0.677

4. Numerical Investigation

The commercial CFD software FLUENT® (Fluent 2006) was utilized to study the external flow around the bulk carrier model. The numerical study was greatly facilitated by utilizing a predominantly hexahedral grid to model the flow domain around the hull of the vessel. A 'double-body' flow model, which does not take the free-surface flow into account, was adopted considering the free surface as a plane of symmetry. This particular grid, shown in Fig. 4.1, allowed a better resolution of the flow inside the boundary layer; thus, providing more accurate results with respect to the mixing of the discharged water (blowing) and the boundary layer flow. The total number of cells was 1,019,973. The grid generation was performed with the aid of Gridgen® (Gridgen 2007).

4.1 Description of the Numerical Solver

The numerical solver of FLUENT is based on a finite-volume method with the flow properties calculated at the cell centers. The fluid velocity is obtained by solving the Reynolds-Averaged Navier-Stokes (RANS) equations. The diffusion terms in the RANS equations are discretized with a central differencing scheme. The convection terms are discretized using a higher-order upwind scheme to minimize numerical diffusion. The discretized equations are solved using the Gauss-Seidel iterative algorithm. The solution convergence is accelerated through the utilization of an algebraic multi-grid method. Further details of the numerical methods can be found in (Mathur and Murthy 1997) and (Kim et al. 1998).

The turbulence model utilized in the computations was the shear-stress transport (SST) model (Menter 1994). This model implements a blending function in order to apply the standard k - ω model close to solid boundaries (ship hull) and a transformed version of the k - ε model in the far field. A low-Reynolds-number version of the k - ω model was employed. The SST model has been shown to provide quite accurate results for ship flows (Kim and Rhee 2002, Duvigneau et al. 2002).

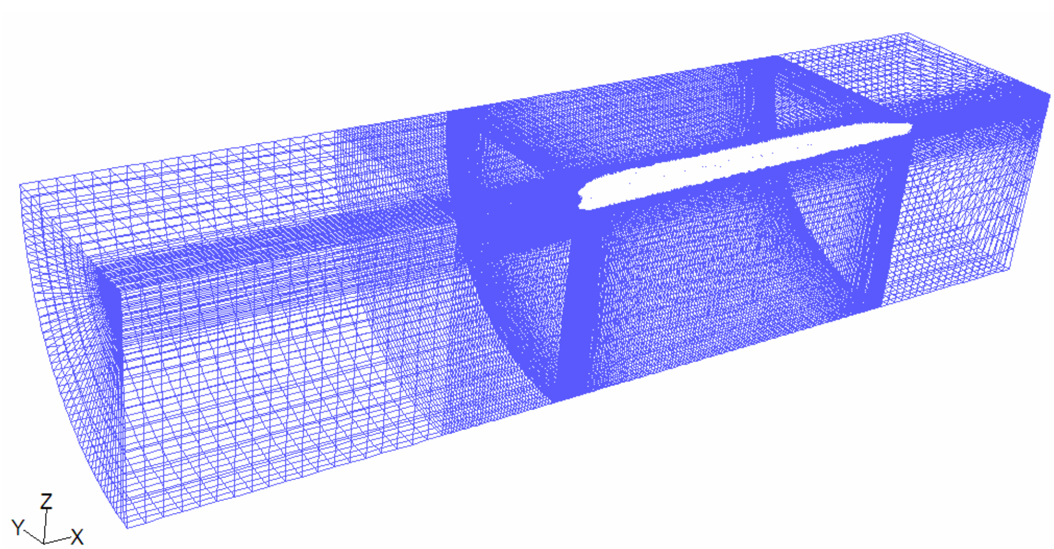

Figure 4.1: Computational Grid for the Ballast-Free Bulk Carrier

4.2 Numerical Investigation Results

Computations were performed for the Ballast-Free bulk carrier model in the ballast condition, where the model-scale speed is 1.295 m/s and the corresponding Reynolds number (in fresh water at 15°C) is 6.10e+6. The pressure coefficient contours at the bow of the Ballast-Free bulk carrier model in the ballast condition are shown in Fig. 4.2. The positive pressure area at the bow extends up to approximately 7% of the ship length aft of the forward perpendicular (FP); thus, the available locations for the inlet of the bow plenum are limited. This corroborates our decision to place the water inlet at the center of the bulbous bow. The corresponding pressure coefficient contours at the stern are presented in Fig. 4.3. Suction pressure exists over the parallel section and most of the ship stern. Between Stations 17 and 18 ($0.85 \leq x/L_{PP} \leq 0.90$) and close to the free surface, a low suction pressure region exists. The latter interacts with the suction pressure peak that exists close to the keel at Station 18 (x/L = 0.90) and produces a considerable girthwise pressure gradient. The end result is the formation of a streamwise vortex, which moves downstream and crosses the propeller plane.

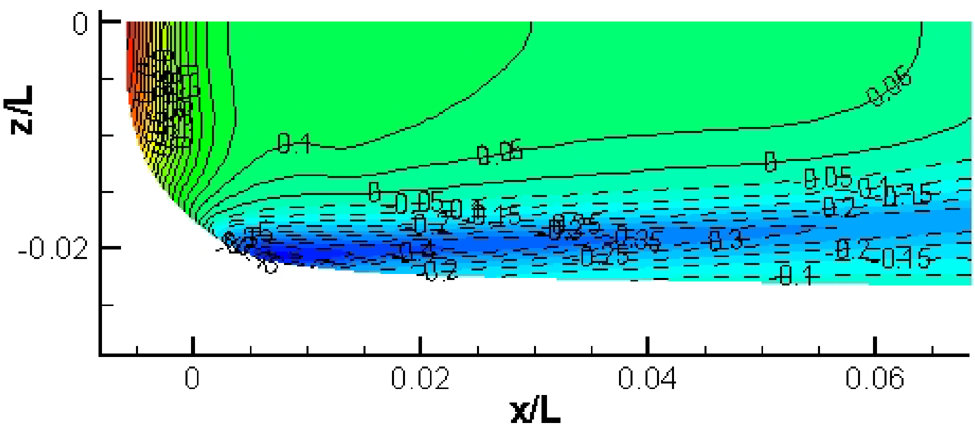

Figure 4.2: Bow Pressure Coefficient Contours

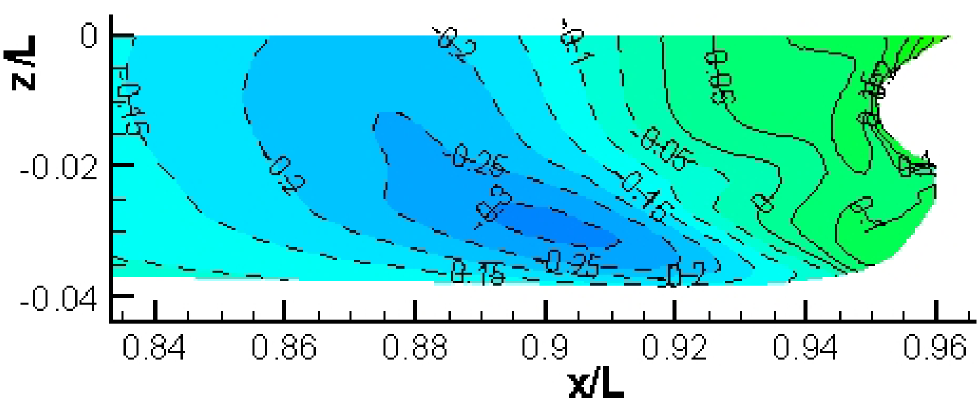

Figure 4.3: Stern Pressure Coefficient Contours

4.3 Numerical Investigation of the Water Inlet at the Bow and the Water Discharge at the Stern

The effect of the water suction at the end of the bulbous bow and the water discharge close to Station 17 on the flow around the model was investigated numerically using FLUENT®. The discharge flow direction was set to 10° with respect to the surface tangent to avoid obstructing the boundary layer flow. A smaller angle would probably be infeasible to implement in model or full scale. The major modeling requirement was to provide adequate grid resolution close to the hull to account for the interaction between the boundary layer flow and the trunk inflow and outflow. For this purpose, a slightly modified version of the original grid shown in Fig. 4.1 was utilized. The modifications were limited to the modeling of the region close to the inlet and discharge locations. In this case, the total number of cells was increased to 1,074,580.

The pressure coefficient contours with the water inlet at the bow are shown in Fig. 4.4. A comparison with the pressure coefficient contours in Fig. 4.2 reveals that the positive pressure levels increase in the vicinity of the water inlet, even though this effect vanishes downstream, of x/L = 0.02. The pressure coefficient contours at the stern are shown in Fig. 4.5. A small reduction in suction pressure, relative to the pressure distribution shown in Fig. 4.3, is observed slightly upstream of the discharge location. The opposite effect is observed slightly downstream. The net effect on the pressure force is shown to be minimal. However, these observations do not take into account the effect on the propeller inflow and the interaction between propeller and hull. Based on the results shown in Table 3.7, this interaction seems to be significantly affected by the water discharge at the stern.

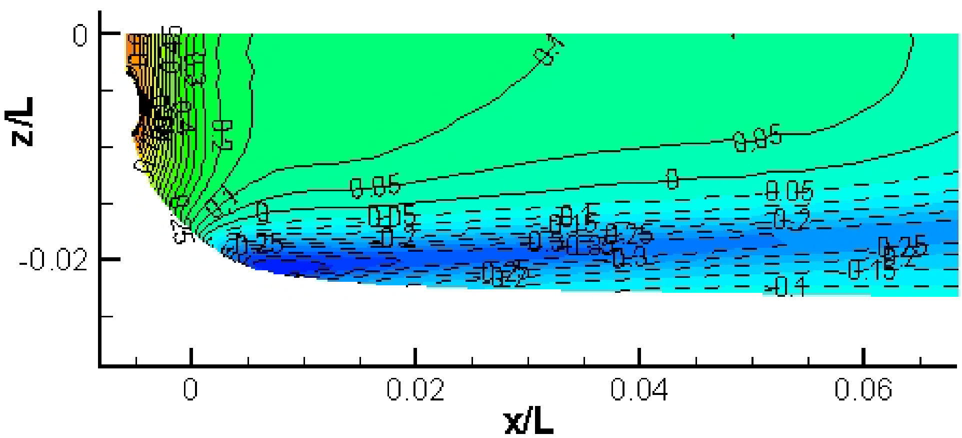

Figure 4.4: Bow Pressure Coefficient Contours – Water Inlet

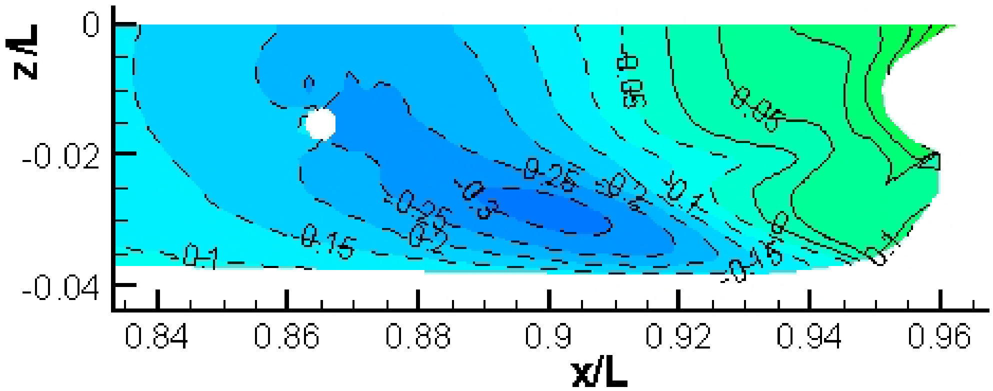

Figure 4.5: Stern Pressure Coefficient Contours – Water Discharge

4.4 Numerical Investigation of the Water Discharge Effect on the Model Hull Nominal Wake

As a first step in investigating the water discharge effect on the propulsion of the vessel, the effect of the water discharge on the nominal wake of the model hull was investigated. A qualitative measure of propulsive performance improvement and also vibration reduction is the uniformity of the nominal wake field in the propeller disk. Increased nominal wake uniformity can be obtained through the introduction of water into the flow deficit region in the upper half of the propeller disc and the interaction of the discharged flow with the longitudinal bilge vortex formed at the stern of the vessel. This interaction can be optimized by selecting the appropriate discharge location. A single-objective optimization problem can be formed with the wake uniformity in the propeller disk as the objective function. This analysis, even though based on a simplistic criterion, can serve a twofold purpose: first, to verify the potential for increased wake uniformity through an optimum discharge location and, second, to shed some light on the stern flow physics.

In order to minimize the computational time in this parametric study, the flow was restricted to the aft part of the vessel. This enabled investigation of the stern flow with a more refined grid. The flow domain was truncated by removing the bow and part of the ship parallel mid-body. The total number of cells in this case was 519,750. The plane at Station 14 ($x/L_{PP} = 0.70$) was considered as the new flow-inlet boundary. The velocity components and the turbulence characteristics at this plane were set equal to the corresponding profile obtained from the converged full-length hull solution. The position of the discharge location, the coordinates of the centroid of the trunk flow outlet, was considered as the problem variable. Bounds on the problem variables were set by considering operational and design constraints. The longitudinal coordinate range was between 85%L_{PP} (Station 17) and 94%L_{PP} (slightly forward of Station 19), which correspond roughly to the engineroom forward and aft bulkhead. The vertical coordinate of the centroid was limited to the range between 25 and 45%DWL, measured upward from the baseline.

A complete factorial design was utilized for the numerical simulations; three equi-spaced positions in the longitudinal direction (85, 89.5 and 94% L_{PP}) and two in the vertical direction (25 and 45% DWL) were used. This complete factorial design is also a mixed orthogonal array of strength 2 capable of capturing the main effects of each variable (Hedayat et al. 1999). The goal was to sample the domain in such a way that it would facilitate the building (training) of an Artificial Neural Network (ANN)-based metamodel to be utilized in the optimization phase.

The numerical investigation results are presented in Table 4.1. These results reveal that a slightly more uniform wake in the propeller disk can be obtained by discharging closer to the bilge. In addition to this, a reduction of the standard deviation of the axial velocity (σ_{Vax}) by approximately 2% in comparison to the no-discharge-flow (initial) case can be achieved by discharging at x/L = 0.895 (slightly forward of Station 18).

Table 4.1: Standard Deviation of Axial Velocity in the Propeller Disk

Case ID	*x (%L_{BP})*	*z (%DWL)*	*σ_{Vax} (m/s)*
Initial	-	-	0.157
1	85.0	25	0.159
2	85.0	45	0.158
3	86.5	35	0.159
4	88.0	25	0.157
5	88.0	45	0.160
6	89.5	25	0.154
7	89.5	45	0.160
8	92.5	35	0.156
9	94.5	25	0.157
10	94.5	45	0.161

Contours of axial vorticity at different stations along the vessel hull as well as contours of the axial velocity inside the propeller disk are shown in Figs. 4.6 and 4.7. The contour plots in Fig. 4.6 reveal that water discharge near the bilge (i.e. case no. 6) causes a stretching of the vortex in the transverse direction. On the other hand, water discharge at a higher vertical position causes a stretching of the vortex in the vertical direction and a slight contraction in the transverse direction. The stretching of the vortex in the transverse direction explains the increased uniformity of the wake in the propeller disk. As shown in Fig. 4.7, a larger part of the longitudinal bilge vortex appears to pass through the propeller disk in case no. 6 compared with the two other cases. The bilge vortex collects frictional wake from the ship boundary layer. By delivering the frictional wake to the propeller disk, it facilitates the recovery of the axial kinetic energy produced by the ship (Dyne 1995).

An optimum discharge location was found by utilizing a real-parameter Genetic Algorithm (GA) (Deb 2001). Ranking selection was used as the survival operator in a similar manner as the roulette operator is utilized in simple binary GAs. Crossover and mutation operators were utilized in a modified form appropriate for bounded variables encoded in real-parameter chromosomes. Specifically, the simulated binary crossover (SBX) operator adjusted for bounded variables (Deb and Agrawal 1995, Deb 2000) was utilized with a crossover rate of 0.7 and a distribution index of 2. The parameter-based mutation operator (Deb and Goyal 1996), adjusted for bounded variables (Deb 2000), was also employed for the genetic operations. The mutation rate was set to a value of 0.5. An elite-preserving operator was added to the optimizer by carrying the best two solutions over to the next generation.

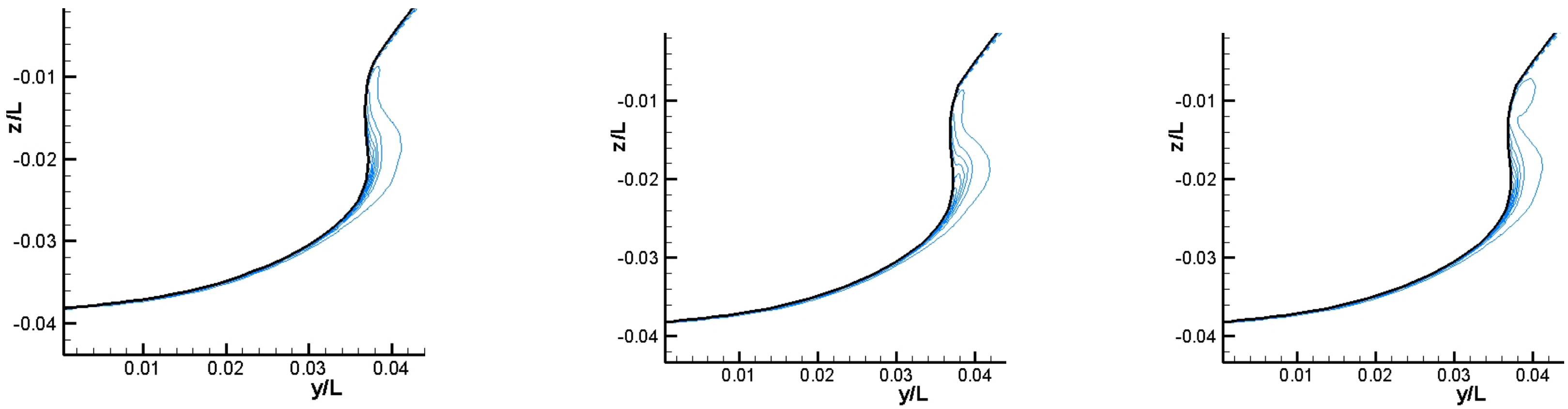

Figure 4.6: Axial Vorticity Contours at x/L_{PP} = 0.92, Initial Case (left), Case no. 6 (center) and Case no. 7 (right)

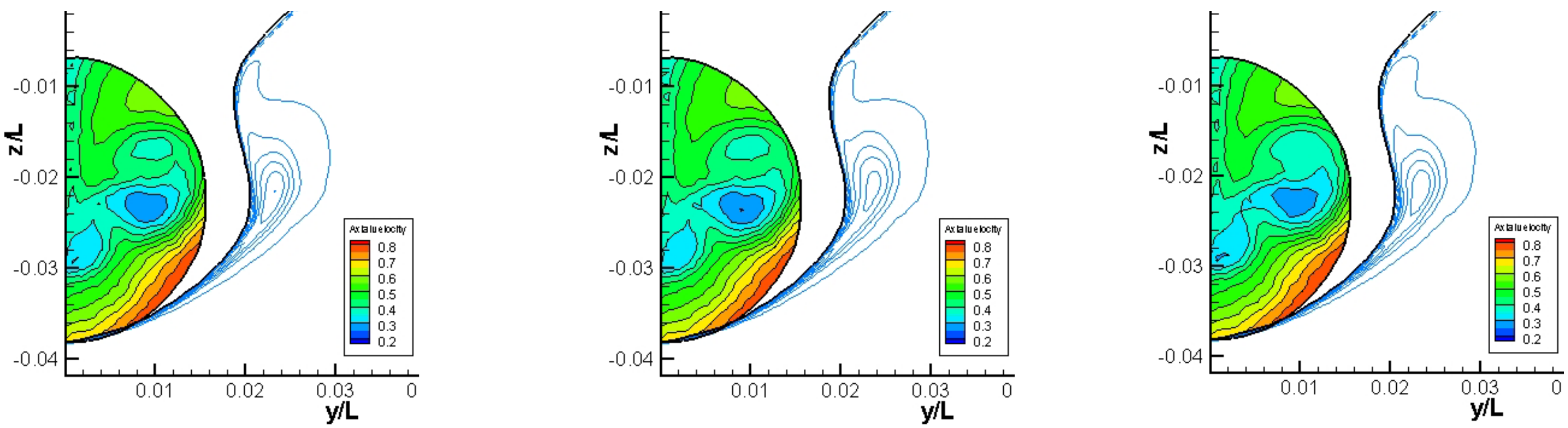

Figure 4.7: Axial Vorticity Contours at x/L_{PP} = 0.95 and Axial Velocity (nondimensional) Contours in Propeller Disk, Initial Case (left), Case no. 6 (center) and Case no. 7 (right)

The optimization procedure requires multiple evaluations of the objective function at points within the bounded variable space. In the current research, a surrogate model using an Artificial Neural Network (ANN) was created in order to approximate the nonlinear objective function and eliminate the costly numerical . A network based on sigmoidal logistics activation functions was developed using an input layer with two nodes; two hidden layers each consisting of three nodes, and a single-node output layer. The back-propagation algorithm (Rumelhart et al. 1986) was utilized for training of the network. A learning rate of 0.2 was used for the hidden layers and a rate of 0.1 for the output layer. The update of the network weights was performed only after all training data points were presented to the network ("per-epoch" learning). Momentum terms were added to the learning algorithm to achieve a more stable training procedure.

The discharge location that minimized the objective function within the bounded variable space was centered at x/L = 0.915 and z/DWL = 0.25. The corresponding standard deviation of the axial velocity in the propeller disk was 0.152 m/s. This value provides a 3.2% reduction compared to the initial case without the trunk flow discharge. A comparison between the initial case and the optimum case is shown in Fig. 4.8. In the optimum case, the improvement in wake uniformity due to the water discharge, especially in the upper propeller plane, is apparent.

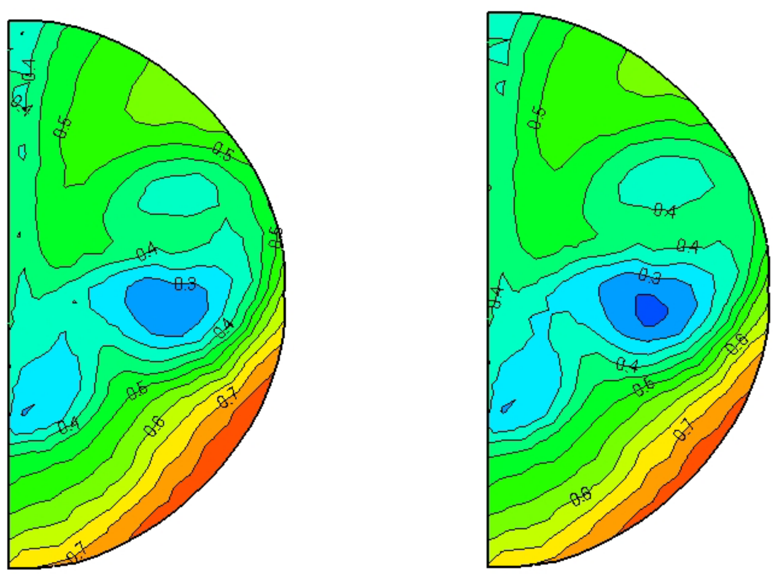

Figure 4.8: Axial Velocity Contours in Propeller Disk, Initial Case (left), Optimum Case (right)

5. Potential Economic Impact of the Research Results

The economic impact of the Ballast-Free Ship concept on the capital and operating cost of a typical Seaway-sized bulk carrier was estimated in a manner similar to that used in the initial investigation of the concept (Kotinis et al. 2004). The results for the water discharge close to Station 17 and close to Station 19 are presented in Fig. 5.1. A realistic scenario was adopted for the economic analysis: a handy-sized bulk carrier transporting grain from the upper Great Lakes (e.g. Duluth, Thunder Bay) to ports in Northern Europe and occasionally transporting steel into the Great Lakes. A North Atlantic voyage route between Rotterdam and Montreal, entering the Great Lakes through the St. Lawrence Seaway while in a ballast condition, is assumed.

A major, conservative assumption is that the 2.1% and 7.3 % reductions in the required power of the Ballast Free bulk carrier will not be enough to permit a change in the main engine; thus, no propulsion machinery capital cost reduction is included. Foreign new construction, typical of Korea, was assumed for the calculation of the hull steel and other construction costs. The eliminated ballast water treatment system was assumed to consist of automatic backflush filtration as a primary treatment combined with UV irradiation for a secondary treatment. The estimated cost of this treatment equipment was based upon a study commissioned by the Great Lakes Ballast Technology Demonstration Project (Hurley et al. 2001).

The net savings in terms of the ΔRFR with the ballast trunk water discharge close to Station 17 is estimated to be about $0.93 per ton of cargo. The corresponding savings with the water discharge close to Station 19 is estimated to be about $0.44 per ton of cargo. These savings are relative to the use of filtration primary and UV secondary ballast water treatment when ballast water exchange is no longer permitted in the future.

Vessel data and trip scenario	*Typical bulk carrier*	*Ballast-free bulk carrier*		*Comments*
		Discharge at St.17	*Discharge at St.19*	
Round-trip distance (nautical miles)	6,280			Montreal (CAN) to Rotterdam (NL) through the Seaway
Service speed (kts)	14.5			Typical data for an ocean-going Handymax bulk carrier transporting grain cargo from the Great Lakes (Duluth, Thunder Bay) to ports in Northern Europe and occasionally transporting steel into the Great Lakes.
Speed in ballast condition (kts)	15.5			
Proportion of miles in ballast (%)	35			
Average loaded cargo / maximum cargo (%)	90			
Load factor (%)	58.5			
Days of navigation through the Great Lakes	8			Passage up through the Great Lakes towards the western end
Port days per round trip	14			Includes loading/unloading time, bunkering time, and time waiting for berth
Round trips per annum	7			
Maximum payload (metric tons)	32,000			
Cargo carried per annum (metric tons)	131,000			
Engine nominal MCR (kW)	8,580			Data for the MAN B&W 6S50MC two-stroke engine
Block coefficient	0.835	0.841		Compensate for increased hull steel weight and lost buoyancy at plena
Hull steel weight (metric tons)	5,550	5,770		
Hull steel cost ($)	2,220,000	2,308,000		Assuming a steel price of $400/metric ton
Continuous service rating in ballast condition (kW)	7,700	7,140	7,540	Includes 15% sea margin and effect of change in C_B value
Continuous service rating in full load condition (kW)	7,700	7,155	7,555	Includes 15% sea margin and effect of inlet/outlet hull openings and change in C_B value
Specific fuel consumption (g/(kW*hr))	168.7	166.4	168.0	Data for the MAN B&W 6S50MC engine, ISO ambient conditions
Annual heavy fuel cost ($)	1,039,000	951,000	1,014,000	Fuel price (IFO380) of $270/metric ton, transatlantic part of trip only
Changes in capital cost				
Additional hull steel cost ($)	88,000			
Sluice gates cost ($)	260,000			Acquisition cost plus labor for 52 450x600 mm sluice gates (@ $5,000 each)
Elimination of ballast tank valves ($)	-14,000			14 @ 1,000 each
Reduction in ballast piping cost ($)	-314,000			Removal of main ballast headers (material plus labor)
Reduction in welding cost ($)	-9,500			Reduced welding at the bottom of solid floors (material plus labor)
Additional ballast piping cost ($)	79,000			Addition of ballast piping for F.P. tank (material plus labor)
Additional welding cost ($)	2,600			Additional welding due to raise of inner bottom (material plus labor)
Elimination of ballast water treatment system ($)	-375,000			Assuming automatic backflush filtration combined with UV irradiation
Changes in operating cost				
	Discharge at St.17	*Discharge at St.19*		
Change in heavy fuel oil cost ($)	-88,000	-25,000		
Net capital cost change ($)	-282,900			
Net operating cost change per annum ($)	-88,000	-25,000		
Capital recovery factor	0.1175			i = 10%, n = 20 years
Change in required freight rate ($/metric ton)	-0.93	-0.44		savings

Figure 5.1: Economics Summary Comparing a Typical Bulk Carrier with Filtration and UV Treatment with Ballast-Free Bulk Carrier with Two Different Discharge Locations

6. Dissemination of Study Results

The following publications were related to this funded research:

- Parsons, M. G., "Ballast-free ships: Investigations at the University of Michigan use local water for ballast," *Great Lakes Seaway Review*, **35**-2: 19 & 21, January-March, 2007.

- Kotinis, M. and Parsons, M. G. 2007a "Numerical Investigation of the Flow at the Stern of a Ballast-Free Bulk Carrier Model" *Proceedings* of the 9th Int. Conference in Numerical Ship Hydrodynamics, Aug. 2007.

- Kotinis, M. and Parsons, M. G., "Hydrodynamic Optimization of the Ballast-Free Ship Concept" to appear in *Transactions* SNAME, **115**, 2007.

- A *University Record* article is under preparation by the University of Michigan News Services.

The following presentations were related to this funded research:

- Parsons, M. G. and Kotinis, M., "Hydrodynamic Optimization of the Ballast-Free Ship Concept," presented at the 50th Annual Conference on Great Lakes Research, International Association for Great Lakes Research, May 31, 2007, University Park, PA.

- Kotinis, M. and Parsons, M. G., "Hydrodynamic Optimization of the Ballast-Free Ship Concept" to be presented at the Society of Naval Architects and Marine Engineers Annual Meeting, Ft. Lauderdale, FL, Nov. 2007.

- A ~5 min. video is under preparation by the University of Michigan News Services.

The results of the funded research were reviewed in the following class:

- The results of this investigation were presented in the graduate class NA570 Advanced Marine Design at the University of Michigan in the Winter Semester 2007.

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Expanding Regional Freight Information Resources for the Upper Midwest
Phase II:
Implementation of The Great Lakes Maritime Information Delivery System

Interim Report

PI: Dr. Peter Lindquist, Associate Professor/ Chair — The University of Toledo, peter.lindquist@utoledo.edu, (419) 530-2545

Co-PI: Dr. Mark Vonderembse, Professor — The University of Toledo, mark.vonderembse@utoledo.edu, (419) 530-4319

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The University of Toledo
Department of Geography and Planning, MS 932
2801 W. Bancroft
Toledo, OH 43606

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Executive Summary

This project marked the second phase of a long-term endeavor to develop and manage a comprehensive data repository and information clearinghouse for the maritime industry in the Great Lakes. The system is envisioned to facilitate the acquisition, storage, management, analysis and exchange of data between analysts and decision makers within the industry. This system will thus serve as a resource for public policy decisions and for drawing the link between maritime freight movements, economic viability, and environmental quality throughout the Great Lakes and St. Lawrence Seaway. This data gateway is particularly focused on the following areas of interest:

- Jobs
- Economic impact of Great Lakes shipping
- Safety issues associated with diverting freight traffic to GL MTS
- Environmental impacts/benefits compared to other modes
- Shipper savings associated with GL MTS
- Congestion effects of other modes in comparison to GL MTS
- Competition effects of Maritime Transportation and rate increases in other modes
- Shift in intermodal connections and transshipment costs (*e.g.*, “full cost” studies – pavement damage, fuel savings, crashes, *etc.)*
- The value of shipping to states, cities, regions, *etc*.

This project was originally proposed to focus on expanding an existing detailed GIS-based multimodal regional freight data reporting system named ***Midwest FreightView*** (MWFV). This system was developed on a ***Citrix Metraframe*** installation. Currently a specialized ***ArcView GIS*** application provides the user interface. Users can access MWFV with a web browser and Internet connection; all operations are carried out on the Toledo Server—the user’s computers simply act as a terminal. This single approach was amended in Phase I of the project in response to recommendations from stakeholders during our June 2006 Data Workshop, where participants effectively argued that any system that requires a significant amount of training and practice would not be used as heavily as a more “user friendly” system consisting of prepared graphs, maps, bullet points, tables, and other features such as prepackaged reports in basic standard formats such as Annual Reports, Executive Summaries, and reports of studies completed by analysts who used data from the repository. The project team responded to this point by proposing to develop a system that offers a variety of products and functions among varying degrees of expertise required by users. These include:

- A detailed data repository for vessel movements, port functions, commodity flows, economic activities and environmental impacts, etc.
- A GIS data viewer for advanced users to view and analyze a variety of data
- An information delivery site for maps, tables, graphics, text and other features
- A data exchange to support user inquiries and furnish information on demand
- Assembly of data and report information among different geographic areas of impacts and jurisdictions (*e.g.*, states and provinces, congressional districts, cities, counties, ports, *etc*.)

- Establishment of a communication link within the system (*e.g.*, email access) for regional stakeholders to request specific information to be posted on the site. This function was agreed upon as essential if the information delivery was to be successful
- Establishment of a system for data exchange to analysts in maritime agencies and organizations; also develop a site in the system for analysts within the region to publish the results of their analysis—particularly with regard to public policy issues of interest to the Great Lakes Maritime Industry
- Development of a library function in the form of a data clearinghouse that reviews and summarizes data from diverse sources--both public and commercial--and provide links for users to branch to from the site. The result of which is to provide the Great Lakes Maritime Industry with a comprehensive centralized resource for data and information. An example of such a link would be for taxes, fees, and other costs; however, this component would not represent a core function of the data resource. It was further suggested that the site become a gateway to maritime agencies (*e.g.*, Coast Guard, USACE, *etc*.)

All of these functions are currently undergoing development within the design of the prototype information delivery site that was opened in November 2006.

The main objective originally envisioned for the project still remains the same: to generate and maintain a long-term database and data distribution system that is available for state transportation agencies, regional planning agencies, port authorities and economic development organizations, as well as other interested decision makers and stakeholders within the region. Acquisition efforts continued though the second phase of this project with the addition of the following data sets:

1. Population and socioeconomic data representing market demand within the region (U.S. Census)
2. Port locations—U.S. (BTS National Transportation Atlas);
3. Dock locations (Army Corps of Engineers) and attributes:
4. Waterway network—Great Lakes and inland waterways (Army Corps of Engineers)
5. Baseline 2002 commodity flows through the Saint Lawrence Seaway and Great Lakes System obtained from the FHWA Freight Analysis Framework estimated from 2002 Commodity Flow Survey Data. This data set provided the research team with a skeleton framework upon which to add subsequent flow data.
6. Employment by NAICS Classification among counties and MSAs in study region (Source: BLS ES/202);
7. Lock locations and lock performance statistics—U.S. side;
8. Weather station data (NOAA, to approx. 60 miles inland);

9. Updated U.S. Highway Network that combines the National Highway Planning Network and ORNL Network attributes and includes speeds and estimated travel times on links;
10. Integrated network—Great Lakes waterway, highway, rail linked to commercial docks, locks (Army Corps of Engineers);
11. MARAD annual vessel movements (1994-2004);
12. Import/export flows (Great Lakes East Coast and Gulf Ports);
13. FAF Zones and centroids;
14. FAF2 OD Flows (National and Regional Scale);
15. Satellite imagery / aerial photography of dock facilities;
16. Vessel inventory—Great Lakes Fleet;
17. Updated Canadian rail and highway networks.

The data listed above resides in a database outside of the MWFV data viewer. Given the tremendous volume of the database, only selected portions of the database have been added to the reporting system to date.

In addition to data acquisition activities listed above, other work has begun involving the compilation of aerial photography of GL docks and terminals and incorporating them into the database. Docks and terminals are spatially registered to the GIS database as a means to provide a backdrop for connecting the waterway, highway and rail networks into a comprehensive intermodal network. This “last mile” approach to connectivity will provide a framework for simulating commodity flows between modes within the system. Other efforts by the project team involved acquisition of AIS data to track vessel movements. The emphasis here will also involve lock and dock performance data for a more accurate account of commodity flows through the network. Implementation of this technology will be actively pursued in the next phase of the project.

The vision for the Great Lakes Maritime Information Delivery System Project evolved over the course of the project to produce a multidimensional system that will support a wider array of functions that include data storage, delivery of prepared documents, GIS functionality, and a clearinghouse for information over the entire industry. The project team will solicit feedback and suggestions for continuous improvement of the information delivery system; communication with the industry will be a major objective as this resource develops over the next several years.

Introduction

This phase of the project is a continuation of a long-term endeavor to develop and maintain a comprehensive data repository and information clearinghouse for the maritime industry in the Great Lakes. The system will serve as a central focus for diverse interests within the industry and is designed to support the promotion of sustainable maritime transportation in the region. The first major function of the system involved the acquisition, management and exchange of data for dissemination to analysts within the industry. In addition, the system also provides a central location for the dissemination of information for public policy decisions and for drawing the linkage between maritime freight movements, economic viability, and environmental quality throughout the Great Lakes and St. Lawrence Seaway.

Furthermore, this system will serve as an effective tool for evaluating intermodal transportation opportunities in the Great Lakes Region; it can be used to model flows between modes to improve the flow of commodities within the region and to minimize environmental impacts. This project started with the development of a comprehensive GIS-based freight database for the Upper Midwest Freight Corridor Study (**M**id**w**est **F**reight**V**iew). The maritime database has thus been added to the existing database and provides a framework for establishing intermodal connections between waterborne transportation and other modes in the region. This location-based GIS database will remain as the core for the maritime transportation database in this project, but we will expand the information delivery system beyond this geographic focus to include text, tabular, graphic and prepared maps for users.

Finally, significant effort has been devoted to acquiring, managing and storing detailed economic data to document patterns of activity among all of the economic sectors linked to freight movements. This resource will be a multidimensional web-based delivery system designed to support the following functions:

- A detailed data repository for vessel movements, port functions, commodity flows, economic activities and environmental impacts, etc.,
- A GIS data viewer for advanced users to view and analyze a variety of data,
- An information delivery site for maps, tables, graphics, text and other features,
- An information clearinghouse and centralized data facility to furnish links to other information resources, private vendors furnishing commercial products, and government agencies,
- A data exchange to support user inquiries and furnish information on demand.

This system has been launched on an initial web prototype and will be continuously updated over the next phase of the project.

As a result, this system will enable analysts to more effectively measure the economic impacts of great lakes shipping on the regional economy by understanding the directions of the flow of freight within the region. The system will thus provide valuable data dealing with estimated origins and destinations of freight movements within the region as a means to support the modeling of freight flows among modes--including water--within the region.

As stated above, the original intent of this project was to expand MWFV to include maritime transportation in the Great Lakes Region. This system was well positioned to carry out the task of assembling, storing and managing maritime data for the Great Lakes system. A major effort had already been undertaken in the development of MWFV. MWFV started as a distributed GIS developed to track patterns of intermodal freight movements within a seven state area of the upper Midwest and two provinces of Canada. The principal objectives of MWFV were threefold: 1) to provide a means to spatially relate existing and projected freight flows to the regulatory environment and the physical capacity of the infrastructure, 2) to track trends in freight movement over time and space, and 3) to link freight movement to population characteristics and economic activity within the region. Users can take advantage of the GIS location-based query and selection capabilities as well as mapping functions to illustrate these relationships. In addition, the system was designed to expand into providing advanced analysis capabilities such as vehicle routing and travel time computations to evaluate the effectiveness of the network to support freight movement. As a result, the system has begun to evolve into an effective tool for economic development planning as a means to measure accessibility to markets, identify bottlenecks in the network that hinder freight flows, and for identifying feasible locations for warehousing, manufacturing, retail and intermodal connection facilities. The original system displayed data on highways, railroads, intermodal connections, and air transportation.

One of the main objectives originally envisioned for MWFV was to generate and maintain a long-term database and data distribution system that would be available for state transportation agencies, regional planning agencies, port authorities and economic development organizations, as well as other interested decision makers and stakeholders within the region. This requires ongoing efforts to furnish the most up-to-date data available from all modes in the transportation system. This process expanded during the first phase of this project to include maritime data and continued into this phase of the project.

As the first phase of this project focused primarily on acquiring data on facilities and freight flows, the second phase documented here expanded into acquiring flow data in greater detail with respect to commodities, origins and destinations, vessel characteristics and weather data. The research team has linked the maritime transportation "network" to the highway and rail networks, which in turn will be linked to the regional economy. The data library and clearinghouse function have also been emphasized to a greater extent in this phase. The project proposal outlined the project methodology for Phase II into the following distinct tasks:

- Continue to assemble data in the centralized repository to include the following:

- Cargo flows—vessel types, vessel size, types of commodities, origins, destinations
- Baseline data for vessel movements including size, horsepower, emissions, fuel consumption, ballast inventories, etc.
- Port facilities including docks, terminals, etc. and relevant attributes dealing with capacity, tonnages, *etc*.
- Linking Great Lakes maritime freight movements between origins, routes, ports and destinations as a means to link maritime freight flows to the regional economy
- Acquisition of additional economic data dealing with employment by sector, establishments, *etc*.
- Locks including relevant attributes dealing with size, capacity, tolls, etc.

- Documentation of data standards derived from data sources in the region (including consultation with data source agencies, maritime exchanges, ports and other related organizations) and reporting data in units consistent with the maritime industry and related transportation modes.
- Begin a dialog with regional stakeholders with respect to their information needs in order to prepare maps, graphics, tables and text in a user-friendly format
- The development of an internet-based data reporting site for data resources and organizations within the region including links to related sites
- Documentation of the data resources on the site.

The progress of the project team in reaching these goals is presented in the following chapters of this report. This report documents our dialog with members of the maritime community in the Great Lakes Region and the data acquisition, management and documentation efforts undertaken to date. Additional information is provided in the appendices to illustrate the documentation of the database contents and products from the data reporting system.

Dialog with the Great Lakes Maritime Industry

One of the first tasks undertaken by the project team was to establish a dialog with industry officials to identify data needs, priorities, and objectives for the project. To date, the Great Lakes Maritime Research Institute hosted two Great Lakes Maritime Data Workshops to discuss data and information needs for government, commerce, education and other interests in the region. The first of these workshops took place in Detroit on June 9, 2006. The second was held in Toledo in conjunction with the ICHCA Short Sea Shipping Meeting on November 7, 2006. Representatives from the following organizations participated in these workshops:

- US Army Corps of Engineers
- Lakes Carriers Association
- American Great Lakes Ports Assn.
- Transport Canada
- Canadian Chamber of Maritime Commerce
- Great Lakes Commission
- US Maritime Administration
- St. Lawrence Seaway Development Corporation
- NOAA
- Port of Duluth
- Univ. Wisconsin-Superior (GLMRI)
- Detroit Port Authority
- Univ. Minnesota Duluth (GLMRI)
- University of Toledo

The discussion of objectives for the continued success of the project is a direct result of these meetings. Based on discussions with stakeholders within the region pertaining to their data and information needs, the research team changed the emphasis from a purely GIS-based system to a more user-friendly information resource center. Workshop participants discussed in detail the purpose, goals and content of the data delivery system. This served to further define the scope of the project and gave rise to the objectives for this phase as summarized below.

Workshop participants readily agreed that the data delivery system must serve as an accurate, current, comprehensive and user-driven data resource center. In terms of its purpose, a critical objective of the system must be to provide data and information to inform public policy decision makers as to the value and utility of the GL MTS. Of particular importance in reporting to public officials are:

- Employment sustainability;
- Economic impact of Great Lakes shipping;
- Safety issues associated with diverting freight traffic to GL MTS;
- Environmental impacts/benefits compared to other modes;
- Shipper savings associated with GL MTS;

- Congestion effects of other modes in comparison to GL MTS;
- Competition effects of Maritime Transportation and rate increases in other modes;
- Shift in intermodal connections and transshipment costs (e.g., "full cost" studies – pavement damage, fuel savings, crashes, *etc*.);
- The value of shipping to states, cities, regions, *etc*.

Workshop participants discussed additional data needs for regional stakeholders that concern data to facilitate projections and forecasts for freight movements under alternative scenarios involving alternative modes or intermodal movements. Regulatory impacts were also emphasized in the discussion along with improved coordination of public investments over the entire system to benefit all stakeholders within the region despite their location or jurisdiction. One additional concern dealing with the purpose of the data delivery system dealt with the question of "Where does the reach of the Marine Industry begin or end?" Does it begin and end at the ports or should it extend all the way from the origin to the destination? Participants argued for the scope of the database to "follow the cargo" to consider ripple effects, regional impacts and locational patterns in the supply chain (e.g., steelworkers and farmers in the region both depend on the maritime industry). This perspective certainly coincides with one of the original objectives of this project in linking marine freight movements to the regional economy. These recommendations will be addressed in subsequent stages of the project; Phase II was concerned primarily with identification of data sources and acquisition of data.

The most important outcome of the meetings pertains to the form that the information delivery should take. The original design of the data delivery system was for a GIS format where users would query the database, perform simple analysis functions and prepare graphics, tables, text and maps as output. The challenge in implementing such a system however, concerns the extent to which the system should support the query, manipulation and analysis of data (e.g., vehicle routing, OD flow modeling, intermodal transfer simulation, etc.). In turn, developers of the system are further challenged by the need for users to gain the necessary expertise to operate the system. In response, meeting participants effectively argued that any system that requires a significant amount of training and practice would not be used as heavily as a more user-friendly system consisting of prepared graphs, maps, bullet points, tables, and other features such as prepackaged reports in basic standard formats such as Annual Reports, Executive Summaries, and reports of studies completed by analysts who used data from the repository. The research team responded to this point by adding to the system a variety of products and functions usable among varying degrees of expertise required by users. These include:

- Basic prepared maps for viewing and download;
- Prepared tables and graphs for viewing and download;
- Simple mapping functions in the data viewer;
- Query functions for more advanced users; and

- Analytical and other specialized functions in the database for advanced users.

Many of the above functions are available for all users now; functions for advanced users are still in the development stage and will continue into Phase III of this project. In addition, the research team will continue to add help functions to assist users, such as:

- Technical manuals available in PDF format in downloadable form for detailed directions on use.

- Tutorials for instruction on the Toledo web site for specific functions such as basic mapping, query functions, and more advanced analytical functions. Additional tutorials can be posted documenting the contents of the database.

- On-line help functions to solve routine problems that are encountered as users operate the system.

- Technical support via telephone or email using staff at the Toledo site at specified times to help users with more complex problems not available in the on-line help functions.

The discussion concluded with the following recommended tasks for the research team in this phase of the project:

- Acquire, assemble, transform, store, and manage raw data in the data repository.

- Begin to develop data reporting standards with regard to data reconciliation among diverse sources, standardization of reported units, "currentness" of reported statistics, establishment of data acquisition protocols, quality control and accuracy checking, and to develop mechanisms to check for redundancy and duplication of efforts among contributors to the database. It was strongly recommended that this system "level the playing field" in data reporting by using the same units as other modes and regions—this resource must reflect the metrics used in the industry. Data reporting standards should be discussed and reviewed on an ongoing basis (revisited every three years).

- Assemble data and report information among different geographic areas of impacts and jurisdictions:
    - States and provinces
    - Congressional districts
    - Cities
    - Counties
    - Ports

- Prepare information in the form of maps, tables, text and graphics for stakeholders pertaining to public policy interests.

- Establish a communication link within the system (e.g., email access) for regional stakeholders to request specific information to be posted on the site.

- Establish a system for data exchange to analysts in maritime industry agencies and organizations.

- Develop a site in the system for analysts within the region to publish the results of their analysis—particularly with regard to public policy issues of interest to the Great Lakes Maritime Industry.

- Begin to develop a library function in the form of a data clearinghouse that reviews and summarizes data from diverse sources--both public and commercial--and provide links for users to branch to from the site. The result of which is to provide the Great Lakes Maritime Industry with a comprehensive centralized resource for data and information. An example of such a link would be for taxes, fees, and other costs; however, this component would not represent a core function of the data resource.

It was further suggested by stakeholders that the site become a gateway to maritime agencies (*e.g*., Coast Guard, USACE, *etc*.). One final charge to the research team resulting from the discussion was to begin thinking about how to implement expedited data collection through technological innovations (*e.g*., GPS, informatics, electronic forms, *etc*.). It was suggested that a pilot project for automated data acquisition through AIS would be extremely useful in later phases of the project; this will be undertaken in Phase III of the project.

Finally, industry representatives recommended that data acquisition efforts be prioritized given constraints in time, staffing and budget. The highest priorities for data acquisition according to regional stakeholders are listed below:

- Cargo flows—vessel types, vessel size, types of commodities, origins, destinations

- Facilities including docks, terminals, locks, equipment, and navigation facilities

- Linking Great Lakes maritime freight movements and the economy of the Great Lakes Region (e.g., evaluating impacts of GL MTS freight movements on regional employment)

- Environmental data dealing with air and water emissions from Great Lakes vessels, including a baseline inventory of emissions data from great lakes vessels and a baseline ballast inventory

- Data to support air and water pollution reductions based on diverting traffic from highway and rail modes to marine transport modes

- Data to support comparative analysis of Great Lakes Fleet vs. railroads vs. trucks in terms of fuel consumption per ton-mile along with effects of fuel costs on transport economics of great lakes vessels vs. rail vs. truck over time

- Compiled Lists of current sources of data as part of the data library and clearinghouse function of the site

Our partners in the industry also contributed a number of additional recommendations related to long-term issues associated with the assembly, storage and management of the database. Of great importance was the establishment of both baseline information and projected trends among a wide range of factors in the industry. Specific recommendations included:

- Consider the utility of data for projections into the future and tracking trends.
- Data pertaining to investments in the infrastructure are critical. The system should account for current costs, projected costs, investments (over different planning horizons) and the benefits of investments; include the costs of making no investments.
- Include data that have been developed jointly between government and private interests—these data have considerable utility and credibility.
- Seek permissions in acquiring, storing and disseminating data. Acquire MOUs before including data in the system.
- Check for gaps in the data and additional needs for data that may not yet be available.
- Document caveats in working with the data—prepare a metadata reference page.

The recommendations gathered from the June 9 and November 7 meetings thus formed the basis for data collection efforts in Phase II. Much of the effort in Phase II has thus dealt with freight flows, facilities, intermodal connections and the link between the GL MTS and the regional economy. These data collection efforts are outlined in the next chapter.

Data Collection

Much of the data acquired in the first phase of this project came from existing sources—both commercial and government. The data are currently being stored on designated server space at the GISAG Center at The University of Toledo. Specific data assembled into the centralized data repository currently include the following:

1. Intrastate Employment patterns for each commodity type by SIC, NAICS, (Demographics Plus, Inc. *Business Counts Database*);
2. Population and socioeconomic data representing market demand within the region;
3. Port locations—U.S. (BTS National Transportation Atlas);
4. Dock locations (Army Corps of Engineers) and attributes;
5. Waterway network—Great Lakes and inland waterways (Army Corps of Engineers);
6. Baseline 2002 commodity flows through the Saint Lawrence Seaway and Great Lakes System obtained from the FHWA Freight Analysis Framework estimated from 2002 Commodity Flow Survey Data.

The challenge to the project team at that stage was to organize the data in such a way that all elements of the database were spatially compatible with respect to data structure format, geo-referencing, scale, segmentation, and compatibility with widely-used GIS software. Phase II of the project saw significant progress in the acquisition of additional data into the repository. This data set provided the research team with a skeleton framework upon which to add subsequent flow data as it is obtained. The second phase focused on linking the networks for a true intermodal connection picture within the "last mile" for freight delivery and commodity flows. The following data has been updated or added during Phase II of this project:

1. Employment by NAICS Classification among counties and MSAs in study region (Source: BLS ES/202);
2. Lock locations and lock performance statistics—U.S. side;
3. Weather station data to approx. 60 miles inland (NOAA);
4. Updated US Highway Network that combines the National Highway Planning Network and ORNL Network attributes and includes speeds and estimated travel times on links;
5. Integrated network—Great Lakes waterway, highway, rail linked to commercial docks, locks (Army Corps of Engineers);
6. MARAD annual vessel movements (1994-2004);
7. Import/export flows (Great Lakes East Coast and Gulf Ports);
8. FAF Zones and centroids;

9. FAF2 OD Flows (National and Regional Scale);
10. Satellite imagery / aerial photography of dock facilities;
11. Vessel inventory—Great Lakes Fleet;
12. Updated Canadian rail and highway networks.

Please refer to Appendix A for a set of maps prepared on MWFV that display a number of the data sets listed above. The data listed above resides in a database outside of the MWFV data viewer. Given the tremendous volume of the database, only selected portions of the database have been added to the reporting system to date. However, additional data will be posted upon request.

In addition to data acquisition activities listed above, other work has begun involving the compilation of aerial photography of GL docks and terminals and incorporating them into the database. Docks and terminals are spatially registered to the GIS database as a means to provide a backdrop for connecting the waterway, highway and rail networks into a comprehensive seamless intermodal network. This "last mile" approach was adopted to produce a seamless intermodal network for simulating commodity flows between modes in the system. The USACE water network for the great lakes will be connected via a transshipment link to rail and highway networks at the docks and terminals on the lakes and the St. Lawrence Seaway. Each transshipment link at each terminal will be encoded with attributes dealing with equipment, capacities, transfer characteristics, supported commodities, berthing characteristics and other factors affecting transshipment of cargoes between modes. This system will also contain specialized software for simulating commodity flows through the region and computing transshipment costs at the ports. In addition to dock and terminal connections, the waterway network will be modified to include navigation locks and lock performance characteristics to further aid in simulating vessel movements through the network.

The resulting integrated network will facilitate the simulation of commodity flows through the Great Lakes and Seaway as a means to evaluate the potential for short sea shipping, to explore opportunities for new cargoes, and to compare lake traffic with competing modes. As such, the system is envisioned as a resource to optimize the use of maritime transportation assets within the region.

Other efforts by the project team involved acquisition of AIS data to track vessel movements. The emphasis here will also involve lock and dock performance data for a more accurate account of commodity flows through the network. Implementation of this technology will be actively pursued in the next phase of the project.

Most of the data listed above have been obtained from existing digital data sources. These data have been re-projected, rectified and registered to a standardized coordinate system in MWFV. Other data dealing with dock locations and related operational attributes were manually entered into the database. This process was the most labor intensive and time consuming of the data assembly tasks. These efforts yielded a data layer that displays the location of commercial docks with their associated dock data available to be viewed

One further development in Phase II of the project was the negotiation of the project team with the U.S. Army Corps of Engineers Navigation Data Center to manage the MD+ Master Dock File for the Great Lakes. The project team is currently working with USACE to develop a prototype data collection and data transfer protocols. This work will take place during Phase III of the project. This positive outcome will provide the project team with additional resources for data collection and management over the long term. This portion of the project will be reported in greater detail in the next phase of the project.

The data listed above are available on the MWFV data reporting site for viewing (*as allowable by law, no disaggregate data is displayed if non-disclosures are attached to it*). The reporting site is best described as a file sharing data library consisting of geospatial data and non-spatial data in a usable format. Users of the site will have secured access to this repository. The repository is situated in the GISAG (Geographic Information Science and Applied Geography lab) at The University of Toledo.

The user interface for this data reporting system is built on a ***Citrix Metraframe*** installation of a specialized ***ArcView GIS*** application. Users can access MWFV with a web browser and Internet connection; all operations are carried out on the Toledo Server—the users' computers simply act as a terminal. The site is thus able to accommodate a wide range of users that extends between casual browsers and "basic mappers" to more experience GIS and database users.

The most recent activities undertaken have been to continue compiling information on the various types of commodities transported on the Great Lakes, with an emphasis on observing the origins and destinations of these commodities, flow routes, tonnages, *etc*. The major challenge to the acquisition of these data is confidentiality. Individual vessel movements, port calls, employment statistics and similar forms of data will require obtaining permissions and memoranda of understanding to collect the data and added security measures to store and manage the data. This includes the acquisition of AIS data. Phase II of the project saw significant progress toward the acquisition of these detailed confidential data; the project team is confident that these data will be acquired and added to the repository in Phase III.

So far, the discussion in this report has been devoted to the assembly of data into a central data repository within MWFV. However, the project team was also charged with the task of developing a wider information delivery system that requires very little technical training and GIS expertise on the part of users. Representatives of the Great Lakes Maritime Industry emphasized the importance of providing useful information in a more generalized format that could be taken directly off of the web-based delivery system. In addition, industry representatives acknowledged the importance of storing and managing data that could be accessed and exchanged with other analysts in the industry. The results of studies conducted with data from the data repository could then be posted on this centralized delivery site. The prototype delivery site was unveiled at the November 7, 2006 International Cargo Handling and Coordination Association's (ICHCA) Short Sea Shipping meeting in Toledo, Ohio.

Potential Economic Impacts of the Project and the Relationship to the GLMRI Focus Areas

As work on this system progresses, it can provide a strong integrating function for the GLMRI focus areas and for the wide range of organizations, firms and agencies that constitute the maritime industry on both sides of the international boundary. The work resulting from this project can directly interface with many of the research projects listed by GLMRI in its RFP for the Phase II Project:

- Economics and development of the Great Lakes Marine Transportation System (GL MTS)
- Regulatory barriers to maritime commerce in the Great Lakes
- Modeling movements with alternative vessel designs
- Market research for passenger movements
- Great Lakes port development issues
- Security issues in the GL MTS
- Intermodal transportation opportunities for Great Lakes transportation
- Relieving road congestion using Great Lakes vessel movements
- Distribution centers linked to the GL MTS
- Sustainable marine transportation and port environmental issues
- Marine transportation and port education

Each of the topics listed above can be readily applied to the database and information delivery system, as they all contain significant locational components and are readily adaptable for modeling and simulation.

As noted in Phase I of this project, the MWFV System is well positioned to carry out the task of assembling, storing and managing maritime data for the Great Lakes system. Users can take advantage of the GIS location-based query and selection capabilities as well as mapping functions to illustrate these relationships. In addition, the system will support advanced analysis capabilities such as vehicle routing and travel time computations to evaluate the effectiveness of the network to support freight movement. As a result, the system has begun to evolve into an effective tool for economic development planning as a means to measure accessibility to markets, identify bottlenecks in the network that hinder freight flows, and for identifying feasible locations for warehousing, manufacturing, retail and intermodal connection facilities. At the same time, information can be derived from the system in a more user-friendly format in the forms of prepared maps, graphics, tables, text and reports.

The main objective of this resource is to maintain a long-term database and data distribution system built on a strong relationship with the political jurisdictions and stakeholders listed above. This data resource will serve as a central focus for these various interests to come together to focus on optimizing freight movements within the region. With the addition of other interests such as firms, shippers, carriers, regional planning agencies, port authorities and economic development organizations, this resource can have a direct positive impact on the regional economy.

Another important development pursued in Phase II of the project is a Great Lakes Maritime Exchange to promote maritime commerce and regional economic development in the Great Lakes. One of the long-term objectives of this project is to develop a self-sustaining information delivery resource for the Great Lakes Region. Eventually this data repository and delivery system must be able to sustain itself financially as a member of the maritime industry in this region. To this end, it is proposed in this report that GLMRI and its partners in the industry consider the establishment of a ***Great Lakes Maritime Exchange*** (GLMX) in the form of a non-profit organization that would be financed through subscription fees by its partners in the industry. There are a number of such exchanges in the coastal regions of the United States and in British Columbia. These exchanges partner with one another through The Maritime Information Services of North America (MISNA), an umbrella organization of non-profit ***501(c)(6)*** maritime exchanges in the United States and British Columbia. According to MISNA:

> [these maritime exchanges] represent a broad cross section of maritime interests in their respective regions -- vessel owners and agents, ports, pilots, towboat companies, stevedores and terminal operators, admiralty lawyers, customs brokers and freight forwarders, ship repair firms, employer associations, insurance agencies, marine surveyors, maritime unions and oil spill response organizations, just to name a few. Collectively, over 8,000 private and public maritime businesses, agencies and associations are represented by MISNA [1].

Again, according to MISNA, the marine exchanges comprising this type of organization carry out a range of tasks that include:

- Advance vessel schedule information, including ETAs and ETDs
- Advance and real-time vessel movement monitoring (AIS)
- Actual arrival and departure data
- Vessel traffic analysis
- Historical vessel movement
- Port and terminal utilization studies
- Promote maritime interests
- Expert maritime analysis and assistance with Regulatory Compliance [1].

The principal investigator on the project team was contacted by MISNA in June 2006 with the proposal to begin a maritime exchange in the Great Lakes. To date, none exist in this region. Subsequently the principal investigator was invited to a MISNA National Meeting in Portland, Oregon in September 2006. It is argued here that this initiative merits consideration. MISNA has established standards and protocols for data reporting that could be adopted in the Great Lakes without developing a new set independently. A sample of data obtained from vessel tracking includes the following fields:

- Ship Name
- Lloyd's Number
- Ship Flag
- Ship Type
- Local Agent
- Estimated Date of Arrival
- Estimated Time of Arrival
- Actual Date of Arrival
- Actual Time of Arrival
- Arrival Port
- Arrival Berth
- Actual Date of Departure
- Actual Time of Departure
- Last Port of Call
- Next Port of Call

One of the main functions for many of the maritime exchanges is real-time vessel tracking using the AIS System as shown in the Great Lakes/St. Lawrence Seaway system [2]. The advantages noted at their web site is that continuous tracking enhances safety, optimizes transit times through better traffic management, optimizes scheduling of lock passages, improves fleet management for ship owners and assists in navigation through the system, provides faster response times following accidents/incidents, provides data to support national security efforts, and assists in tracking hazardous cargoes [2].

It is further argued here that continuous tracking of vessels can provide a means for effective coordination of intermodal connections in short sea shipping. The system can also provide input functions for long-term vessel tracking such as with the Automated Secure Vessel Tracking System [3]. Long-term vessel tracking can provide useful data to track total vessel traffic over the entire system—including specific channels where dredging is needed or other navigation improvements are required. Continuous vessel tracking can also provide needed data to track vessel emissions and to demonstrate savings in overall emissions by diverting freight traffic from rail and highway to the lakes.

It should be emphasized that maritime exchanges maintain strict confidentiality with their client organizations and do not disclose data among organizations without authorization. As discussed previously in this report, the same approach would be adopted in the Great Lakes. Thus a great lakes maritime exchange could serve as another partner with GLMRI and the maritime industry as a commercial resource and merits consideration.

Conclusion

The combined vision of the project team and our partners in the industry has led to the version of the Great Lakes Maritime Information Delivery System presented here. To date, the project has produced a multidimensional data gateway system that will support the following functions:

- A detailed data repository for vessel movements, port functions, commodity flows, economic activities and environmental impacts, etc.
- A GIS data viewer for advanced users to view and analyze a variety of data
- An information delivery site for maps, tables, graphics, text and other features
- An information clearinghouse and centralized data facility to furnish links to other information resources, private vendors furnishing commercial products, and government agencies
- A data exchange to support user inquiries and furnish information on demand.

The project team unveiled the initial prototype of the web-based information delivery resource system to the Great Lakes Maritime Community at the November 7, 2006 International Cargo Handling and Coordination Association (ICHCA) Short Sea Shipping meeting in Toledo, Ohio. The project team will continue solicit feedback and suggestions for improvements of the system. Phase II of this project has focused primarily on continued efforts in the identification and acquisition of data for the repository and began work on data acquisition involving the “last mile” approach for integrating intermodal connections into the database. In addition, the project team has formed a partnership with the U.S. Army Corps of Engineers Data Navigation Center to manage the Master Dock File in the new MD+ system for the Great Lakes.

Continuous improvement of the information delivery system will continue be a major objective as this resource evolves in the coming years. The project team will strive to maintain an open dialog with the members of the industry to assure success in this endeavor. Our dialog has also expanded to a wider audience through the dissemination of results shown in the references section of this report.

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[1] Maritime Information Service of North America (MISNA), (2004) (Internet), *History of MISNA*, (cited September, 2006), http://www.misnadata.org/content/history.php?m=15.

[2] Great Lakes/St. Lawrence Seaway System (SLSDC and SLSMC), (2006) (Internet), *AIS Project* (cited September, 2006), http://www.greatlakes-seaway.com/en/navigation/ais_project.html.

[3] Maritime Information Service of North America (MISNA), (2006) (Internet), *Automated Secure Vessel Tracking System (ASVTS)*, (cited September, 2006), http://www.asvts.org

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Dissemination of Results

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Lindquist, P.S., 2007. "The Great Lakes Maritime Information Delivery System“, Association of American Geographers Annual Meeting, San Francisco, California, April 19, 2007.

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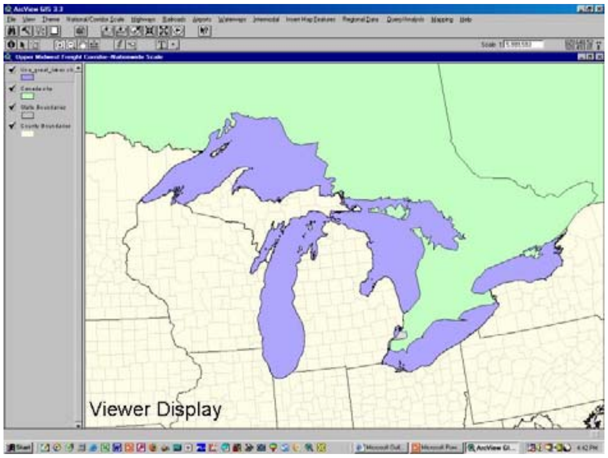
Adams, T., S. Van Hecke, E. Wittwer, D.Szymkowski, and P.S. Lindquist. 2007 "Regional Approach to Improving Freight Transportation", Transportation Research Board 86th Annual Meeting , January 23, 2007

Lindquist, P.S., 2006. "Expanding Regional Freight Information Resources for the Upper Midwest: The Great Lakes Maritime Information Delivery System", Great Lakes Maritime Research Institute Affiliates Meeting, October 7, 2006, Duluth, MN.

Lindquist, P.S., 2006. "Progress Report: The Great Lakes Maritime Information Delivery System", Joint Conference on the Great Lakes: From Data to Markets to Shipping Opportunities, GLMRI, UT ITI, ICHCA International, Toledo, Ohio, November 7, 2006.

APPENDIX A

Sample of Map Output from *Midwest FreightView* Great Lakes Maritime Database



Example 1: Basic Mapping Functions

Figure A.1
Initial display for the user Interface in ***Midwest FreightView***

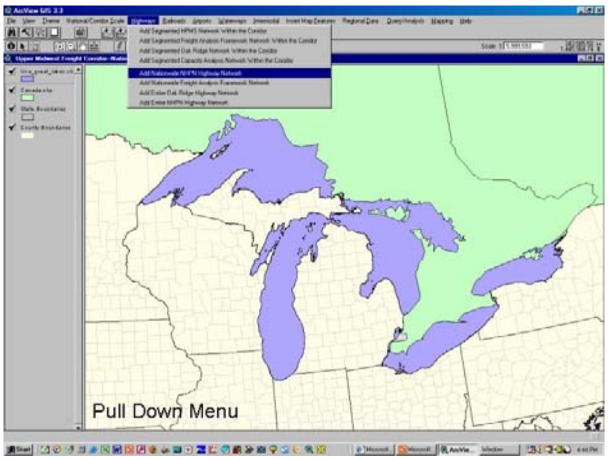


Figure A.2
User activates pull down menu to open the highway network in the Great Lakes Region.

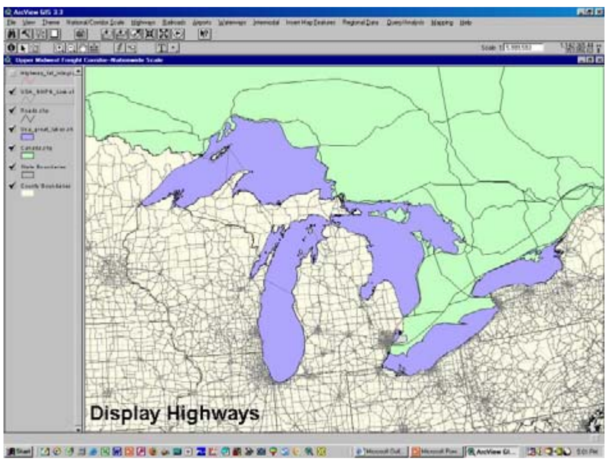


Figure A.3
MWFV displays highway network in the view window.

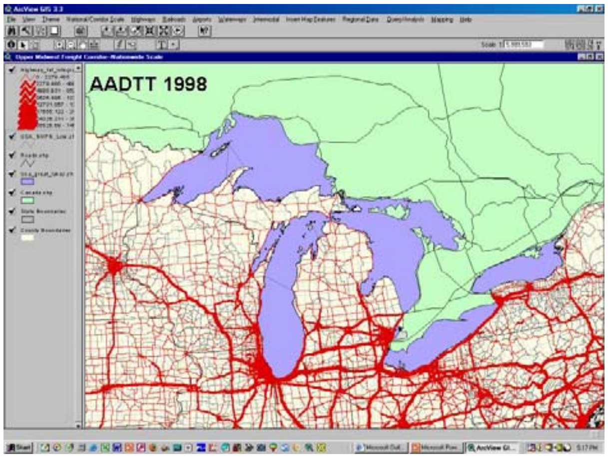


Figure A.4
MWFV provides users with the ability to highlight specific features in the display. In this case, interstate highways are highlighted according to 1998 Average Annual Daily Truck Traffic (Source: FAF).

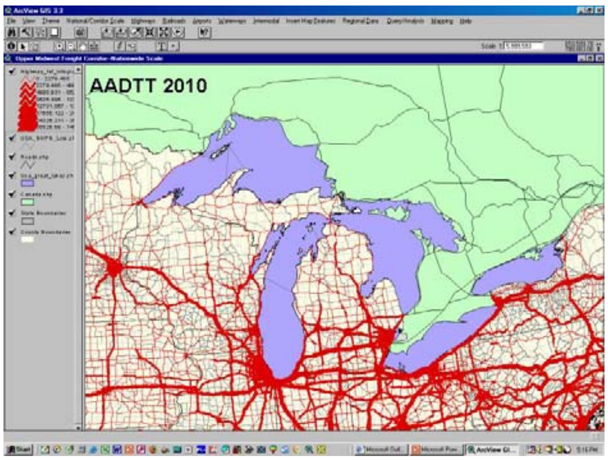


Figure A.5
The view now displays projected 2010 Average Annual Daily Truck Traffic (Source: FAF).

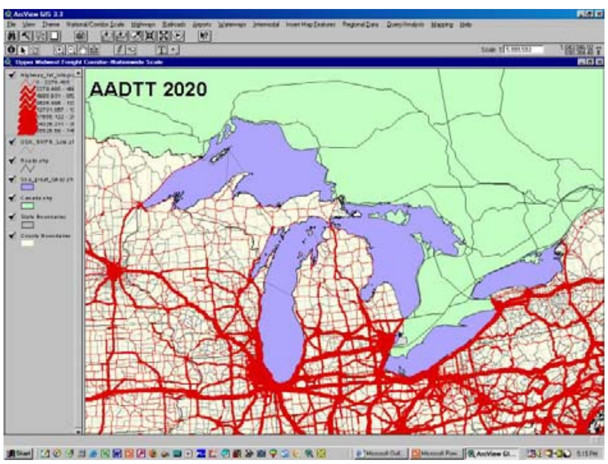


Figure A.6
Finally the view displays projected 2020 Average Annual Daily Truck Traffic—An argument for Short Sea Shipping. (Source: FAF).

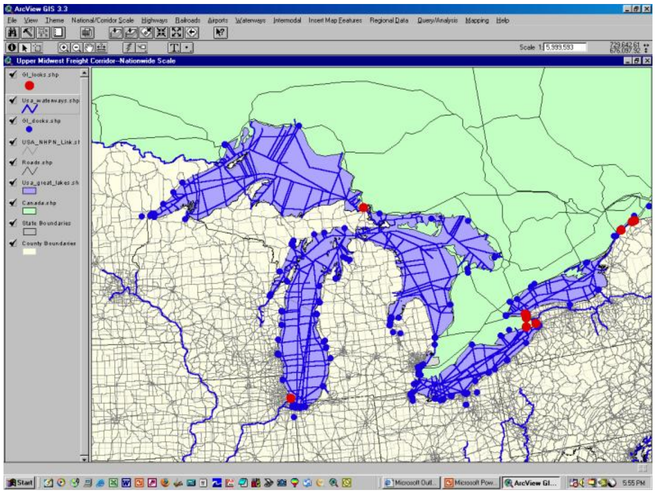


Figure A.7
MWFV displays integrated waterway network connecting docks/terminals, navigational locks, and waterway routes in the Great Lakes

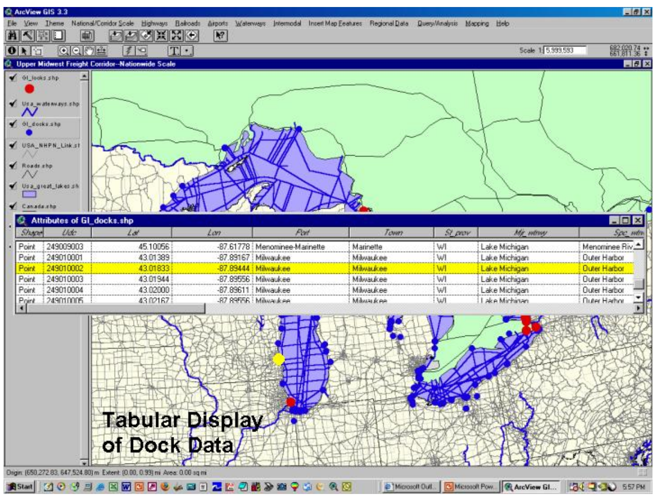


Figure A.8
User highlights individual dock on map display in MWFV and retrieves spreadsheet display of dock/terminal attributes.

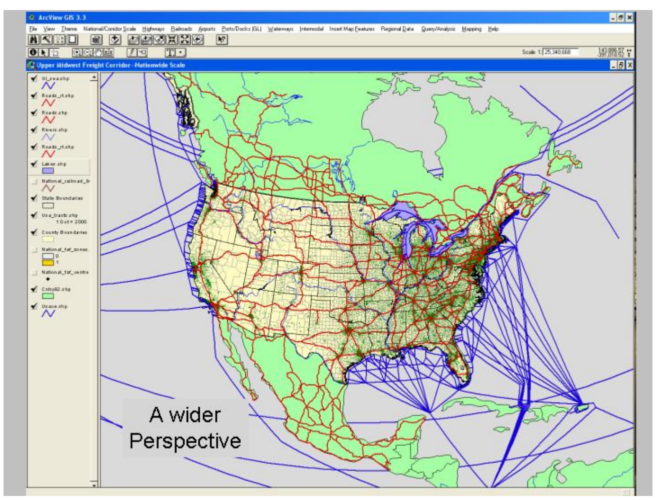
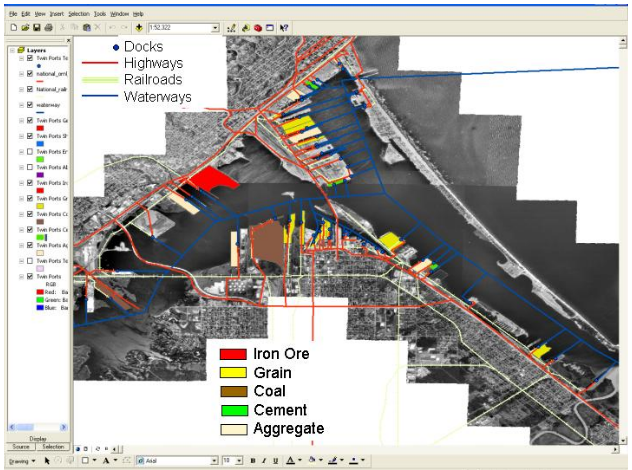


Figure A.9
A wider view of continental-scale waterway and highway networks connected to the Great Lakes Ports.



Example 2: Integrating the Waterway Network to the Landside Rail and Highway Networks at Terminals

Figure A.10

Aerial Photograph and GIS Data Layers: Port of Duluth / Superior

Superimposed Highway, Rail, Waterway and Dock Connections in Intermodal Network; Docks displayed by commodity

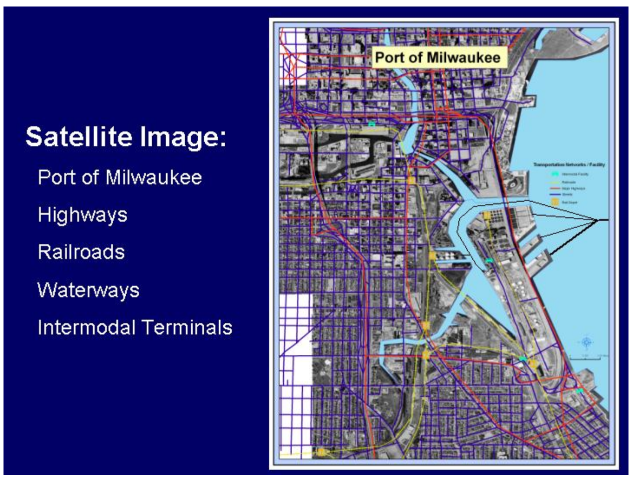


Figure A.11

Aerial Photograph and GIS Data Layers: Port of Milwaukee

Superimposed Highway, Rail, Waterway and Dock Connections in Intermodal Network

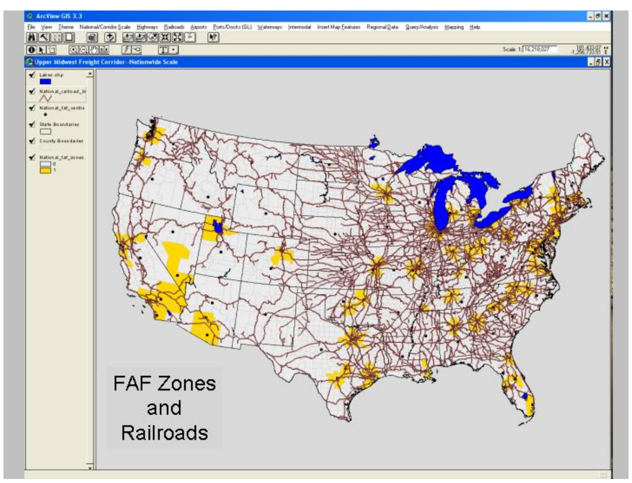
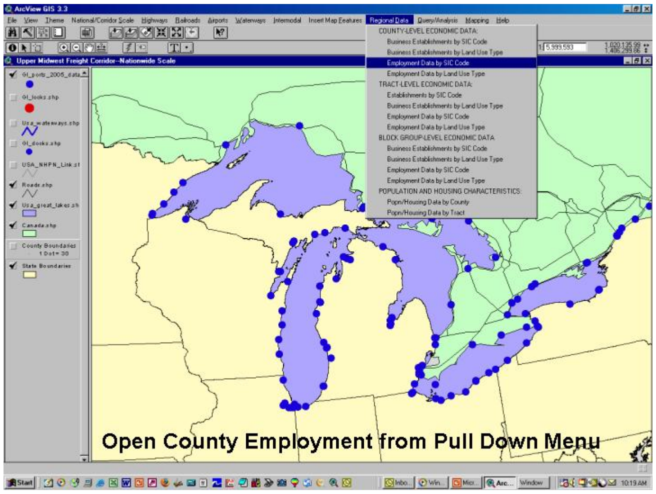


Figure A.12
A Wider View of Rail Connections
Linking the National Railway Network (ORNL) to FAF Zones and Great Lakes Terminals



Example 4: Linking the Great Lakes Martitime Transportation System to the Regional Economy.

Figure A.13
User activates pull down menu to open the regional employment database. In this case, the user is opening employment data by census tract.

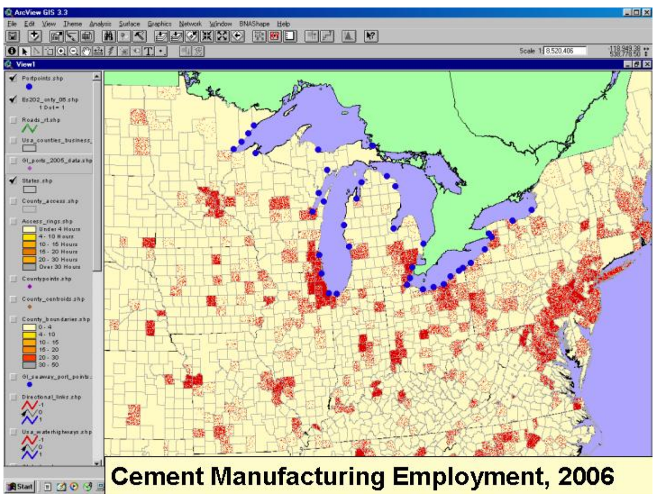


Figure A.14
MWFV displays a dot distribution map of cement manufacturing employment alongside Great Lakes dock locations. A complete list of economic data by County and MSA is available in Appendix C.

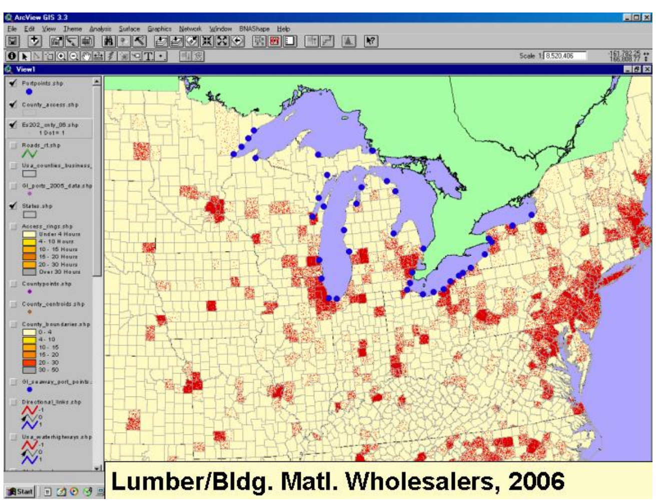


Figure A.15
MWFV displays a dot distribution map of Lumber and Building Material Wholesaler employment alongside Great Lakes dock locations—a potential market for imported building products. A complete list of economic data by County and MSA is available in Appendix C.

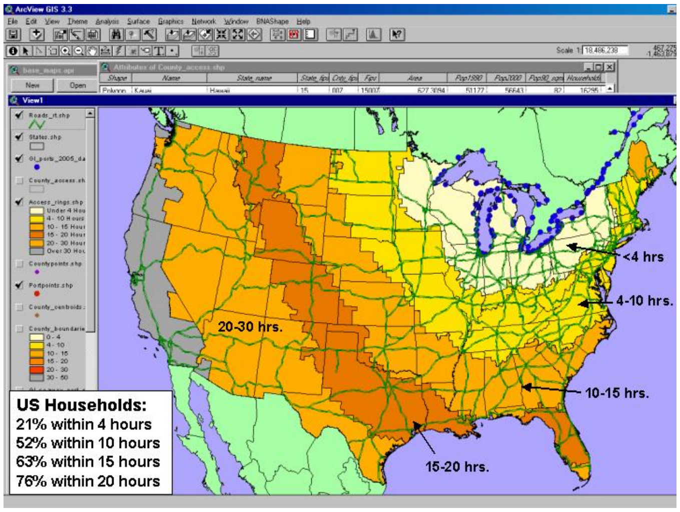


Figure A.15
Accessibility from Great Lakes Ports to National Market

Travel Time from Great Lakes Ports by Highway relative to the National Market (defined by households)

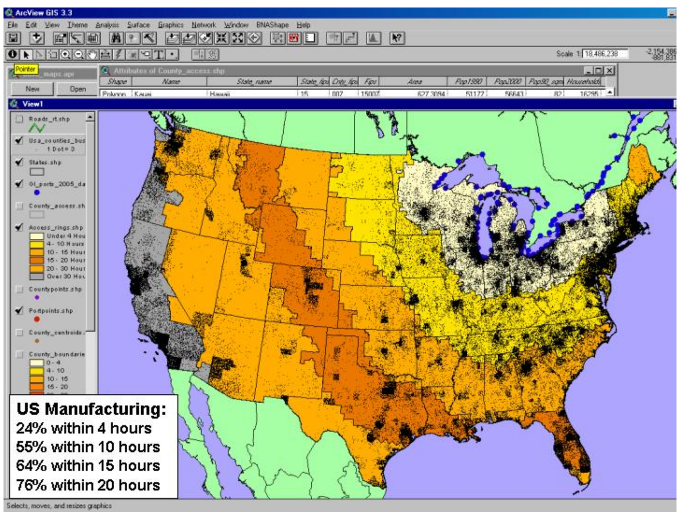


Figure A.16
Accessibility from Great Lakes Ports to National Manufacturing

Travel Time from Great Lakes Ports by Highway relative to The Distribution of Manufacturing Establishments Nationwide

APPENDIX B

Code Specifications for Great Lakes Commercial Docks

Code Specifications for Great Lakes Commercial Docks

Currently our Dock and Terminal Database contains the following fields (currently for the U.S. side only):

1. I.D. code number (please see Appendix C)
2. Name
3. Location
4. Address
5. Phone number
6. County
7. State/Province
8. Waterway
9. Port
10. Mile (if located on a river)
11. Latitude
12. Longitude
13. Operator
14. Owner
15. Purpose
16. Slip length
17. Slip width
18. Slip depth
19. Vessel loading equipment
20. Vessel loading speed
21. Vessel unloading equipment
22. Vessel unloading speed
23. Railway connections
24. Notes of interest

In addition, an identification code system has been developed by the project team to uniquely identify the commercial docks in this database. This code was developed because of a lack of standardization in identification codes among agencies and firms. As this project is looking at the Great Lakes system as a whole, our ID code was designed to work for all docks on both the Canadian and American sides of the Lakes. The code is an eight-digit number system where each digit, or set of digits, represents a specific category. The advantage of this I.D. system is that each number represents something real, it is not a mere arbitrary number used for administrative functions. This code system enables individuals to easily identify and locate a dock and determine the types of commodities it handles.

Code Key

- **X**0000000 First Digit – Country Code
- 0**XX**00000 Second & Third Digit – State/Province Code
- 000**XX**000 Fourth & Fifth Digit – Port Code
- 00000**X**00 Sixth Digit – Commodity Code
- 000000**XX** Seventh & Eight Digit – Specific Dock Code

The advantage of this I.D. system is that each number represents an actual characteristic of the dock; it is not an arbitrary number used for administrative functions.

Identification System Code Index

- **X**0000000 First Digit – Country Code
  - - 1 Canada
  - - 2 United States

- 0**XX**00000 Second & Third Digit – State/Province Code
  - - 01 Illinois
  - - 02 Indiana
  - - 03 Michigan
  - - 04 Minnesota
  - - 05 New York
  - - 06 Ohio
  - - 07 Ontario
  - - 08 Pennsylvania
  - - 09 Quebec
  - - 10 Wisconsin

- 000**XX**000 Fourth & Fifth Digit – Port Code

Illinois:

- - 01 Chicago
- - 02 Waukegan

Indiana:

- - 01 Buffington
- - 02 Burns International Harbor
- - 03 Gary
- - 04 Indiana Harbor

Michigan:

- 01	Alpena	-19	Marine City
- 02	Brevort	-20	Menominee-Marinette
- 03	Calcite	-21	Marquette
- 04	Charlevoix	-22	Marysville
- 05	Cheboygan	-23	Monroe
- 06	Detroit	-24	Munising
- 07	Escanaba	-25	Muskegon
- 08	Filer City	-26	Ontanagon
- 09	Frankfort Harbor	-27	Port Dolomite
- 10	Gladstone	-28	Port Gypsum
- 11	Grand Haven	-29	Port Huron
- 12	Gulliver	-30	Port Inland
- 13	Harbor Beach	-31	Portage Canal
- 14	Holland	-32	Saginaw River
- 15	Ludington	-33	Sault Ste. Marie
- 16	Macinac Island	-34	St. Joseph
- 17	Manistee Harbor	-35	Stoneport
- 18	Manistique	-36	Traverse City

Minnesota:

- - 01 Duluth – Superior
- - 02 Silver Bay
- - 03 Taconite Harbor
- - 04 Two Harbors

New York:

- 01	Buffalo
- 02	Dunkirk
- 03	Ogdensburg
- 04	Oswego
- 05	Rochester

Ohio:

- 01	Ashtabula
- 02	Cleveland
- 03	Conneaut
- 04	Fairport Harbor
- 05	Huron
- 06	Kelly’s Island
- 07	Lorain
- 08	Marblehead
- 09	Sandusky
- 10	Toledo

Ontario:

- 01	Amherstburg	-13	Morrisburg
- 02	Bath	-14	Nanticoke
- 03	Bowmanville	-15	Oshawa
- 04	Britt	-16	Owen Sound
- 05	Bruce Mines	-17	Pelee Island
- 06	Cornwall	-18	Port Colborne
- 07	Goderich	-19	Port Stanley
- 08	Hamilton	-20	Sarnia
- 09	Little Current	-21	Thunder Bay
- 10	Marathon	-22	Toronto
- 11	Millhaven	-23	Windsor
- 12	Mississauga		

Pennsylvania:

- 01	Erie

Quebec:

- 01	Baie Comeau	-11	Port Alfred
- 02	Becancour	-12	Port Cartier
- 03	Contrecoeur	-13	Quebec City
- 04	Cote Ste. Catherine	-14	Rimouski
- 05	Gros-Cacouna	-15	Sept Iles
- 06	La Baie	-16	Sorel
- 07	Lauzon Levis	-17	St. Romuald
- 08	Mataine	-18	Tracy
- 09	Montreal	-19	Trois Riveres
- 10	Pointe Naire	-20	Valleyfield

Wisconsin:

- 01 Ashland
- 02 Duluth – Superior
- 03 Green Bay
- 04 Manitowoc
- 05 Menominee – Marinette
- 06 Milwaukee
- 07 Sheboygan
- 08 Sturgeon Bay
- 09 Washburn

- 00000**X**00 Sixth Digit – Commodity Code
  - 1 Aggregate
  - 2 Coal
  - 3 General Cargo
  - 4 Government
  - 5 Grain
  - 6 Iron Ore
  - 7 Liquid
  - 8 Passenger
  - 9 Shipyard / Lay-Up

- 000000**XX** Seventh & Eighth Digit – Specific Dock Code

  The Specific Dock Code is a two-digit number used to differentiate between docks in a particular port that handle the same type of commodity. It is possible that there will be multiple docks with identical code numbers up until these last two digits, which will always show the difference between specific docks in a port.

APPENDIX C

Selected List of NAICS Data Available in the Repository

Selected List of NAICS Data Available in the Repository

2007 NAICS US Code	2007 NAICS US Title	2007 NAICS US Code	2007 NAICS US Title
11	Agriculture, Forestry, Fishing and Hunting	11192	Cotton Farming
111	Crop Production	111920	Cotton Farming
1111	Oilseed and Grain Farming	11193	Sugarcane Farming
11111	Soybean Farming	111930	Sugarcane Farming
111110	Soybean Farming	11194	Hay Farming
11112	Oilseed (except Soybean) Farming	111940	Hay Farming
111120	Oilseed (except Soybean) Farming	11199	All Other Crop Farming
11113	Dry Pea and Bean Farming	111991	Sugar Beet Farming
111130	Dry Pea and Bean Farming	111992	Peanut Farming
11114	Wheat Farming	111998	All Other Miscellaneous Crop Farming
111140	Wheat Farming	112	Animal Production
11115	Corn Farming	1121	Cattle Ranching and Farming
111150	Corn Farming	11211	Beef Cattle Ranching and Farming, including Feedlots
11116	Rice Farming	112111	Beef Cattle Ranching and Farming
111160	Rice Farming	112112	Cattle Feedlots
11119	Other Grain Farming	11212	Dairy Cattle and Milk Production
111191	Oilseed and Grain Combination Farming	112120	Dairy Cattle and Milk Production
111199	All Other Grain Farming	11213	Dual-Purpose Cattle Ranching and Farming
1112	Vegetable and Melon Farming	112130	Dual-Purpose Cattle Ranching and Farming
11121	Vegetable and Melon Farming	1122	Hog and Pig Farming
111211	Potato Farming	11221	Hog and Pig Farming
111219	Other Vegetable (except Potato) and Melon Farming	112210	Hog and Pig Farming
1113	Fruit and Tree Nut Farming	1123	Poultry and Egg Production
11131	Orange Groves	11231	Chicken Egg Production
111310	Orange Groves	112310	Chicken Egg Production
11132	Citrus (except Orange) Groves	11232	Broilers and Other Meat Type Chicken Production
111320	Citrus (except Orange) Groves	112320	Broilers and Other Meat Type Chicken Production
11133	Noncitrus Fruit and Tree Nut Farming	11233	Turkey Production
111331	Apple Orchards	112330	Turkey Production
111332	Grape Vineyards	11234	Poultry Hatcheries
111333	Strawberry Farming	112340	Poultry Hatcheries
111334	Berry (except Strawberry) Farming	11239	Other Poultry Production
111335	Tree Nut Farming	112390	Other Poultry Production
111336	Fruit and Tree Nut Combination Farming	1124	Sheep and Goat Farming
111339	Other Noncitrus Fruit Farming	11241	Sheep Farming
1114	Greenhouse, Nursery, and Floriculture Production	112410	Sheep Farming
11141	Food Crops Grown Under Cover	11242	Goat Farming
111411	Mushroom Production	112420	Goat Farming
111419	Other Food Crops Grown Under Cover	1125	Aquaculture
11142	Nursery and Floriculture Production	11251	Aquaculture

2007 NAICS US Code	2007 NAICS US Title	2007 NAICS US Code	2007 NAICS US Title
111421	Nursery and Tree Production	112511	Finfish Farming and Fish Hatcheries
111422	Floriculture Production	112512	Shellfish Farming
1119	Other Crop Farming	112519	Other Aquaculture
11191	Tobacco Farming	1129	Other Animal Production
111910	Tobacco Farming	11291	Apiculture
11292	Horses and Other Equine Production	211112	Natural Gas Liquid Extraction
112920	Horses and Other Equine Production	212	Mining (except Oil and Gas)
11293	Fur-Bearing Animal and Rabbit Production	2121	Coal Mining
112930	Fur-Bearing Animal and Rabbit Production	21211	Coal Mining
11299	All Other Animal Production	212111	Bituminous Coal and Lignite Surface Mining
112990	All Other Animal Production	212112	Bituminous Coal Underground Mining
113	Forestry and Logging	212113	Anthracite Mining
1131	Timber Tract Operations	2122	Metal Ore Mining
11311	Timber Tract Operations	21221	Iron Ore Mining
113110	Timber Tract Operations	212210	Iron Ore Mining
1132	Forest Nurseries and Gathering of Forest Products	21222	Gold Ore and Silver Ore Mining
11321	Forest Nurseries and Gathering of Forest Products	212221	Gold Ore Mining
113210	Forest Nurseries and Gathering of Forest Products	212222	Silver Ore Mining
1133	Logging	21223	Copper, Nickel, Lead, and Zinc Mining
11331	Logging	212231	Lead Ore and Zinc Ore Mining
113310	Logging	212234	Copper Ore and Nickel Ore Mining
114	Fishing, Hunting and Trapping	21229	Other Metal Ore Mining
1141	Fishing	212291	Uranium-Radium-Vanadium Ore Mining
11411	Fishing	212299	All Other Metal Ore Mining
114111	Finfish Fishing	2123	Nonmetallic Mineral Mining and Quarrying
114112	Shellfish Fishing	21231	Stone Mining and Quarrying
114119	Other Marine Fishing	212311	Dimension Stone Mining and Quarrying
1142	Hunting and Trapping	212312	Crushed and Broken Limestone Mining and Quarrying
11421	Hunting and Trapping	212313	Crushed and Broken Granite Mining and Quarrying
114210	Hunting and Trapping	212319	Other Crushed and Broken Stone Mining and Quarrying
115	Support Activities for Agriculture and Forestry	21232	Sand, Gravel, Clay, and Ceramic and Refractory Minerals Mining and Quarrying
1151	Support Activities for Crop Production	212321	Construction Sand and Gravel Mining
11511	Support Activities for Crop Production	212322	Industrial Sand Mining
115111	Cotton Ginning	212324	Kaolin and Ball Clay Mining
115112	Soil Preparation, Planting, and Cultivating	212325	Clay and Ceramic and Refractory Minerals Mining
115113	Crop Harvesting, Primarily by Machine	21239	Other Nonmetallic Mineral Mining and Quarrying
115114	Postharvest Crop Activities (except Cotton Ginning)	212391	Potash, Soda, and Borate Mineral Mining
115115	Farm Labor Contractors and Crew Leaders	212392	Phosphate Rock Mining
115116	Farm Management Services	212393	Other Chemical and Fertilizer Mineral Mining
1152	Support Activities for Animal Production	212399	All Other Nonmetallic Mineral Mining
11521	Support Activities for Animal Production	213	Support Activities for Mining

2007 NAICS US Code	2007 NAICS US Title	2007 NAICS US Code	2007 NAICS US Title
115210	Support Activities for Animal Production	2131	Support Activities for Mining
1153	Support Activities for Forestry	21311	Support Activities for Mining
11531	Support Activities for Forestry	213111	Drilling Oil and Gas Wells
115310	Support Activities for Forestry	213112	Support Activities for Oil and Gas Operations
21	Mining, Quarrying, and Oil and Gas Extraction	213113	Support Activities for Coal Mining
211	Oil and Gas Extraction	213114	Support Activities for Metal Mining
2111	Oil and Gas Extraction	213115	Support Activities for Nonmetallic Minerals (except Fuels) Mining
21111	Oil and Gas Extraction	22	Utilities
211111	Crude Petroleum and Natural Gas Extraction	221	Utilities
2211	Electric Power Generation, Transmission and Distribution	237310	Highway, Street, and Bridge Construction
22111	Electric Power Generation	2379	Other Heavy and Civil Engineering Construction
221111	Hydroelectric Power Generation	23799	Other Heavy and Civil Engineering Construction
221112	Fossil Fuel Electric Power Generation	237990	Other Heavy and Civil Engineering Construction
221113	Nuclear Electric Power Generation	238	Specialty Trade Contractors
221119	Other Electric Power Generation	2381	Foundation, Structure, and Building Exterior Contractors
22112	Electric Power Transmission, Control, and Distribution	23811	Poured Concrete Foundation and Structure Contractors
221121	Electric Bulk Power Transmission and Control	238110	Poured Concrete Foundation and Structure Contractors
221122	Electric Power Distribution	23812	Structural Steel and Precast Concrete Contractors
2212	Natural Gas Distribution	238120	Structural Steel and Precast Concrete Contractors
22121	Natural Gas Distribution	23813	Framing Contractors
221210	Natural Gas Distribution	238130	Framing Contractors
2213	Water, Sewage and Other Systems	23814	Masonry Contractors
22131	Water Supply and Irrigation Systems	238140	Masonry Contractors
221310	Water Supply and Irrigation Systems	23815	Glass and Glazing Contractors
22132	Sewage Treatment Facilities	238150	Glass and Glazing Contractors
221320	Sewage Treatment Facilities	23816	Roofing Contractors
22133	Steam and Air-Conditioning Supply	238160	Roofing Contractors
221330	Steam and Air-Conditioning Supply	23817	Siding Contractors
23	Construction	238170	Siding Contractors
236	Construction of Buildings	23819	Other Foundation, Structure, and Building Exterior Contractors
2361	Residential Building Construction	238190	Other Foundation, Structure, and Building Exterior Contractors
23611	Residential Building Construction	2382	Building Equipment Contractors
236115	New Single-Family Housing Construction (except Operative Builders)	23821	Electrical Contractors and Other Wiring Installation Contractors
236116	New Multifamily Housing Construction (except Operative Builders)	238210	Electrical Contractors and Other Wiring Installation Contractors
236117	New Housing Operative Builders	23822	Plumbing, Heating, and Air-Conditioning Contractors
236118	Residential Remodelers	238220	Plumbing, Heating, and Air-Conditioning Contractors
2362	Nonresidential Building Construction	23829	Other Building Equipment Contractors
23621	Industrial Building Construction	238290	Other Building Equipment Contractors
236210	Industrial Building Construction	2383	Building Finishing Contractors
23622	Commercial and Institutional Building Cons.	23831	Drywall and Insulation Contractors

2007 NAICS US Code	2007 NAICS US Title	2007 NAICS US Code	2007 NAICS US Title
236220	Commercial and Institutional Building Construction	238310	Drywall and Insulation Contractors
237	Heavy and Civil Engineering Construction	23832	Painting and Wall Covering Contractors
2371	Utility System Construction	238320	Painting and Wall Covering Contractors
23711	Water and Sewer Line and Related Structures Construction	23833	Flooring Contractors
237110	Water and Sewer Line and Related Structures Construction	238330	Flooring Contractors
23712	Oil and Gas Pipeline and Related Structures Construction	23834	Tile and Terrazzo Contractors
237120	Oil and Gas Pipeline and Related Structures Construction	238340	Tile and Terrazzo Contractors
23713	Power and Communication Line and Related Structures Construction	23835	Finish Carpentry Contractors
237130	Power and Communication Line and Related Structures Construction	238350	Finish Carpentry Contractors
2372	Land Subdivision	23839	Other Building Finishing Contractors
23721	Land Subdivision	238390	Other Building Finishing Contractors
237210	Land Subdivision	2389	Other Specialty Trade Contractors
2373	Highway, Street, and Bridge Construction	23891	Site Preparation Contractors
23731	Highway, Street, and Bridge Construction	238910	Site Preparation Contractors
23899	All Other Specialty Trade Contractors	31152	Ice Cream and Frozen Dessert Manufacturing
238990	All Other Specialty Trade Contractors	311520	Ice Cream and Frozen Dessert Manufacturing
31-33	Manufacturing	3116	Animal Slaughtering and Processing
311	Food Manufacturing	31161	Animal Slaughtering and Processing
3111	Animal Food Manufacturing	311611	Animal (except Poultry) Slaughtering
31111	Animal Food Manufacturing	311612	Meat Processed from Carcasses
311111	Dog and Cat Food Manufacturing	311613	Rendering and Meat Byproduct Processing
311119	Other Animal Food Manufacturing	311615	Poultry Processing
3112	Grain and Oilseed Milling	3117	Seafood Product Preparation and Packaging
31121	Flour Milling and Malt Manufacturing	31171	Seafood Product Preparation and Packaging
311211	Flour Milling	311711	Seafood Canning
311212	Rice Milling	311712	Fresh and Frozen Seafood Processing
311213	Malt Manufacturing	3118	Bakeries and Tortilla Manufacturing
31122	Starch and Vegetable Fats and Oils Manufacturing	31181	Bread and Bakery Product Manufacturing
311221	Wet Corn Milling	311811	Retail Bakeries
311222	Soybean Processing	311812	Commercial Bakeries
311223	Other Oilseed Processing	311813	Frozen Cakes, Pies, and Other Pastries Manufacturing
311225	Fats and Oils Refining and Blending	31182	Cookie, Cracker, and Pasta Manufacturing
31123	Breakfast Cereal Manufacturing	311821	Cookie and Cracker Manufacturing
311230	Breakfast Cereal Manufacturing	311822	Flour Mixes and Dough Manufacturing from Purchased Flour
3113	Sugar and Confectionery Product Manufacturing	311823	Dry Pasta Manufacturing
31131	Sugar Manufacturing	31183	Tortilla Manufacturing
311311	Sugarcane Mills	311830	Tortilla Manufacturing
311312	Cane Sugar Refining	3119	Other Food Manufacturing
311313	Beet Sugar Manufacturing	31191	Snack Food Manufacturing

2007 NAICS US Code	2007 NAICS US Title	2007 NAICS US Code	2007 NAICS US Title
31132	Chocolate and Confectionery Manufacturing from Cacao Beans	311911	Roasted Nuts and Peanut Butter Manufacturing
311320	Chocolate and Confectionery Manufacturing from Cacao Beans	311919	Other Snack Food Manufacturing
31133	Confectionery Manufacturing from Purchased Chocolate	31192	Coffee and Tea Manufacturing
311330	Confectionery Manufacturing from Purchased Chocolate	311920	Coffee and Tea Manufacturing
31134	Nonchocolate Confectionery Manufacturing	31193	Flavoring Syrup and Concentrate Manufacturing
311340	Nonchocolate Confectionery Manufacturing	311930	Flavoring Syrup and Concentrate Manufacturing
3114	Fruit and Vegetable Preserving and Specialty Food Manufacturing	31194	Seasoning and Dressing Manufacturing
31141	Frozen Food Manufacturing	311941	Mayonnaise, Dressing, and Other Prepared Sauce Manufacturing
311411	Frozen Fruit, Juice, and Vegetable Manufacturing	311942	Spice and Extract Manufacturing
311412	Frozen Specialty Food Manufacturing	31199	All Other Food Manufacturing
31142	Fruit and Vegetable Canning, Pickling, and Drying	311991	Perishable Prepared Food Manufacturing
311421	Fruit and Vegetable Canning	311999	All Other Miscellaneous Food Manufacturing
311422	Specialty Canning	312	Beverage and Tobacco Product Manufacturing
311423	Dried and Dehydrated Food Manufacturing	3121	Beverage Manufacturing
3115	Dairy Product Manufacturing	31211	Soft Drink and Ice Manufacturing
31151	Dairy Product (except Frozen) Manufacturing	312111	Soft Drink Manufacturing
311511	Fluid Milk Manufacturing	312112	Bottled Water Manufacturing
311512	Creamery Butter Manufacturing	312113	Ice Manufacturing
311513	Cheese Manufacturing	31212	Breweries
311514	Dry, Condensed, and Evaporated Dairy Product Manufacturing	312120	Breweries
31213	Wineries	314991	Rope, Cordage, and Twine Mills
312130	Wineries	314992	Tire Cord and Tire Fabric Mills
31214	Distilleries	314999	All Other Miscellaneous Textile Product Mills
312140	Distilleries	315	Apparel Manufacturing
3122	Tobacco Manufacturing	3151	Apparel Knitting Mills
31221	Tobacco Stemming and Redrying	31511	Hosiery and Sock Mills
312210	Tobacco Stemming and Redrying	315111	Sheer Hosiery Mills
31222	Tobacco Product Manufacturing	315119	Other Hosiery and Sock Mills
312221	Cigarette Manufacturing	31519	Other Apparel Knitting Mills
312229	Other Tobacco Product Manufacturing	315191	Outerwear Knitting Mills
313	Textile Mills	315192	Underwear and Nightwear Knitting Mills
3131	Fiber, Yarn, and Thread Mills	3152	Cut and Sew Apparel Manufacturing
31311	Fiber, Yarn, and Thread Mills	31521	Cut and Sew Apparel Contractors
313111	Yarn Spinning Mills	315211	Men's and Boys' Cut and Sew Apparel Contractors
313112	Yarn Texturizing, Throwing, and Twisting Mills	315212	Women's, Girls', and Infants' Cut and Sew Apparel Contractors
313113	Thread Mills	31522	Men's and Boys' Cut and Sew Apparel Manufacturing
3132	Fabric Mills	315221	Men's and Boys' Cut and Sew Underwear and Nightwear Manufacturing

2007 NAICS US Code	2007 NAICS US Title	2007 NAICS US Code	2007 NAICS US Title
31321	Broadwoven Fabric Mills	315222	Men's and Boys' Cut and Sew Suit, Coat, and Overcoat Manufacturing
31322	Narrow Fabric Mills and Schiffli Machine Embroidery	315224	Men's and Boys' Cut and Sew Trouser, Slack, and Jean Manufacturing
313221	Narrow Fabric Mills	315225	Men's and Boys' Cut and Sew Work Clothing Manufacturing
313222	Schiffli Machine Embroidery	315228	Men's and Boys' Cut and Sew Other Outerwear Manufacturing
31323	Nonwoven Fabric Mills	31523	Women's and Girls' Cut and Sew Apparel Manufacturing
313230	Nonwoven Fabric Mills	315231	Women's and Girls' Cut and Sew Lingerie, Loungewear, and Nightwear Manufacturing
31324	Knit Fabric Mills	315232	Women's and Girls' Cut and Sew Blouse and Shirt Manufacturing
313241	Weft Knit Fabric Mills	315233	Women's and Girls' Cut and Sew Dress Manufacturing
313249	Other Knit Fabric and Lace Mills	315234	Women's and Girls' Cut and Sew Suit, Coat, Tailored Jacket, and Skirt Manufacturing
3133	Textile and Fabric Finishing and Fabric Coating Mills	315239	Women's and Girls' Cut and Sew Other Outerwear Manufacturing
31331	Textile and Fabric Finishing Mills	31529	Other Cut and Sew Apparel Manufacturing
313311	Broadwoven Fabric Finishing Mills	315291	Infants' Cut and Sew Apparel Manufacturing
313312	Textile and Fabric Finishing (except Broadwoven Fabric) Mills	315292	Fur and Leather Apparel Manufacturing
31332	Fabric Coating Mills	315299	All Other Cut and Sew Apparel Manufacturing
313320	Fabric Coating Mills	3159	Apparel Accessories and Other Apparel Manufacturing
314	Textile Product Mills	31599	Apparel Accessories and Other Apparel Manufacturing
3141	Textile Furnishings Mills	315991	Hat, Cap, and Millinery Manufacturing
31411	Carpet and Rug Mills	315992	Glove and Mitten Manufacturing
314110	Carpet and Rug Mills	315993	Men's and Boys' Neckwear Manufacturing
31412	Curtain and Linen Mills	315999	Other Apparel Accessories and Other Apparel Manufacturing
314121	Curtain and Drapery Mills	316	Leather and Allied Product Manufacturing
314129	Other Household Textile Product Mills	3161	Leather and Hide Tanning and Finishing
3149	Other Textile Product Mills	31611	Leather and Hide Tanning and Finishing
31491	Textile Bag and Canvas Mills	316110	Leather and Hide Tanning and Finishing
314911	Textile Bag Mills	3162	Footwear Manufacturing
314912	Canvas and Related Product Mills	31621	Footwear Manufacturing
31499	All Other Textile Product Mills	316211	Rubber and Plastics Footwear Manufacturing
316212	House Slipper Manufacturing	322212	Folding Paperboard Box Manufacturing
316213	Men's Footwear (except Athletic) Manufacturing	322213	Setup Paperboard Box Manufacturing
316214	Women's Footwear (except Athletic) Manufacturing	322214	Fiber Can, Tube, Drum, and Similar Products Manufacturing
316219	Other Footwear Manufacturing	322215	Nonfolding Sanitary Food Container Manufacturing
3169	Other Leather and Allied Product Manufacturing	32222	Paper Bag and Coated and Treated Paper Manufacturing
31699	Other Leather and Allied Product Manufacturing	322221	Coated and Laminated Packaging Paper Manufacturing
316991	Luggage Manufacturing	322222	Coated and Laminated Paper Manufacturing
316992	Women's Handbag and Purse Manufacturing	322223	Coated Paper Bag and Pouch Manufacturing
316993	Personal Leather Good (except Women's Handbag and Purse) Manufacturing	322224	Uncoated Paper and Multiwall Bag Manufacturing

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316999	All Other Leather Good and Allied Product Manufacturing	322225	Laminated Aluminum Foil Manufacturing for Flexible Packaging Uses
3211	Sawmills and Wood Preservation	32223	Stationery Product Manufacturing
32111	Sawmills and Wood Preservation	322231	Die-Cut Paper and Paperboard Office Supplies Manufacturing
321113	Sawmills	322232	Envelope Manufacturing
321114	Wood Preservation	322233	Stationery, Tablet, and Related Product Manufacturing
3212	Veneer, Plywood, and Engineered Wood Product Manufacturing	32229	Other Converted Paper Product Manufacturing
32121	Veneer, Plywood, and Engineered Wood Product Manufacturing	322291	Sanitary Paper Product Manufacturing
321211	Hardwood Veneer and Plywood Manufacturing	322299	All Other Converted Paper Product Manufacturing
321212	Softwood Veneer and Plywood Manufacturing	323	Printing and Related Support Activities
321213	Engineered Wood Member (except Truss) Manufacturing	3231	Printing and Related Support Activities
321214	Truss Manufacturing	32311	Printing
321219	Reconstituted Wood Product Manufacturing	323110	Commercial Lithographic Printing
3219	Other Wood Product Manufacturing	323111	Commercial Gravure Printing
32191	Millwork	323112	Commercial Flexographic Printing
321911	Wood Window and Door Manufacturing	323113	Commercial Screen Printing
321912	Cut Stock, Resawing Lumber, and Planing	323114	Quick Printing
321918	Other Millwork (including Flooring)	323115	Digital Printing
32192	Wood Container and Pallet Manufacturing	323116	Manifold Business Forms Printing
321920	Wood Container and Pallet Manufacturing	323117	Books Printing
32199	All Other Wood Product Manufacturing	323118	Blankbook, Looseleaf Binders, and Devices Manufacturing
321991	Manufactured Home (Mobile Home) Manufacturing	323119	Other Commercial Printing
321992	Prefabricated Wood Building Manufacturing	32312	Support Activities for Printing
321999	All Other Miscellaneous Wood Product Manufacturing	323121	Tradebinding and Related Work
322	Paper Manufacturing	323122	Prepress Services
3221	Pulp, Paper, and Paperboard Mills	324	Petroleum and Coal Products Manufacturing
32211	Pulp Mills	3241	Petroleum and Coal Products Manufacturing
322110	Pulp Mills	32411	Petroleum Refineries
32212	Paper Mills	324110	Petroleum Refineries
322121	Paper (except Newsprint) Mills	32412	Asphalt Paving, Roofing, and Saturated Materials Manufacturing
322122	Newsprint Mills	324121	Asphalt Paving Mixture and Block Manufacturing
32213	Paperboard Mills	324122	Asphalt Shingle and Coating Materials Manufacturing
322130	Paperboard Mills	32419	Other Petroleum and Coal Products Manufacturing
3222	Converted Paper Product Manufacturing	324191	Petroleum Lubricating Oil and Grease Manufacturing
32221	Paperboard Container Manufacturing	324199	All Other Petroleum and Coal Products Manufacturing
322211	Corrugated and Solid Fiber Box Manufacturing	325	Chemical Manufacturing
3251	Basic Chemical Manufacturing	325612	Polish and Other Sanitation Good Manufacturing
32511	Petrochemical Manufacturing	325613	Surface Active Agent Manufacturing

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325110	Petrochemical Manufacturing	32562	Toilet Preparation Manufacturing
32512	Industrial Gas Manufacturing	325620	Toilet Preparation Manufacturing
325131	Inorganic Dye and Pigment Manufacturing	325910	Printing Ink Manufacturing
325132	Synthetic Organic Dye and Pigment Manufacturing	32592	Explosives Manufacturing
32518	Other Basic Inorganic Chemical Manufacturing	325920	Explosives Manufacturing
325181	Alkalies and Chlorine Manufacturing	32599	All Other Chemical Product and Preparation Manufacturing
325182	Carbon Black Manufacturing	325991	Custom Compounding of Purchased Resins
325188	All Other Basic Inorganic Chemical Manufacturing	325992	Photographic Film, Paper, Plate, and Chemical Manufacturing
32519	Other Basic Organic Chemical Manufacturing	325998	All Other Miscellaneous Chemical Product and Preparation Manufacturing
325191	Gum and Wood Chemical Manufacturing	326	Plastics and Rubber Products Manufacturing
325192	Cyclic Crude and Intermediate Manufacturing	3261	Plastics Product Manufacturing
325193	Ethyl Alcohol Manufacturing	32611	Plastics Packaging Materials and Unlaminated Film and Sheet Manufacturing
325199	All Other Basic Organic Chemical Manufacturing	326111	Plastics Bag and Pouch Manufacturing
3252	Resin, Synthetic Rubber, and Artificial Synthetic Fibers and Filaments Manufacturing	326112	Plastics Packaging Film and Sheet (including Laminated) Manufacturing
32521	Resin and Synthetic Rubber Manufacturing	326113	Unlaminated Plastics Film and Sheet (except Packaging) Manufacturing
325211	Plastics Material and Resin Manufacturing	32612	Plastics Pipe, Pipe Fitting, and Unlaminated Profile Shape Manufacturing
325212	Synthetic Rubber Manufacturing	326121	Unlaminated Plastics Profile Shape Manufacturing
32522	Artificial and Synthetic Fibers and Filaments Manufacturing	326122	Plastics Pipe and Pipe Fitting Manufacturing
325221	Cellulosic Organic Fiber Manufacturing	32613	Laminated Plastics Plate, Sheet (except Packaging), and Shape Manufacturing
325222	Noncellulosic Organic Fiber Manufacturing	326130	Laminated Plastics Plate, Sheet (except Packaging), and Shape Manufacturing
3253	Pesticide, Fertilizer, and Other Agricultural Chemical Manufacturing	32614	Polystyrene Foam Product Manufacturing
32531	Fertilizer Manufacturing	326140	Polystyrene Foam Product Manufacturing
325311	Nitrogenous Fertilizer Manufacturing	32615	Urethane and Other Foam Product (except Polystyrene) Manufacturing
325312	Phosphatic Fertilizer Manufacturing	326150	Urethane and Other Foam Product (except Polystyrene) Manufacturing
325314	Fertilizer (Mixing Only) Manufacturing	32616	Plastics Bottle Manufacturing
32532	Pesticide and Other Agricultural Chemical Manufacturing	326160	Plastics Bottle Manufacturing
325320	Pesticide and Other Agricultural Chemical Manufacturing	32619	Other Plastics Product Manufacturing
3254	Pharmaceutical and Medicine Manufacturing	326191	Plastics Plumbing Fixture Manufacturing
32541	Pharmaceutical and Medicine Manufacturing	326192	Resilient Floor Covering Manufacturing
325411	Medicinal and Botanical Manufacturing	326199	All Other Plastics Product Manufacturing
325412	Pharmaceutical Preparation Manufacturing	3262	Rubber Product Manufacturing
325413	In-Vitro Diagnostic Substance Manufacturing	32621	Tire Manufacturing
325414	Biological Product (except Diagnostic) Manufacturing	326211	Tire Manufacturing (except Retreading)
3255	Paint, Coating, and Adhesive Manufacturing	326212	Tire Retreading
32551	Paint and Coating Manufacturing	32622	Rubber and Plastics Hoses and Belting Manufacturing

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325510	Paint and Coating Manufacturing	326220	Rubber and Plastics Hoses and Belting Manufacturing
32552	Adhesive Manufacturing	32629	Other Rubber Product Manufacturing
325520	Adhesive Manufacturing	326291	Rubber Product Manufacturing for Mechanical Use
3256	Soap, Cleaning Compound, and Toilet Preparation Manufacturing	326299	All Other Rubber Product Manufacturing
32561	Soap and Cleaning Compound Manufacturing	327	Nonmetallic Mineral Product Manufacturing
325611	Soap and Other Detergent Manufacturing	3271	Clay Product and Refractory Manufacturing
32711	Pottery, Ceramics, and Plumbing Fixture Manufacturing	33121	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel
327111	Vitreous China Plumbing Fixture and China and Earthenware Bathroom Accessories Manufacturing	331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel
327112	Vitreous China, Fine Earthenware, and Other Pottery Product Manufacturing	33122	Rolling and Drawing of Purchased Steel
327113	Porcelain Electrical Supply Manufacturing	331221	Rolled Steel Shape Manufacturing
32712	Clay Building Material and Refractories Manufacturing	331222	Steel Wire Drawing
327121	Brick and Structural Clay Tile Manufacturing	3313	Alumina and Aluminum Production and Processing
327122	Ceramic Wall and Floor Tile Manufacturing	33131	Alumina and Aluminum Production and Processing
327123	Other Structural Clay Product Manufacturing	331311	Alumina Refining
327124	Clay Refractory Manufacturing	331312	Primary Aluminum Production
327125	Nonclay Refractory Manufacturing	331314	Secondary Smelting and Alloying of Aluminum
3272	Glass and Glass Product Manufacturing	331315	Aluminum Sheet, Plate, and Foil Manufacturing
32721	Glass and Glass Product Manufacturing	331316	Aluminum Extruded Product Manufacturing
327211	Flat Glass Manufacturing	331319	Other Aluminum Rolling and Drawing
327212	Other Pressed and Blown Glass and Glassware Manufacturing	3314	Nonferrous Metal (except Aluminum) Production and Processing
327213	Glass Container Manufacturing	33141	Nonferrous Metal (except Aluminum) Smelting and Refining
327215	Glass Product Manufacturing Made of Purchased Glass	331411	Primary Smelting and Refining of Copper
3273	Cement and Concrete Product Manufacturing	331419	Primary Smelting and Refining of Nonferrous Metal (except Copper and Aluminum)
32731	Cement Manufacturing	33142	Copper Rolling, Drawing, Extruding, and Alloying
327310	Cement Manufacturing	331421	Copper Rolling, Drawing, and Extruding
32732	Ready-Mix Concrete Manufacturing	331422	Copper Wire (except Mechanical) Drawing
327320	Ready-Mix Concrete Manufacturing	331423	Secondary Smelting, Refining, and Alloying of Copper
32733	Concrete Pipe, Brick, and Block Manufacturing	33149	Nonferrous Metal (except Copper and Aluminum) Rolling, Drawing, Extruding, and Alloying
327331	Concrete Block and Brick Manufacturing	331491	Nonferrous Metal (except Copper and Aluminum) Rolling, Drawing, and Extruding
327332	Concrete Pipe Manufacturing	331492	Secondary Smelting, Refining, and Alloying of Nonferrous Metal (except Copper and Aluminum)
32739	Other Concrete Product Manufacturing	3315	Foundries
327390	Other Concrete Product Manufacturing	33151	Ferrous Metal Foundries
3274	Lime and Gypsum Product Manufacturing	331511	Iron Foundries
32741	Lime Manufacturing	331512	Steel Investment Foundries
327410	Lime Manufacturing	331513	Steel Foundries (except Investment)
32742	Gypsum Product Manufacturing	33152	Nonferrous Metal Foundries
327420	Gypsum Product Manufacturing	331521	Aluminum Die-Casting Foundries

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3279	Other Nonmetallic Mineral Product	331522	Nonferrous (except Aluminum) Die-Casting Foundries
327910	Abrasive Product Manufacturing	331525	Copper Foundries (except Die-Casting)
32799	All Other Nonmetallic Mineral Product Manufacturing	331528	Other Nonferrous Foundries (except Die-Casting)
327991	Cut Stone and Stone Product Manufacturing	332	Fabricated Metal Product Manufacturing
327992	Ground or Treated Mineral and Earth Manufacturing	3321	Forging and Stamping
327993	Mineral Wool Manufacturing	33211	Forging and Stamping
327999	All Other Miscellaneous Nonmetallic Mineral Product Manufacturing	332111	Iron and Steel Forging
331	Primary Metal Manufacturing	332112	Nonferrous Forging
3311	Iron and Steel Mills and Ferroalloy Manufacturing	332114	Custom Roll Forming
33111	Iron and Steel Mills and Ferroalloy Manufacturing	332115	Crown and Closure Manufacturing
331111	Iron and Steel Mills	332116	Metal Stamping
331112	Electrometallurgical Ferroalloy Product Manufacturing	332117	Powder Metallurgy Part Manufacturing
3312	Steel Product Manufacturing from Purchased Steel	3322	Cutlery and Handtool Manufacturing
33221	Cutlery and Handtool Manufacturing	332913	Plumbing Fixture Fitting and Trim Manufacturing
332211	Cutlery and Flatware (except Precious) Manufacturing	332919	Other Metal Valve and Pipe Fitting Manufacturing
332212	Hand and Edge Tool Manufacturing	33299	All Other Fabricated Metal Product Manufacturing
332213	Saw Blade and Handsaw Manufacturing	332991	Ball and Roller Bearing Manufacturing
332214	Kitchen Utensil, Pot, and Pan Manufacturing	332992	Small Arms Ammunition Manufacturing
3323	Architectural and Structural Metals Manufacturing	332993	Ammunition (except Small Arms) Manufacturing
33231	Plate Work and Fabricated Structural Product Manufacturing	332994	Small Arms Manufacturing
332311	Prefabricated Metal Building and Component Manufacturing	332995	Other Ordnance and Accessories Manufacturing
332312	Fabricated Structural Metal Manufacturing	332996	Fabricated Pipe and Pipe Fitting Manufacturing
332313	Plate Work Manufacturing	332997	Industrial Pattern Manufacturing
33232	Ornamental and Architectural Metal Products Manufacturing	332998	Enameled Iron and Metal Sanitary Ware Manufacturing
332321	Metal Window and Door Manufacturing	332999	All Other Miscellaneous Fabricated Metal Product Manufacturing
332322	Sheet Metal Work Manufacturing	333	Machinery Manufacturing
332323	Ornamental and Architectural Metal Work Manufacturing	3331	Agriculture, Construction, and Mining Machinery Manufacturing
3324	Boiler, Tank, and Shipping Container Manufacturing	33311	Agricultural Implement Manufacturing
33241	Power Boiler and Heat Exchanger Manufacturing	333111	Farm Machinery and Equipment Manufacturing
332410	Power Boiler and Heat Exchanger Manufacturing	333112	Lawn and Garden Tractor and Home Lawn and Garden Equipment Manufacturing
33242	Metal Tank (Heavy Gauge) Manufacturing	33312	Construction Machinery Manufacturing
332420	Metal Tank (Heavy Gauge) Manufacturing	333120	Construction Machinery Manufacturing
33243	Metal Can, Box, and Other Metal Container (Light Gauge) Manufacturing	33313	Mining and Oil and Gas Field Machinery Manufacturing
332431	Metal Can Manufacturing	333131	Mining Machinery and Equipment Manufacturing
332439	Other Metal Container Manufacturing	333132	Oil and Gas Field Machinery and Equipment Manufacturing

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3325	Hardware Manufacturing	3332	Industrial Machinery Manufacturing
33251	Hardware Manufacturing	33321	Sawmill and Woodworking Machinery Manufacturing
332510	Hardware Manufacturing	333210	Sawmill and Woodworking Machinery Manufacturing
3326	Spring and Wire Product Manufacturing	33322	Plastics and Rubber Industry Machinery Manufacturing
33261	Spring and Wire Product Manufacturing	333220	Plastics and Rubber Industry Machinery Manufacturing
332611	Spring (Heavy Gauge) Manufacturing	33329	Other Industrial Machinery Manufacturing
332612	Spring (Light Gauge) Manufacturing	333291	Paper Industry Machinery Manufacturing
332618	Other Fabricated Wire Product Manufacturing	333292	Textile Machinery Manufacturing
3327	Machine Shops; Turned Product; and Screw, Nut, and Bolt Manufacturing	333293	Printing Machinery and Equipment Manufacturing
33271	Machine Shops	333294	Food Product Machinery Manufacturing
332710	Machine Shops	333295	Semiconductor Machinery Manufacturing
33272	Turned Product and Screw, Nut, and Bolt Manufacturing	333298	All Other Industrial Machinery Manufacturing
332721	Precision Turned Product Manufacturing	3333	Commercial and Service Industry Machinery Manufacturing
332722	Bolt, Nut, Screw, Rivet, and Washer Manufacturing	33331	Commercial and Service Industry Machinery Manufacturing
3328	Coating, Engraving, Heat Treating, and Allied Activities	333311	Automatic Vending Machine Manufacturing
33281	Coating, Engraving, Heat Treating, and Allied Activities	333312	Commercial Laundry, Drycleaning, and Pressing Machine Manufacturing
332811	Metal Heat Treating	333313	Office Machinery Manufacturing
332812	Metal Coating, Engraving (except Jewelry and Silverware), and Allied Services to Manufacturers	333314	Optical Instrument and Lens Manufacturing
332813	Electroplating, Plating, Polishing, Anodizing, and Coloring	333315	Photographic and Photocopying Equipment Manufacturing
3329	Other Fabricated Metal Product Manufacturing	333319	Other Commercial and Service Industry Machinery Manufacturing
33291	Metal Valve Manufacturing	3334	Ventilation, Heating, Air-Conditioning, and Commercial Refrigeration Equipment Manufacturing
332911	Industrial Valve Manufacturing	33341	Ventilation, Heating, Air-Conditioning, and Commercial Refrigeration Equipment Manufacturing
332912	Fluid Power Valve and Hose Fitting Manufacturing	333411	Air Purification Equipment Manufacturing
333412	Industrial and Commercial Fan and Blower Manufacturing	33421	Telephone Apparatus Manufacturing
333414	Heating Equipment (except Warm Air Furnaces) Manufacturing	334210	Telephone Apparatus Manufacturing
333415	Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing	33422	Radio and Television Broadcasting and Wireless Communications Equipment Manufacturing
3335	Metalworking Machinery Manufacturing	334220	Radio and Television Broadcasting and Wireless Communications Equipment Manufacturing
33351	Metalworking Machinery Manufacturing	33429	Other Communications Equipment Manufacturing
333511	Industrial Mold Manufacturing	334290	Other Communications Equipment Manufacturing
333512	Machine Tool (Metal Cutting Types) Manufacturing	3343	Audio and Video Equipment Manufacturing
333513	Machine Tool (Metal Forming Types) Manufacturing	33431	Audio and Video Equipment Manufacturing
333514	Special Die and Tool, Die Set, Jig, and Fixture Manufacturing	334310	Audio and Video Equipment Manufacturing

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333515	Cutting Tool and Machine Tool Accessory Manufacturing	3344	Semiconductor and Other Electronic Component Manufacturing
333518	Other Metalworking Machinery Manufacturing	334411	Electron Tube Manufacturing
3336	Engine, Turbine, and Power Transmission Equipment Manufacturing	334412	Bare Printed Circuit Board Manufacturing
33361	Engine, Turbine, and Power Transmission Equipment Manufacturing	334413	Semiconductor and Related Device Manufacturing
333611	Turbine and Turbine Generator Set Units Manufacturing	334414	Electronic Capacitor Manufacturing
333612	Speed Changer, Industrial High-Speed Drive, and Gear Manufacturing	334415	Electronic Resistor Manufacturing
333613	Mechanical Power Transmission Equipment Manufacturing	334416	Electronic Coil, Transformer, and Other Inductor Manufacturing
333618	Other Engine Equipment Manufacturing	334417	Electronic Connector Manufacturing
3339	Other General Purpose Machinery Manufacturing	334418	Printed Circuit Assembly (Electronic Assembly) Manufacturing
33391	Pump and Compressor Manufacturing	334419	Other Electronic Component Manufacturing
333911	Pump and Pumping Equipment Manufacturing	3345	Navigational, Measuring, Electromedical, and Control Instruments Manufacturing
333912	Air and Gas Compressor Manufacturing	33451	Navigational, Measuring, Electromedical, and Control Instruments Manufacturing
333913	Measuring and Dispensing Pump Manufacturing	334510	Electromedical and Electrotherapeutic Apparatus Manufacturing
33392	Material Handling Equipment Manufacturing	334511	Search, Detection, Navigation, Guidance, Aeronautical, and Nautical System and Instrument Manufacturing
333921	Elevator and Moving Stairway Manufacturing	334512	Automatic Environmental Control Manufacturing for Residential, Commercial, and Appliance Use
333922	Conveyor and Conveying Equipment Manufacturing	334513	Instruments and Related Products Manufacturing for Measuring, Displaying, and Controlling Industrial Process Variables
333923	Overhead Traveling Crane, Hoist, and Monorail System Manufacturing	334514	Totalizing Fluid Meter and Counting Device Manufacturing
333924	Industrial Truck, Tractor, Trailer, and Stacker Machinery Manufacturing	334515	Instrument Manufacturing for Measuring and Testing Electricity and Electrical Signals
33399	All Other General Purpose Machinery Manufacturing	334516	Analytical Laboratory Instrument Manufacturing
333991	Power-Driven Handtool Manufacturing	334517	Irradiation Apparatus Manufacturing
333992	Welding and Soldering Equipment Manufacturing	334518	Watch, Clock, and Part Manufacturing
333993	Packaging Machinery Manufacturing	334519	Other Measuring and Controlling Device Manufacturing
333994	Industrial Process Furnace and Oven Manufacturing	3346	Manufacturing and Reproducing Magnetic and Optical Media
333995	Fluid Power Cylinder and Actuator Manufacturing	33461	Manufacturing and Reproducing Magnetic and Optical Media
333996	Fluid Power Pump and Motor Manufacturing	334611	Software Reproducing
333997	Scale and Balance Manufacturing	334612	Prerecorded Compact Disc (except Software), Tape, and Record Reproducing
333999	All Other Miscellaneous General Purpose Machinery Manufacturing	334613	Magnetic and Optical Recording Media Manufacturing
334	Computer and Electronic Product Manufacturing	335	Electrical Equipment, Appliance, and Component Manufacturing
3341	Computer and Peripheral Equipment Manufacturing	3351	Electric Lighting Equipment Manufacturing
33411	Computer and Peripheral Equipment Manufacturing	33511	Electric Lamp Bulb and Part Manufacturing
334111	Electronic Computer Manufacturing	335110	Electric Lamp Bulb and Part Manufacturing
334112	Computer Storage Device Manufacturing	33512	Lighting Fixture Manufacturing

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334113	Computer Terminal Manufacturing	335121	Residential Electric Lighting Fixture Manufacturing
334119	Other Computer Peripheral Equipment Manufacturing	335122	Commercial, Industrial, and Institutional Electric Lighting Fixture Manufacturing
3342	Communications Equipment Manufacturing	335129	Other Lighting Equipment Manufacturing
3352	Household Appliance Manufacturing	33632	Motor Vehicle Electrical and Electronic Equipment Manufacturing
33521	Small Electrical Appliance Manufacturing	336321	Vehicular Lighting Equipment Manufacturing
335211	Electric Housewares and Household Fan Manufacturing	336322	Other Motor Vehicle Electrical and Electronic Equipment Manufacturing
335212	Household Vacuum Cleaner Manufacturing	33633	Motor Vehicle Steering and Suspension Components (except Spring) Manufacturing
33522	Major Appliance Manufacturing	336330	Motor Vehicle Steering and Suspension Components (except Spring) Manufacturing
335221	Household Cooking Appliance Manufacturing	33634	Motor Vehicle Brake System Manufacturing
335222	Household Refrigerator and Home Freezer Manufacturing	336340	Motor Vehicle Brake System Manufacturing
335224	Household Laundry Equipment Manufacturing	33635	Motor Vehicle Transmission and Power Train Parts Manufacturing
335228	Other Major Household Appliance Manufacturing	336350	Motor Vehicle Transmission and Power Train Parts Manufacturing
3353	Electrical Equipment Manufacturing	33636	Motor Vehicle Seating and Interior Trim Manufacturing
33531	Electrical Equipment Manufacturing	336360	Motor Vehicle Seating and Interior Trim Manufacturing
335311	Power, Distribution, and Specialty Transformer Manufacturing	33637	Motor Vehicle Metal Stamping
335312	Motor and Generator Manufacturing	336370	Motor Vehicle Metal Stamping
335313	Switchgear and Switchboard Apparatus Manufacturing	33639	Other Motor Vehicle Parts Manufacturing
335314	Relay and Industrial Control Manufacturing	336391	Motor Vehicle Air-Conditioning Manufacturing
3359	Other Electrical Equipment and Component Manufacturing	336399	All Other Motor Vehicle Parts Manufacturing
33591	Battery Manufacturing	3364	Aerospace Product and Parts Manufacturing
335911	Storage Battery Manufacturing	33641	Aerospace Product and Parts Manufacturing
335912	Primary Battery Manufacturing	336411	Aircraft Manufacturing
33592	Communication and Energy Wire and Cable Manufacturing	336412	Aircraft Engine and Engine Parts Manufacturing
335921	Fiber Optic Cable Manufacturing	336413	Other Aircraft Parts and Auxiliary Equipment Manufacturing
335929	Other Communication and Energy Wire Manufacturing	336414	Guided Missile and Space Vehicle Manufacturing
33593	Wiring Device Manufacturing	336415	Guided Missile and Space Vehicle Propulsion Unit and Propulsion Unit Parts Manufacturing
335931	Current-Carrying Wiring Device Manufacturing	336419	Other Guided Missile and Space Vehicle Parts and Auxiliary Equipment Manufacturing
335932	Noncurrent-Carrying Wiring Device Manufacturing	3365	Railroad Rolling Stock Manufacturing
33599	All Other Electrical Equipment and Component Manufacturing	33651	Railroad Rolling Stock Manufacturing
335991	Carbon and Graphite Product Manufacturing	336510	Railroad Rolling Stock Manufacturing
335999	All Other Miscellaneous Electrical Equipment and Component Manufacturing	3366	Ship and Boat Building
336	Transportation Equipment Manufacturing	33661	Ship and Boat Building
3361	Motor Vehicle Manufacturing	336611	Ship Building and Repairing
33611	Automobile and Light Duty Motor Vehicle Manufacturing	336612	Boat Building

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336111	Automobile Manufacturing	3369	Other Transportation Equipment Manufacturing
33612	Heavy Duty Truck Manufacturing	336991	Motorcycle, Bicycle, and Parts Manufacturing
336120	Heavy Duty Truck Manufacturing	336992	Military Armored Vehicle, Tank, and Tank Component Manufacturing
3362	Motor Vehicle Body and Trailer Manufacturing	336999	All Other Transportation Equipment Manufacturing
33621	Motor Vehicle Body and Trailer Manufacturing	337	Furniture and Related Product Manufacturing
336211	Motor Vehicle Body Manufacturing	3371	Household and Institutional Furniture and Kitchen Cabinet Manufacturing
336212	Truck Trailer Manufacturing	33711	Wood Kitchen Cabinet and Countertop Manufacturing
336213	Motor Home Manufacturing	337110	Wood Kitchen Cabinet and Countertop Manufacturing
336214	Travel Trailer and Camper Manufacturing	33712	Household and Institutional Furniture Manufacturing
3363	Motor Vehicle Parts Manufacturing	337121	Upholstered Household Furniture Manufacturing
33631	Motor Vehicle Gasoline Engine and Engine Parts Manufacturing	337122	Nonupholstered Wood Household Furniture Manufacturing
336311	Carburetor, Piston, Piston Ring, and Valve Manufacturing	337124	Metal Household Furniture Manufacturing
336312	Gasoline Engine and Engine Parts Manufacturing	337125	Household Furniture (except Wood and Metal) Manufacturing
337127	Institutional Furniture Manufacturing	339999	All Other Miscellaneous Manufacturing
337129	Wood Television, Radio, and Sewing Machine Cabinet Manufacturing	42	Wholesale Trade
3372	Office Furniture (including Fixtures) Manufacturing	423	Merchant Wholesalers, Durable Goods
33721	Office Furniture (including Fixtures) Manufacturing	4231	Motor Vehicle and Motor Vehicle Parts and Supplies Merchant Wholesalers
337211	Wood Office Furniture Manufacturing	42311	Automobile and Other Motor Vehicle Merchant Wholesalers
337212	Custom Architectural Woodwork and Millwork Manufacturing	423110	Automobile and Other Motor Vehicle Merchant Wholesalers
337214	Office Furniture (except Wood) Manufacturing	42312	Motor Vehicle Supplies and New Parts Merchant Wholesalers
337215	Showcase, Partition, Shelving, and Locker Manufacturing	423120	Motor Vehicle Supplies and New Parts Merchant Wholesalers
3379	Other Furniture Related Product Manufacturing	42313	Tire and Tube Merchant Wholesalers
33791	Mattress Manufacturing	423130	Tire and Tube Merchant Wholesalers
337910	Mattress Manufacturing	42314	Motor Vehicle Parts (Used) Merchant Wholesalers
33792	Blind and Shade Manufacturing	423140	Motor Vehicle Parts (Used) Merchant Wholesalers
337920	Blind and Shade Manufacturing	4232	Furniture and Home Furnishing Merchant Wholesalers
339	Miscellaneous Manufacturing	42321	Furniture Merchant Wholesalers
3391	Medical Equipment and Supplies Manufacturing	423210	Furniture Merchant Wholesalers
33911	Medical Equipment and Supplies Manufacturing	42322	Home Furnishing Merchant Wholesalers
339112	Surgical and Medical Instrument Manufacturing	423220	Home Furnishing Merchant Wholesalers
339113	Surgical Appliance and Supplies Manufacturing	4233	Lumber and Other Construction Materials Merchant Wholesalers
339114	Dental Equipment and Supplies Manufacturing	42331	Lumber, Plywood, Millwork, and Wood Panel Merchant Wholesalers
339115	Ophthalmic Goods Manufacturing	423310	Lumber, Plywood, Millwork, and Wood Panel Merchant Wholesalers
339116	Dental Laboratories	42332	Brick, Stone, and Related Construction Material Merchant Wholesalers

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3399	Other Miscellaneous Manufacturing	423320	Brick, Stone, and Related Construction Material Merchant Wholesalers
33991	Jewelry and Silverware Manufacturing	42333	Roofing, Siding, and Insulation Material Merchant Wholesalers
339911	Jewelry (except Costume) Manufacturing	423330	Roofing, Siding, and Insulation Material Merchant Wholesalers
339912	Silverware and Hollowware Manufacturing	42339	Other Construction Material Merchant Wholesalers
339913	Jewelers' Material and Lapidary Work Manufacturing	423390	Other Construction Material Merchant Wholesalers
339914	Costume Jewelry and Novelty Manufacturing	4234	Professional and Commercial Equipment and Supplies Merchant Wholesalers
33992	Sporting and Athletic Goods Manufacturing	42341	Photographic Equipment and Supplies Merchant Wholesalers
339920	Sporting and Athletic Goods Manufacturing	423410	Photographic Equipment and Supplies Merchant Wholesalers
33993	Doll, Toy, and Game Manufacturing	42342	Office Equipment Merchant Wholesalers
339931	Doll and Stuffed Toy Manufacturing	423420	Office Equipment Merchant Wholesalers
339932	Game, Toy, and Children's Vehicle Manufacturing	42343	Computer and Computer Peripheral Equipment and Software Merchant Wholesalers
33994	Office Supplies (except Paper) Manufacturing	423430	Computer and Computer Peripheral Equipment and Software Merchant Wholesalers
339941	Pen and Mechanical Pencil Manufacturing	42344	Other Commercial Equipment Merchant Wholesalers
339942	Lead Pencil and Art Good Manufacturing	423440	Other Commercial Equipment Merchant Wholesalers
339943	Marking Device Manufacturing	42345	Medical, Dental, and Hospital Equipment and Supplies Merchant Wholesalers
339944	Carbon Paper and Inked Ribbon Manufacturing	423450	Medical, Dental, and Hospital Equipment and Supplies Merchant Wholesalers
33995	Sign Manufacturing	42346	Ophthalmic Goods Merchant Wholesalers
339950	Sign Manufacturing	423460	Ophthalmic Goods Merchant Wholesalers
33999	All Other Miscellaneous Manufacturing	42349	Other Professional Equipment and Supplies Merchant Wholesalers
339991	Gasket, Packing, and Sealing Device Manufacturing	423490	Other Professional Equipment and Supplies Merchant Wholesalers
339992	Musical Instrument Manufacturing	4235	Metal and Mineral (except Petroleum) Merchant Wholesalers
339993	Fastener, Button, Needle, and Pin Manufacturing	42351	Metal Service Centers and Other Metal Merchant Wholesalers
339994	Broom, Brush, and Mop Manufacturing	423510	Metal Service Centers and Other Metal Merchant Wholesalers
339995	Burial Casket Manufacturing	42352	Coal and Other Mineral and Ore Merchant Wholesalers
423520	Coal and Other Mineral and Ore Merchant Wholesalers	42412	Stationery and Office Supplies Merchant Wholesalers
4236	Electrical and Electronic Goods Merchant Wholesalers	424120	Stationery and Office Supplies Merchant Wholesalers
42361	Electrical Apparatus and Equipment, Wiring Supplies, and Related Equipment Merchant Wholesalers	42413	Industrial and Personal Service Paper Merchant Wholesalers
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Great Lakes Maritime Research Institute

A University of Wisconsin - Superior and University of Minnesota Duluth Consortium

A Review of Great Lakes Shipbuilding and Repair Capability: Past, Present and Future

Final Report

David J Singer 2600 Draper Road
Ann Arbor, MI 48109

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University of Michigan College of Engineering
Department of Naval Architecture and Marine Engineering
2600 Draper Road, Ann Arbor MI 48109

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Executive Summary

The study presented addresses the research area of Economics and Development of the Great Lakes Marine Transportation System and specifically Concepts to Expand Great Lakes Ship Repair and Shipbuilding. The study's goal is to provide an analysis of past, present and potential capabilities for the ship repair and shipbuilding on the Great Lakes that will be useful for future ship repair and shipbuilding research and planning projects.

Preliminary findings have been mixed. The Great Lakes shipbuilding industry has a meaningful history, especially in WWII. Except in a few cases, such as the luxury yacht market, in recent years the Great Lakes has suffered from the same plight as the rest of the U.S. shipbuilding industry. There are only a few viable shipbuilding facilities and repair facilities still in business. Occasionally new companies try to enter the ship repair buisness without much success. Even with protective markets and government contracts, the low and unstable demand and more lucrative business opportunities for local governments the U.S. shipbuilding industry, including the Great Lakes, are not competitive in the international commercial shipbuilding market. To compete in this market significant investments would be needed in the facilities, technology, and people.

Another similarity between the Great Lakes shipbuilding when compared to the U.S. shipbuilding industry is the missed opportunities to gain market share in niche markets such as ferries, high-speed vessels, and unique non-steel vessels. The same factors that made U.S. shipbuilding noncompetitive also eliminated those possible opportunities for the Great Lakes.

From a facility capacity perspective, the Great Lakes region has potential excess capacity. Legacy piers, graving and floating dry docks, and general heavy industry infrastructure exist within the states surrounding the Great Lakes. The major issues that the researchers feel inhibit the viability of Great Lakes shipbuilding are the lack of the necessary skilled labor and technical engineering talent needed to either create a new market or compete in the existing general commercial market. Some have commented that the current U.S. Navy and Coast Guard needs could be used to "jump start" the Great Lakes shipbuilding industry recovery. The authors feel that this is a highly unlikely option given the fact that the government, for national security reasons, needs to focus on the currently operating US shipyards to make them more cost effective.

Even though the expansion of shipbuilding as a major industry within the Great Lakes does not look reasonable if no policy, legislation, or funding changes are made, the ship repair business seems to be viable, but again demand is currently met by existing facilities. As the Great Lakes fleet ages, ship owners are opting to convert and repair the vessels, including major machinery upgrades, instead of replacing the vessels. The skills required to maintain a ship repair business are vastly different than shipbuilding, and are better suited for the seasonally variable employee profile that currently exists in the region.

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1.0 Introduction

The presented study addresses the research area: Economics and Development of the Great Lakes (GL) Marine Transportation System (MTS) and specifically Concepts to Expand GL Ship Repair and Shipbuilding. This report provides a database and analysis of past, present and potential capabilities for the ship repair and shipbuilding business on the Great Lakes. The study will be useful for future ship repair and shipbuilding research and planning projects.

The University of Michigan team has completed a literature search to identify past and current Great Lakes ship repair and shipbuilding facilities. Additionally, they have compiled a list of currently active shipbuilding and ship repair facilities within the Great Lakes.

The final component of the study was the investigation of labor and market conditions within the Great Lakes region as well as the U.S. to analyze the future of Great Lakes shipbuilding and ship repair. Recommendations are given concerning the potential growth of ship repair and shipbuilding opportunities in the Great Lakes.

This research provided a report and a reference database for Great Lakes ship repair and shipbuilding capabilities that documents their past, present and future potential. The database will be provided to the GLMRI to make it available on their website to be accessible for all future research in the area of Great Lakes ship repair and shipbuilding.

2.0 Great Lakes Shipbuilding History

While the Indians surrounding the Great Lakes and its rivers undoubtedly built canoes and even larger boats, shipbuilding did not begin until the European settlers/explorers came to the shores of the Great Lakes. The early French explorers built larger flat bottom boats propelled by oars with auxiliary single sail (more like barges) to aid in their exploration, and the British colonists built small sailing ships.

Naval ships for the British Royal Navy were built in the Great Lakes before the American Revolution for operation on the Great Lakes. The Great Lakes shipbuilding industry contributed to both World Wars and has seen a sharp decline since the end of the last world war.

The following history presented in the remainder of this section from 1776 to 1935, is extracted from the Minnesota Marine Historical Society which was adapted from the National Register's Multiple Property Documentation (MPDF) "Minnesota's Lake Superior Shipwrecks A.D. 1650-1945" (19).

2.1 The Beginning

Sailing craft on the Great Lakes date to the first ships constructed on Lake Ontario in the 17th century. The first ships on the Lakes were built at Lake Ontario due to the natural barriers posed by the St. Lawrence River rapids and the falls at Niagara. Robert Sieur de La Salle built the 70-foot "galliot" GRIFFIN above Niagara Falls in 1679, inaugurating navigation on the upper Great Lakes. Louis Denis, Sieur de la Ronde, French Commandant at Chequamegon, built a sailing craft on Lake Superior around 1734 to exploit the copper of Keweenaw Point and Isle Royale. By the 1740s, the French had four ships on Lake Ontario. The British had begun shipbuilding there as well, in order to assert their influence over the lucrative and growing fur trade.

All the earliest Great Lakes' craft were brigs, schooners, or sloops of traditional European design. Naval personnel probably designed the ships in either France or England. Between 1756 and 1763, the British and French were involved in the Seven Years' War. Shipbuilding during that period followed Admiralty designs.

Not long after the French surrendered Canada in 1763, the British built two small schooners at Navy Island on the Niagara River. The HURON and MICHEGON, each of 80 tons, were the first British craft of any description on the upper Great Lakes. The British built two more schooners in 1766. For the next 19 years, Lakes navigation was restricted to British naval craft. Private enterprise was officially throttled. Merchants and traders were required to ship all their cargoes on government ships manned by the Royal Navy under the title of "Provincial Marine". The British licensed a limited number of privately owned ships, including a barge and a 40-ton sloop that had been built on Lake Superior in 1772 for an English copper-mining syndicate. In the early 1770s, there were only 16 vessels on all of the Great Lakes, including five operating on Lake Ontario and nine on Lake Erie. Others would soon follow despite the policies of the British government. By 1778, fur trader John Askins of Michilimackinac was operating the schooners MACKINAC and DEPEYSTER on Lake Superior between Grand Portage and the Sault Ste.

Marie. With the fur trade flourishing in the West and settlement spreading around Lake Ontario, British merchants protested the prohibition against merchant shipping.

2.2 American Revolution

The Lake Champlain Continental Navy fleet, one of the earliest U.S. fleets, was built during the American Revolution.

The 1812 conflict on the Lakes centered on the massive shipbuilding programs by both sides. Though square-rigged ships tended to be faster under the right conditions, they proved to be a disadvantage on the Lakes. Experience also demonstrated that shallow-draft vessels were as safe and efficient as the traditional deep-draft ships.

After the War of 1812, schooners became the predominant vessels on the Lakes. Most of the merchant ships between 1800 and 1830 were two-masted schooners of about 70 feet in length and 100 tons register. They carried approximately 150 tons or 1,500 barrels of cargo with a crew of three or four men. Brigantines combined the best features of both square and fore-and-aft rigs, and became popular in the 1830s and 1840s. They required crews of eight to ten men and were not as maneuverable as schooners. As a result, few brigs or brigantines were built after 1850 because they were too expensive to outfit and operate when compared with the simpler schooners. The most practical and profitable rig was the topsail schooner, designed for fast trips with heavy payloads (characteristic of square rig) and maneuverability with limited crew. As the rigs of Lakes craft became somewhat standardized in the 1830s and 1840s, a similar trend developed with the hulls. Hull form was determined by geographical conditions and by the configuration and dimension of navigation locks in places like the Welland Ship Canal. Sturdy ships were built with full shapes and flat bottoms to squeeze through the shallow spots and the locks with as much cargo as possible. They were invariably fitted with "centerboards" to improve their sailing qualities. With straight sides and box-like forms, they resembled canal boats and earlier coastal packets. The ships were the models for the early 20th century bulk freighters. The distinctive "canallers" were characterized by their shapes and their dimensions, which conformed to those of the locks themselves. The first Welland Canal, completed in 1832, had locks 100 feet long and 16 feet wide. The "Second Welland," opened in 1845, had 150-foot by 26-foot locks. Canallers built for the second Welland were probably the first distinctly "Lakes" vessel type. In the early 1860s there were reportedly more than 750 canal schooners on the Lakes out of a total of nearly 1,300 sailing craft. The canallers were the backbone of the Great Lakes fleet.

The 1840s and 1850s were prosperous times for the country and for the Midwest. Unfortunately, the great boom ended in the Panic of 1857, which prostrated the nation's economy for the next several years and ruined most of its financial institutions. The Civil War years marked the slow steady recovery from the terrible effects of the depression. With the 1860s, commerce shifted in the Great Lakes. Railroads had penetrated the West and cut into the profitable freight businesses. There were still enormous quantities of foodstuffs and raw materials to be transported by ships, but the lucrative package cargo had decreased. At the same time, bulk cargoes such as salt, grain, coal, and lumber were increasing.

One type of sailing vessel which became popular on the Lakes was the scow schooner. Scows were introduced around 1830. They were shallow craft with flat bottoms and hard chines (square bilges), although they varied in bow and stern configurations. Scows were simply designed and cheaply built. They were popular for the shallowest, poorest ports in the lumber, cordwood, tanbark, sand, or hay trades. A handful of scows were used on Lake Superior, but they were most common on Lake St. Clair, Lake Michigan, and on the Bay of Quinte on Lake Ontario. Some scows survived as late as 1920.

Before and after the Civil War, strong markets for grain and lumber resulted in a shipbuilding boom that began in the mid-1850s and lasted until the late 1860s. Several hundred schooners were built during this period. Many of these ships were 150 feet to 160 feet in length, with almost double the capacity of the canallers. Some of the larger craft built in the Civil War era were fitted out as barkentines, with square sails forward and schooner-rigged main and mizzen masts. These speedy ships were well suited to the competitive Buffalo and Lake Michigan grain trade, where several set records for fast passages. According to contemporary newspaper articles, they could make up to 15 miles an hour for short periods, though they generally averaged less than half that speed. A 15 day round trip from Buffalo to Milwaukee or Chicago and back was considered good time.

After 1880, many builders incorporated iron and steel into the fabric of wooden ships in the form of reinforcing rods and straps, brackets, or plates at critical locations in the hull. In general, ships grew larger as shipbuilding technology improved through the 19th century. The dimensions of Lakes vessels were always limited, however, by the shallow connecting channels and harbors. When the infamous shoals were dredged at the St. Clair Flats in the late 1860s, a whole fleet of large schooners was built for the grain and iron ore trades, including 200 big three-masters and a few four-masters. The new schooners, 200 feet in length and drawing 16 feet, were constructed between 1870 and 1874, until a financial panic ended the temporary boom. Only for a little while longer would the large capacities of the new schooners enable them to compete with the growing fleets of steam-powered freighters.

Very few full-rigged sailing vessels were built on the Lakes after 1880. The last large schooner was launched in 1889. Sailing craft built after that date were all rigged with short masts, and were intended as tow-barges. Some of those built after 1890 measured up to 300 feet in length. Some of the old schooners continued under sail into the 20th century, but few made any money. There was only a handful left after 1920. The schooners OUR SON and LYMAN M. DAVIS lasted into the 1930s. They were the last working survivors of nearly 25,000 of their type.

The first steamboat on the upper Lakes was the 338-ton WALK IN THE WATER. It was built at Black Rock (Tonawanda), New York, for the Lake Erie Steamboat Company. Its machinery was designed by Robert Fulton. Acceptance of steamboats was slow among Lakes vessel owners. Trade in the 1820s was not yet large enough to justify the large investment required to build steamers, so most vessel owners built and operated sailing craft. After completion of the Erie Canal in 1825, however, the commerce of the region grew. The burgeoning passenger traffic offered sufficient returns to justify the more costly steamboats. In the 13 years previous to the opening of the Canal, 25 steamboats had been constructed. In the four years after completion of the canal, 60 new steamboats were built, primarily at Lake Erie ports which connected directly with the Erie Canal.

By 1840, there were more than 100 steamers in service on the Lakes. Most were less than eight years old. About 40 of these craft operated as ferries or on short local routes out of the larger ports. The remainder, principally the larger boats, ran from Buffalo to upper Lakes ports or from Niagara and Toronto to lower Lakes or St. Lawrence River destinations. Most paddle-wheelers carried one, two, or even three masts until about 1850. These were often fitted with sails and jibs. The later screw propelled steamers continued to use sails until after 1870. Some screw freighters carried sails until almost 1900.

The advances in shipbuilding technology during the 1840s brought dramatic changes to the steamboat fleet. The first 1,000-ton steamer in the nation, the 260-foot EMPIRE, was built on the Lakes in 1844. The lavish vessel ushered in the era of "Palace Steamers," which was to last until 1855. Construction of such large craft was possible with the development of new fastenings for wooden hulls, the expanded use of ironwork for strengthening, and the introduction of "hogging-frames" and trusses. The magnificent Palace Steamers of the later 1840s and early 1850s were the most beautifully-appointed craft ever built on the Lakes. In all, there were 25 of them. Most were between 1,000 and 1,600 tons. The CITY OF BUFFALO, built in 1857, was the last and largest of them. It measured 350 feet in length and was 2,026 tons burthen. Most of the Palace Steamers ran from Buffalo to Detroit or Chicago. Only the smallest could fit through the Sault Locks when they were opened in 1855. The passenger business revived after the Civil War, but it was never again able to sustain ships as luxurious as the Palace Steamers. The steamers built for the post-war passenger trade were more modest in size and furnishings.

The development of side-wheel steamers was stemmed by the rapid ascendancy of screw steamers in the various trades. Though side-wheel steamers remained popular in the passenger trade for many decades, they would never again achieve the numbers of the 1830s and 1840s. Side-wheelers reached their zenith between 1845 and 1857 with the 300-foot Palace Steamers. A few paddle-wheel giants were built on the Lakes after 1900, including the 520-foot twins Greater Detroit and Greater Buffalo of 1924, which were the largest side-wheelers ever built. When they entered service, only 37 others were left. After 1950, they were all gone.

The 105-foot screw propelled INDEPENDENCE was brought to Lake Superior in 1845. It was the first steamer of any kind to sail that body of water. The INDEPENDENCE had been built two years earlier at Chicago, and like several other vessels, it was hauled around the falls at Sault Ste. Marie on rollers and launched into Lake Superior many years before the Sault Locks were built.

The number of screw propelled ships on the Lakes grew rapidly and revolutionized the carrying trades. Several companies organized around 1850 to build fleets of screw steamers to carry freight in connection with the Erie Canal, or with the various railroads running to the seaboard from the eastern end of the Lakes. Between 1840 and 1849, 81 propellers were built at Great Lake shipyards. During the next ten years, 133 more were added and during the 1860s another 88 were built, not including screw tugs.

Screw propelled steamers, including passenger ships and package freighters, grew in size during the 19th century, along with deepening channels and improvements in shipbuilding technology. The average size grew from 141 feet (337 tons) in 1845, to 182 feet (641 tons) in 1862 and 220 feet (1,300 tons) in 1877. Forty-five steam barges were built before 1870. Nearly 600 steam barges were built between 1870 and 1900.

While bulk freighters became more numerous in the 1880s and 1890s, other vessel types dwindled and eventually disappeared. Sailing craft were entirely displaced by steamers, except in the lumber trade, where they found a niche in later years as tow barges, though their rigging was cut away and their graceful bowsprits cut short. Steam barges lasted only as long as the lumber trade on the Lakes. When the lumber business moved to the Pacific coast around 1910, the use of steam barges on the Lakes declined sharply after that, although they became widespread along the California, Washington, and Oregon coasts. Most of the steam barges were simply abandoned and dismantled. Some steam barges were used to carry salt, coal, sand, and lumber products on the Lakes, but few survived past the 1920s.

After 1880, relatively few large screw propelled ships were built. Many of those were exclusively passenger ships, with limited cargo space or no freight capacity at all. Most of them were "day boats", excursion steamers with neither overnight accommodations nor cargo space. A dozen passenger ships survived the opening of America's highway networks in the 1930s, but the last of them succumbed to economic pressures and regulatory requirements and were laid up in the mid-1960s. The Georgian Bay Line steamer SOUTH AMERICAN was the last active representative of its type. It retired at the end of the 1967 season.

Iron was used experimentally to build ships' hulls in Scotland and England before 1800, but it was not readily adopted. The U.S. Navy and the Revenue Service ordered iron vessels in the early 1840s. Despite the advantages of iron hulls, however, Great Lakes shipbuilders did not begin iron shipbuilding until after 1860. The practice was not widely accepted until 1880. The first large commercial vessel built of iron on the Lakes was the MERCHANT, a 200-footer launched in July 1862 at Buffalo, New York. Other iron steamers came after 1868, when two firms ordered twelve large iron and package freighters within a few years. By 1885, several respected fleets owned iron ships and there were four fully-equipped iron shipbuilding firms in operation.

Iron proved to be a very practical medium for the construction of ship's hulls. It was far stronger pound-for-pound than the traditional white oak. A structural member made of iron reportedly had only three-eighths the weight and one-eighteenth the volume of its wooden counterpart. Iron hulls were more expensive to build, but they lasted longer than wood, were easier to repair, and were virtually maintenance-free. Mild steel was introduced in the mid-1880s. Though costlier than iron, it was tougher and more resilient. Steel became the standard for shipbuilding after 1885, though some builders continued to use wood until the turn-of-the-century. The last large wooden passenger and package freight steamers were built in 1892.

In Great Lakes shipbuilding, iron and steel came into general use after the popularity of sailing craft had begun to decline. As a result, there were no schooners built of those materials. During the mid-1890s, however, approximately 30 steel tow-barges were built for various fleets as consorts to modern steel freighters. Most of these barges were unpowered versions of the contemporary steam bulk freighters. Some were eventually given engines and converted into typical steamers. The use of tow-barges declined after 1920, though some of these direct descendants of the old schooners survived as late as the 1960s.

Captain Elihu M. Peck designed a variant of the steam barge in 1869 to meet the requirements of the iron ore and grain trades. Peck designed a double-decked vessel with plenty of space below decks for dry bulk cargo, fitted with wide deck hatches evenly spaced to match the 24-foot spacing of the loading chutes at Marquette's ore docks. His vessel had a capacity for 1,200 tons of ore and enough power to tow one or two loaded barges. The result was the 210-foot "bulk freighter", ROBERT J. HACKETT. Bulk freighters had their pilothouses mounted forward to maximize visibility. Their machinery, like that of the steam barges, was placed in the stern. Most bulk freighters had three or four tall masts. They carried sails until around 1890.

Bulk freighters were profitable because they carried large quantities of bulk commodities economically. Few bulk freighters measured less than 200 feet in length. These long, narrow shoal-draft steamers were characterized by very heavy longitudinal framing. From the time the ROBERT J. HACKETT was launched in 1869, until shipbuilding was suspended in the Panic of 1873, 47 bulk freighters averaging just over 1,000 gross tons were constructed. The V.H. Ketchum, built in 1874, was the largest in the fleet at 12,661 gross tons. When shipbuilding resumed again in 1880, even larger bulk freighters were launched. During the 1880s alone, 170 were built. Almost without exception, each had at least one consort barge built to run with it, usually of similar dimensions and tonnage. The typical bulk freighter built in 1890 was of 2,200 gross tons and averaged 260 feet in length. The growth in vessel size was facilitated by improvements to shipping channels and locks.

The first bulk freighter built of iron was the "monster" steamer ONOKO, a 287-foot giant, almost 30 feet longer than the largest wooden craft then afloat. The novel craft had double-bottoms with water-ballast tanks and was designed to carry 3,000 tons of ore on a 14-foot draft. It created quite a sensation. It was said that the ONOKO made money when few other craft in the industry could generate profits. It averaged $25,000 to $40,000 annually. For nearly ten years, the ONOKO carried the largest cargoes on the Lakes. The SPOKANE was built of mild steel in 1885. Soon afterward the industry adopted steel for all subsequent vessel construction.

From 1869 to 1902, the largest wooden bulk freighters grew from 210 feet to 310 feet in length. Iron and steel freighters grew from the 287-foot ONOKO in 1882, to the 400-foot VICTORY in 1894, the 500-foot JOHN W. GATES in 1900, and numerous 600-footers by 1906.

After 1894, the shipbuilding industry began producing steel tow-barge consorts for the powerful new steamers. The barges were copies of the steam bulk freighters, often with the same dimensions, though not fitted with boilers or engines. Like their wooden forebears, they were towed up and down the Lakes. Thirty of these barges were constructed between 1894 and 1902, ranging from 350 to more than 500 feet in length. Some steamers towed barges in the grain trade as late as 1965. A few of the big barges were ultimately fitted with engines and converted into powered freighters.

Steel ships continued to grow after the turn-of-the-century with improvements in technology and changes in the methods of hull-framing. The earliest iron and steel ships had transverse (crosswise) framing, not unlike wooden ships, but spaced at wider intervals. The standard since 1920 has been a system of longitudinal framing on the deck and bottom, with transverse framing in the sides. This system, with its particular emphasis on longitudinal strength, has enabled vessels to grow in size to 640 feet during the Second World War, 730 feet in 1958, and, with the construction of enormous new locks at Sault Ste. Marie, to 1,000 feet by 1973.

The introduction of small craft into Minnesota's North Shore was concurrent with the earliest settlement. Virtually all of the pioneer settlers came to the North Shore in water craft. Canoes and Mackinaw boats carried settlers from Superior City and Duluth. Others arrived in the large steamboats plying Lake Superior from Sault Ste. Marie. After 1880, when coasting steamers ran up the shore from Duluth, fewer travelers used small craft for long-distance trips. Small boats were employed locally and in commercial fishing.

Small, 12-foot to 16-foot skiffs were locally built at Duluth and North Shore settlements after 1870. Boat-builders are mentioned at Grand Portage and Grand Marais in the 1880s, and at Hovland, Cross River, Tofte, and Grand Marais in the 1890s. Although there are few descriptions of these boats, surviving photographs show plank-built, flat-bottomed rowing skiffs with Scandinavian characteristics and clinker built, round-bottomed boats in the more protected waters. The earliest builders were Frenchmen. After the 1880s, however, most builders were Norwegian immigrants.

A few yachts, principally sailing boats, are mentioned in Duluth newspapers in the 1880s. Occasional steam yachts were also noted. Most ranged from 20 feet to 30 feet, though one or two of the more luxurious craft ranged up to 70 feet in length. The growth of boat clubs in the 1880s and 1890s fostered the development of pleasure boating, particularly in the Twin Ports. Extensive clubhouses, warehouses, docks, and bleachers were constructed to accommodate Club members. Frequent regattas and competitions were scheduled.

Standardized "one design" sailboats appeared soon after the turn-of-the-century. Intended for amateur racing, they included a broad range of designs. Many were very modest boats. The one-design classes originated not only to maximize and regulate competition between boats, but also to minimize the cost of designing and building them. The system made boating more affordable to many people. Dozens of sailboat designs resulted from the movement. Some classes were more suitable than others for specific areas. There were few large one-design sailing boats around western Lake Superior, but the less-pretentious 22-foot Star-class, 28-foot and 38-foot Bilge board Scows ("Pancakes"), and 21-foot Shore Bird sloops were fairly common. Although these boat types originated around 1910, they did not appear in the Twin Ports until the mid-1920s. Similar craft were brought to nearby inland lakes in the 1930s.

Steam and naphtha launches appeared in the 1890s. Gasoline launches followed not long afterwards. These were open boats with awnings, measuring from 20 to 35 feet in length. The Pearson Boat Works was organized at Duluth in 1895 to build small powerboats. It became an important source for such boats for 20 years.

The Great Lakes did not suffer from foreign competition because it was land locked. In 1888 and 1889 Great Lakes shipbuilders were building over half (101,000 GT, 225 ships) of the U.S. merchant ship tonnage but this was as much due to the decline in seaboard construction from a high of 505,000 Gross Tons (1,624 ships) to 110,000 (700 ships) as the increase in the Great Lakes. The Great Lakes shipbuilders were also responsible for some of the significant improvements in shipbuilding at that time, including the mechanism of some of the processes and the application of the assembly line to shipbuilding. The Great Lakes shipbuilders had their maximum output of 505,000 GT (317 ships) in 1919 at which time the total U.S. output was 3,326,000 (1,953 ships). They even resorted to creative solutions for ships larger than could transit the canal system at that time by building the ships in parts and joining them after they had passed the Welland Canal.

Table 2.2.1: Great Lakes Shipyard Activity 1900 to 1944 (25)

Yard and location	Years during which each shipyard was able to deliver steel merchant ships, or actually delivered large size naval vessels* as indicated below																																													
	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945
American Shipbuilding Co., Buffalo, N. Y. (1)	x	x	x	x	x	x	x	x	x	x								x	x	x																										
American Shipbuilding Co., Cleveland, O.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
American Shipbuilding Co., Lorain, O.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
American Shipbuilding Co., Wyandotte, Mich. (2)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x																						
American Shipbuilding Co., Superior, Wis. (3)			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x																										
American Shipbuilding Co., Chicago, Ill. (4)		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x																									
W. I. Babcock, Chicago, Ill.	x																																													
Walter Butler Shipbuilders, Inc., Duluth, Minn. (5)																			x	x	x																						x	x	x	
Walter Butler Shipbuilders, Inc., Superior, Wis. (6)																	x	x	x	x																							x	x	x	
Defoe Shipbuilding Co., Bay City, Mich. (7)																																				x	x	x	x	x	x	x	x	x	x	
James Davidson, West Bay City, Mich.			x	x																																										
Cargill, Inc., Savage, Minn.																																											x	x	x	
Dravo Corp., Pittsburgh, Pa.																				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
W. E. Fitzgerald, West Bay City, Mich.	x	x																																												
Froemming Bros., Milwaukee, Wis.																																											x	x	x	
Globe Shipbuilding Co., Superior, Wis.																																											x	x	x	
Great Lakes Engineering Works, Ashtabula, O.													x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Great Lakes Engineering Works, River Rouge, Mich. (8)					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Great Lakes Engineering Works, St. Clair, Mich. (9)						x	x	x	x	x	x																																			
Jenks Shipbuilding Co., Port Huron, Mich.	x	x	x	x																																										
Manistee Shipbuilding Co., Manistee, Mich.																				x	x																									
Manitowoc Shipbuilding Corp., Manitowoc, Wis.																				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Saginaw Shipbuilding Co., Saginaw, Mich.						x	x	x	x	x	x																																			
Leathem D. Smith Shipbuilding Co., Sturgeon Bay, Wis.																				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Sturgeon Bay Shipbuilding & Dry Dock Co., Sturgeon Bay, Wis. (10)																									x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Toledo Shipbuilding Co., Toledo, Ohio (11)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Robert M. Wallace, West Bay City, Mich.			x																																											
West Bay City Shipbuilding Co., West Bay City, Mich.		x	x	x	x	x	x	x	x																																					
Louis Williams, West Superior, Wis.	x	x	x	x																																										

* Merchant ships: Steel, self-propelled, 2000 gross tons minimum.
Naval ships: Battleships, aircraft carriers, cruisers, destroyers, destroyer escorts, frigates, gunboats, submarines.
(1) Includes Buffalo Dy Dock Company, Buffalo, N. Y.
(2) Includes Detroit Shipbuilding Company, Wyandotte, Mich.
(3) Includes Superior Shipbuilding Company, Superior, Wis.
(4) Includes Chicago Shipbuilding Company, Chicago, Ill.
(5) Includes McDougall-Duluth Shipbuilding Company and Barnes-Duluth Shipbuilding Company.
(6) Includes Lake Superior Shipbuilding Company: Globe Shipbuilding Company and Whitney Bros. Towing and Wrecking Company.
(7) Formerly Defoe Boat & Motor Works. Firm in business since 1920.
(8) Includes Great Lakes Engineering Works, Ecorse, Mich.
(9) Includes St. Clair Engineering Works, St. Clair, Mich.
(10) Includes Riebolt, Walter Company, Sturgeon Bay, Wis.
(11) Includes Craig Shipbuilding Company, Toledo, O., (1900-1905).
Source: Shipbuilders Council of America, 21 West Street, New York, N. Y.

2.3 World War I

During Word War I the Great Lakes shipbuilders were very active. They produced many support vessels as well as smaller military ships. Great Lake States were also suppliers of machinery and equipment for the whole of the U.S. shipbuilding industry as can be seen from Table 2.3.1 on the following page.

Table 2.3.1: Machinery Supplied by Great Lakes to U.S (25)

	Machinery	Structural iron and steel	Lumber, cork and rubber	Metal fixtures, fittings and valves	Electrical equipment	Brass, lead and zinc	Paint and interior decoration	Insulation, deck-covering and tiling	Galley and pantry outfit	Furniture	Bedding linen and drapes	Hardware and tools	Fire prevention and interior communication	Life saving equipment	Blocks and rigging	Navigating outfit
Alabama		★	★								★					
Arizona	★					★		★								
Arkansas			★								★					
California	★	★	★				★	★					★	★	★	★
Colorado				★		★										
Connecticut	★			★					★			★	★			
Delaware	★	★						★	★					★		
Florida			★				★									
Georgia								★		★	★					
Idaho			★			★										
Illinois	★			★								★				
Indiana	★		★		★											
Iowa								★		★						
Kansas	★					★			★							
Kentucky			★				★		★						★	
Louisiana			★				★				★				★	
Maine	★		★													
Maryland		★				★		★							★	
Massachusetts	★			★			★				★	★	★	★	★	★
Michigan	★			★	★			★				★				
Minnesota		★	★								★					
Mississippi			★				★				★					
Missouri	★					★										
Montana						★		★			★					
Nebraska						★		★			★					
Nevada						★			★							
New Hampshire	★							★	★							
New Jersey	★						★			★			★	★		★
New Mexico						★	★				★					
New York	★				★				★	★		★	★	★		★
North Carolina			★			★				★	★					
North Dakota							★	★			★				★	
Ohio	★	★		★					★							★
Oklahoma						★	★		★							
Oregon			★							★						
Pennsylvania	★	★		★			★							★	★	★
Rhode Island	★			★	★							★				★
South Carolina	★						★				★					
South Dakota						★	★				★					
Tennessee	★	★	★								★					
Texas			★				★	★			★					
Utah						★		★			★					
Vermont	★			★				★				★				
Virginia	★	★				★	★				★					
Washington	★		★				★			★					★	
West Virginia	★	★					★									
Wisconsin	★	★	★			★										
Wyoming		★				★	★	★			★					

FIG. 8.—SOME PRINCIPAL MATERIALS FURNISHED BY VARIOUS STATES IN SHIPBUILDING

In 1918 in the Great Lakes, the maximum number of shipyards (29) and building berths (153) in comparison to the total for the U.S. shipyards (243) and building berths (1202). In 1944, of the Great Lakes shipyards, 23 were capable of building ships up to 300 feet, 23 up to 400 and 14 over 500 feet. This was a 200% increase over what was in existence in 1939. Of these over half were graving docks and there were only 4 small floating docks. Table 2.3.2 gives details of the Great Lakes shipyard building/launching methods and capacities during that time.

Table 2.3.2: Dry Docks and Marine Railways (200' or more) in Private Ship Repair Yards MR designates marine railways; G, graving docks; F, floating docks (2)

Great Lakes and Rivers

Company and location	Type and No.	Lifting capacity, tons	Length, ft	Width, ft	Depth, ft	Notes
American Bridge Co., Ambridge, Pa.	MR	300	200	40	4	
American Shipbuilding Co., Buffalo, N. Y.	G No. 1	.....	470	59	13	
	G No. 2	.....	630	71	14	
	G No. 3	.....	401	49	14	
American Shipbuilding Co., Chicago, Ill.	G No. 1	.....	569	52	15	
	G No. 2	.....	727	78	15	
American Shipbuilding Co., Lorain, O.	G No. 1	.....	586	60	14	
	G No. 2	.....	736	75	14	
American Shipbuilding Co., Superior, Wis.	G No. 1	.....	609	61	16	
	G No. 2	.....	620	61	19	
Davis Boat Co., Trenton, Mich.	MR*	200	250	24	9	
Dravo Corp., Pittsburgh, Pa.	MR	3,600	300	375	10	Side haul
Erie Concrete & Steel Supply Co., Erie, Pa.	MR*	400	544	26	..	Side haul
A. Gilmore, Toledo, O.	G	.....	240	55	9	Not in use
Great Lakes Engineering Works, Ashtabula, O.	G	...	630	72	16	
Great Lakes Engineering Works, River Rouge, Mich.	F	8,000	627	87	16	
Hillman Barge & Construction Co., Alicia, Pa.	MR*	900	256	40	9	
Ingalls Shipbuilding Corp., Decatur, Ala.	MR	600	200	60	..	
Kewaunee Shipbuilding & Engineering Co., Kewaunee, Wis.	MR*	600	300	16	..	
Koppers Co., Paducah, Ky.	MR	1,800	400	375	8	Side haul
	MR	800	300	60	6	
Madison Marine Ways, Madison, Ind.	MR	2,000	250	60	10	Side haul
Manitowoc Shipbuilding Co., Manitowoc, Wis.	F	6,000	603	88	15	
Mound City Shipyard & Dock Co., Mound City, Ill.	MR	1,600	300	56	10	Side haul
Nashville Bridge Co., Nashville, Tenn.	MR	300	200	36	5	
	MR	300	200	36	5	
State of New York, Lyons, N. Y.	G	.....	370	150	12	
Odenbach Shipbuilding Corp., Rochester, N. Y.	G*	.....	1,400	50	10	
Peterson Boat Works, Sturgeon Bay, Wis.	MR*	150	500	9	12	
	MR*	50	250	9	6	

	MR*	70	250	9	8
Rochester Boat Works, Rochester, N. Y.	MR*	90	500	7	22
St. Louis Shipbuilding & Steel Co., St. Louis, Mo.	MR*	1,200	220	50	9
	MR*	1,200	220	50	9
	MR*	1,200	220	50	9
Toledo Shipbuilding Co., Toledo, O. (now Delta Shipbuilding Co.)	G No. 1	.....	649	90	14
	G No. 2	.....	560	80	13
Wheeling Steel Corp., Steubenville, O.	F*	500	219	37	12

* Indicates facilities added after 1939.

2.4 World War II

During World War II the Great Lakes shipyards increased its number of workers 15 times that of the pre war effort. This is shown in Figures 2.4.1 and 2.4.2. The WWII achievements of Great Lake shipyards was significant, though not as spectacular as other new Maritime Commission shipyards as can be seen from the Table 2.4.1. Table 2.4.1 shows the delivery of self propelled ships from 1939 to 1945. During that time period the Maritime Commission established seven new shipyards in the Great Lakes region. The locations of those yards are shown in Figure 2.4.3.

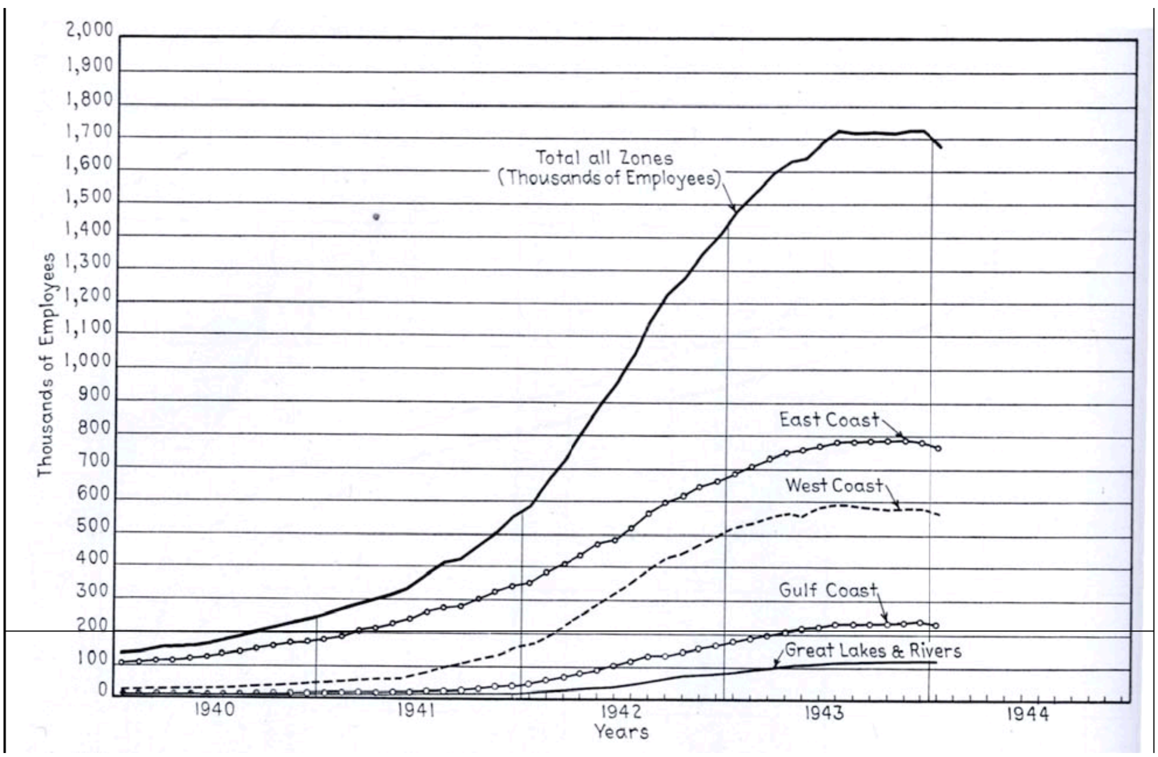


Figure 2.4.1: Employment in Private and Naval Shipyards (20)

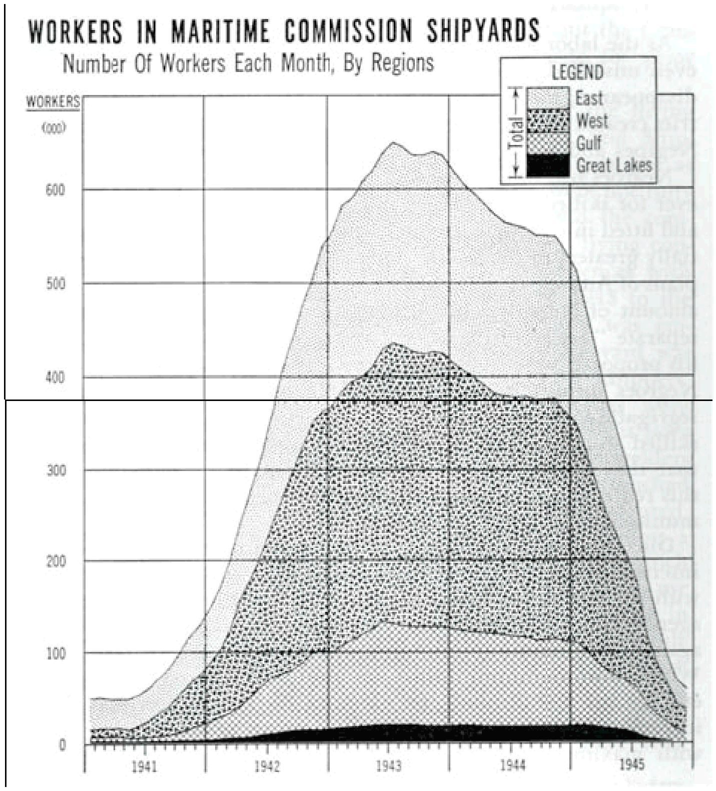


Figure 2.4.2: Manning Levels at the Shipyards by Region. (20)

Table 2.4.1: Merchant Ship Construction in WWII (20)

Number and gross tonnage of steel self-propelled merchant ships over 2,000 gross tons each constructed in the United States during 1939-1945, inclusive

State or Zone	Years	Total No.	Total Gross tons	Cargo No.	Cargo Gross tons	Tanker No.	Tanker Gross tons	Passenger & cargo No.	Passenger & cargo Gross tons
Alabama	1940–45	161	1,418,708	57	366,564	104	1,052,144	...	......
California	1940–45	1,593	11,674,897	1,394	9,811,642	108	1,031,861	91	831,394
Delaware	1942–45	19	97,166	19	97,166	...	....	...	......
Florida	1940, 43–45	211	1,396,791	201	1,364,171	10	32,620	...	......
Georgia	1943–45	197	1,335,334	197	1,335,334	...	....	...	......
Louisiana	1942–45	196	1,352,720	164	1,121,744	32	230,976	...	......
Maine	1941–45	278	1,992,384	278	1,992,384	...	....	...	......
Maryland	1939–45	576	4,377,663	503	3,657,328	67	672,476	6	47,859
Massachusetts	1939–42	20	167,551	8	53,888	9	83,600	3	30,063
Michigan	1942–43	9	85,224	9	85,224	...	....	...	......
Minnesota	1941, 43–45	26	99,713	18	68,490	8	31,223	...	......
Mississippi	1941–45	68	565,108	61	481,288	...	....	7	83,820
New Jersey	1939–45	87	786,071	66	489,399	10	100,693	11	195,979
New York	1940–41	6	36,334	5	33,989	1	2,345	...	......
North Carolina	1942–45	232	1,780,286	232	1,780,286	...	....	...	......
Ohio	1942–43	12	109,364	12	109,364	...	....	...	......
Oregon	1941–45	603	4,861,895	456	3,326,067	147	1,535,828	...	......
Pennsylvania	1939–45	289	2,941,801	40	379,699	249	2,562,102	...	......
Rhode Island	1943–45	43	272,824	43	272,824	...	....	...	......
Texas	1942–45	309	1,952,217	295	1,907,977	14	44,240	...	......
Virginia	1939–45	31	330,093	7	52,233	16	186,583	8	91,277
Washington	1941–45	61	517,812	47	349,034	...	....	14	168,778
Wisconsin	1944–45	64	243,520	64	243,520	...	....	...	......
East Coast	1939–45	1,960	15,392,435	1,537	11,043,335	395	3,983,922	28	365,178
Great Lakes & rivers	1940–45	112	540,166	103	105,598	9	33,568	...	......
Gulf Coast	1940–45	762	5,408,271	639	4,342,939	116	981,512	7	83,820
West Coast	1940–45	2,257	17,054,604	1,897	13,486,743	255	2,567,689	105	1,000,172
Total United States	1939–45	5,091	38,395,476	4,176	29,379,615	775	7,566,691	140	1,449,170

Source: Shipbuilders Council of America, 21 West Street, New York 6, N. Y.

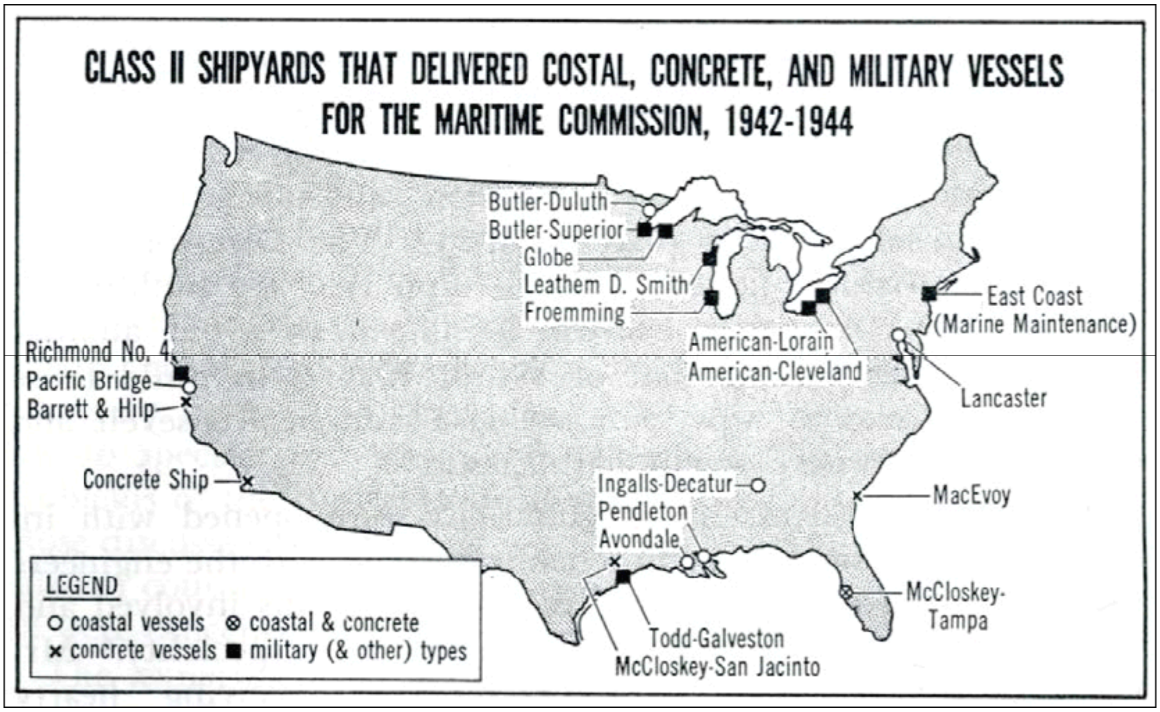


Figure 2.4.3: Location of Maritime Commission Shipyards in the Great Lakes Region (20)

Interestingly the Great Lakes shipyards were the most productive of all the regions; as seen from Figure 2.4.4. The Great Lakes shipyards began their involvement in WWII shipbuilding by building small cargo ships (N3) and tugs and barges for the British. In fact throughout the war and especially after the U.S. had joined, the British continually pressed for more shipbuilding in the Great Lakes. In April 1941 the British mission was increasing its demand for small ships and suggested that the Great Lakes shipbuilding potential be tapped to meet this new demand.

Because of manning problems with the Maritime Commission shipyards in the South from lack of available trained management and workers, and because the required LIBERTY ships could not pass through the then existing locks, American Ship Building Company was asked to operate the new (DELTA Shipbuilding Company) shipyard in New Orleans.

The demand for steel resulting in the massive increase in wartime shipbuilding resulted in the need for more Great Lakes ore carries, and in October 1941 the Maritime Commission awarded a contract for 16 new ore carriers to Great Lakes shipyards. In 1943 the Maritime Commission placed orders for C1-M-AVI 5000ton deadweight cargo ships with Great Lake shipbuilders. Frigates and Submarines were also built at Great Lakes shipyards between 1939 and 1945

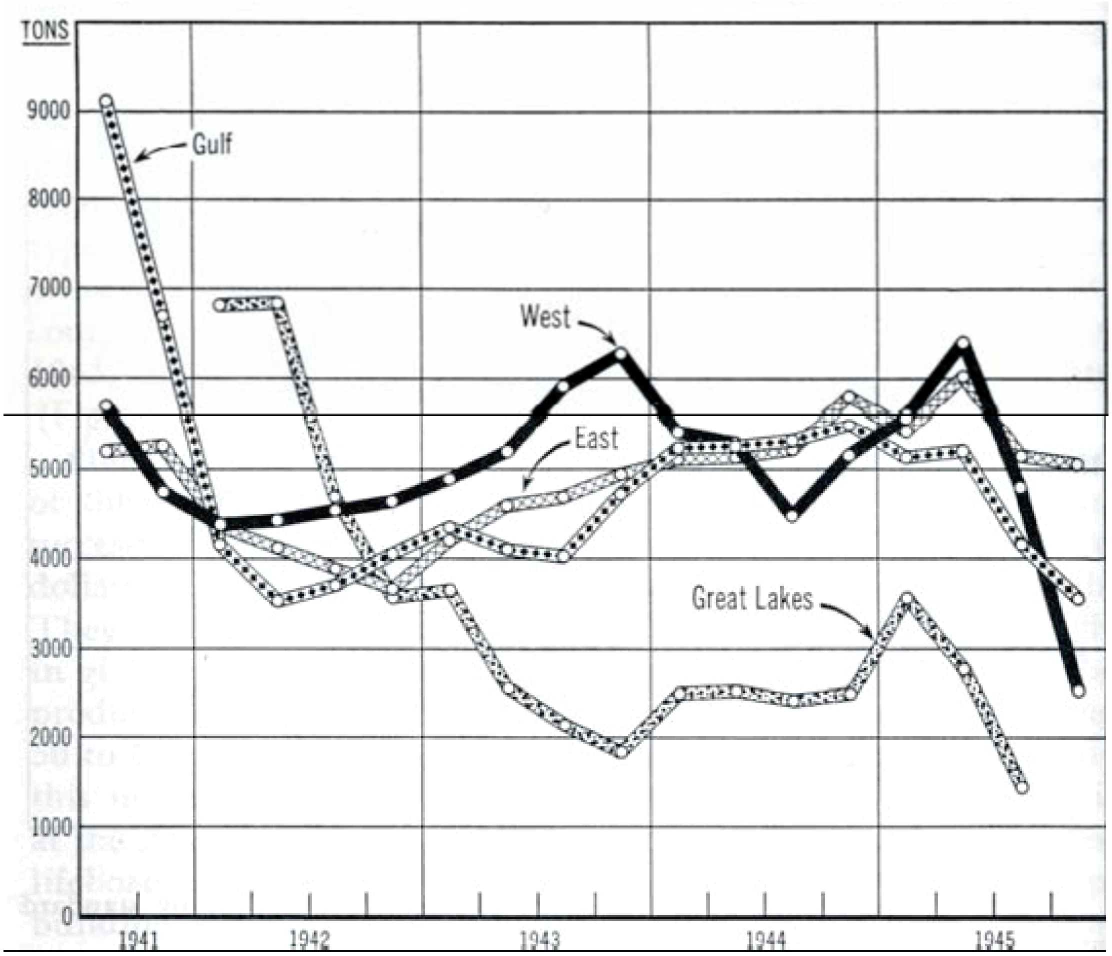


Figure 2.4.4: Labor Productivity in Maritime Commission Shipyards (20)

2.5 Assembly Line Approach

The fact that the wartime shipyards would be producing many ships in short time periods required a change from the traditional building approach and the resulting approach was the adaptation of the mass production approach used by automobile manufacturers, namely the assembly line. Many shipyards only used the assembly line approach to its shops, all leading to the ship being erected on the building berth, but some included prefabrication of hull blocks as an assembly line. A number of shipyards set up special assembly lines for building the deckhouses for their ships. Finally, some shipyards did have a full assembly line in which the ship was moved down it as it was being assembled. The layout of a Great Lakes Maritime Commission shipyard is shown in Figure 2.5.1 and the layout of the famous EAGLE Boat Yard at Rouge River, a full assembly line approach, are shown in Figure 2.5.2.

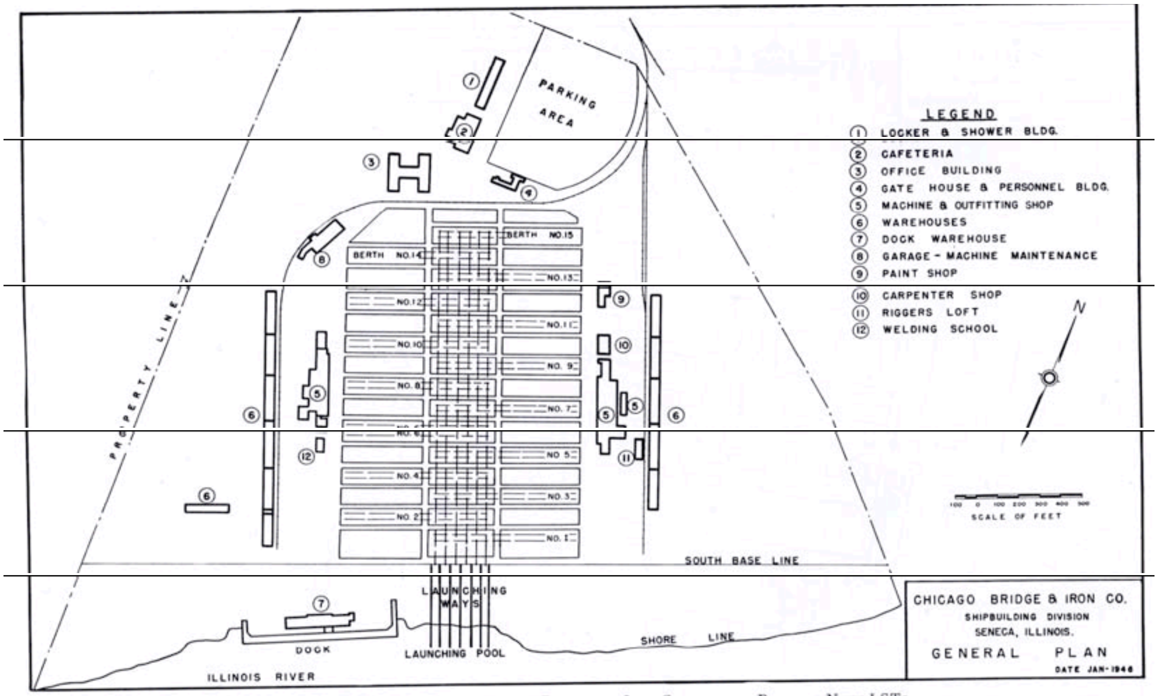


Fig. 4.—Seneca Plant of the Chicago Bridge and Iron Company for Building Navy LSTs

Figure 2.5.1: Layout of a Great Lakes Maritime Commission Shipyard (20)

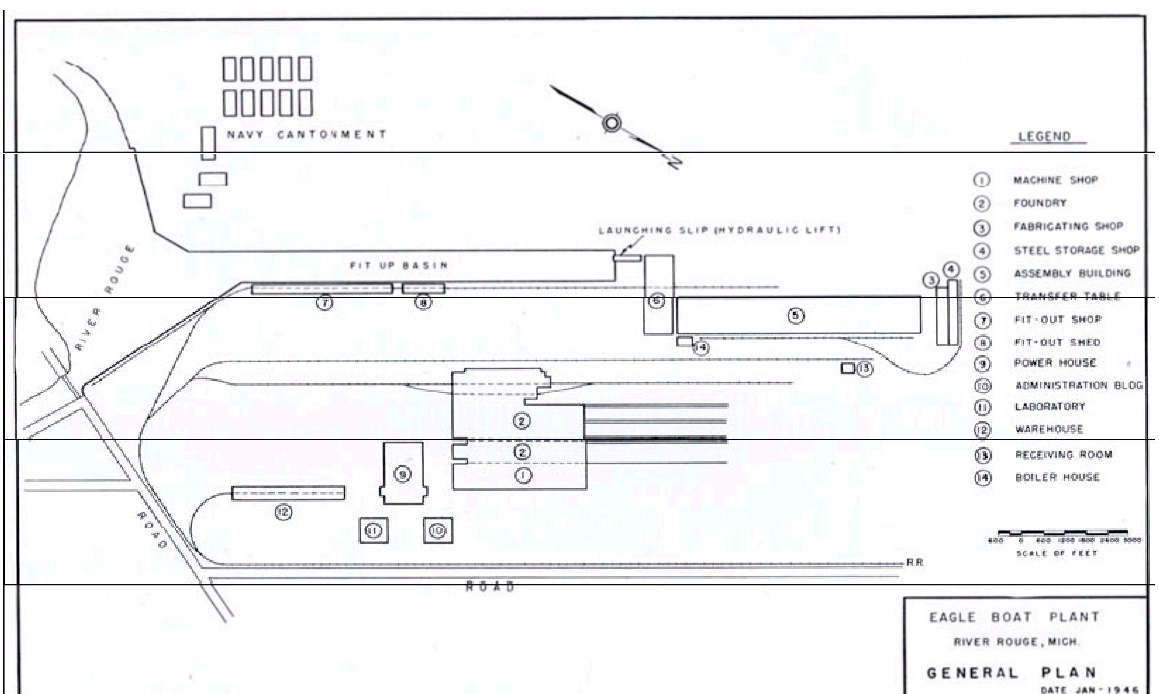


Fig. 3.—River Rouge Plant on the Great Lakes for Building Eagle Boats

Figure 2.5.2: Layout of EAGLE Boat Yard at River Rouge (20)

2.6 Post Wartime

After 1945 the Great Lakes shipyards ceased to build ships for international commerce, concentrating instead on the building of new bulk carriers to take advantage of the improvements to the lock system and dredging. Because the Great Lakes are fresh water, the Great Lakes ships have very long lives since the adverse impact of seawater corrosion on the ships hulls and machinery are almost eliminated. Many of the bulk carriers built during WWII are still in operation today. This adversely impacted Great Lakes shipbuilding because the real demand was very cyclical and the average demand was unable to sustain continuous shipbuilding for even one yard. Add to this that many ship owners decided to replace worn out cargo hulls by building new mid bodies and re-using the bows and sterns, including machinery; and the demand is further reduced. Figure 2.6.1 shows the decline of U.S. shipbuilding from 1940 to 1990. The Great Lakes history is similar to the U.S. shipbuilding industry.

By the late 1960s most of the Great Lakes shipyards had closed, though a new shipyard for Great Lakes Bulk carriers had just been constructed in Erie, PA by Litton Industries, which used a revolutionary shipbuilding approach. Also, the wooden shipbuilding yard in Marinette Wisconsin that closed was bought and reopened as a steel boatbuilding yard. In the late 1980s a new shipyard was opened in Lake Superior, the Upper Peninsular Shipbuilding Co., to build the tugs for a number of integrated tug/barges that were to operate between Milwaukee and Muskegon, but the venture was prone with problems and the shipyard closed (9). The remaining yards involved in new construction were Bay Shipbuilding and Petersen Builders; both of Sturgeon Bay Wisconsin.

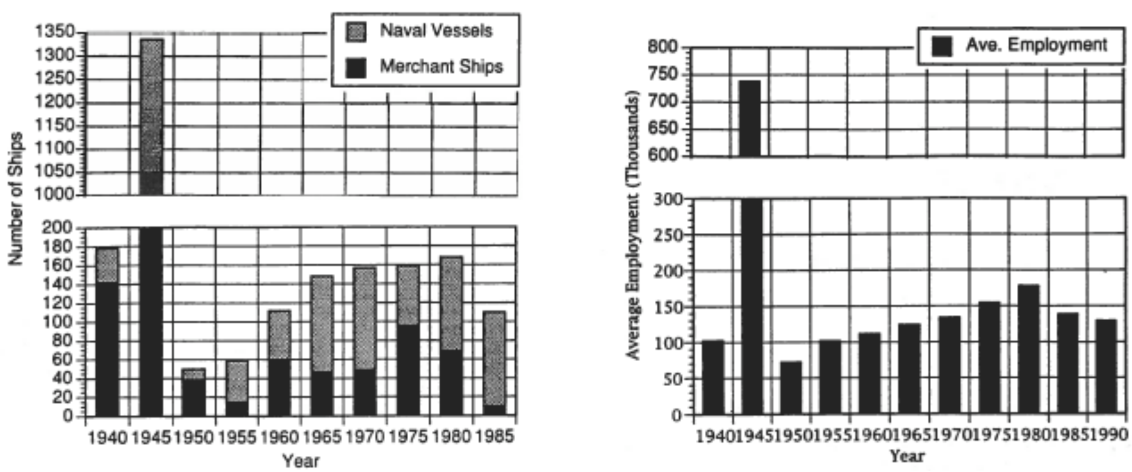


Figure 2.6.1: Number of U.S. Ships Ordered and U.S. Employment from 1940 – 1990 (25)

From 2000 until 2005 a number of U.S. shipyards that belonged to U.S. Great Lakes Shipping companies closed. Also, the Manitowoc Marine Group decided to cease its operation in the leased facility in Toledo. Today only a few U.S. shipyards in the Great Lakes are building large steel ships. Two facilities that do well are Bay Shipbuilding and Marinette Marine who both belong to the Manitowoc Marine Group, which is part of the larger Manitowoc Company. In 2006, two new companies took over old facilities that had been involved in repair of the Great Lakes bulk carrier fleets, with the stated intention to get into new construction.

3.0 Great Lakes Shipbuilding: Past and Present Yard Profiles

The following profiles are the collection of information gathered about the current and previous shipyards in the Great Lakes region that the researchers were able to locate. Many have been renamed through new ownership or merged with other companies and are listed under their current or most recent names. The gathered information includes the kinds of ships the yard builds or repairs, how many employees work for the company, and if the location of the shipyard provides possibility for future growth. Information concerning the company's facilities such as sizes and conditions was requested. Building practices information is intended to provide information about the level of technology and effectiveness of the building process. Production organization section should be used to explain what kind of methods and organization are used in the design and implementation during building or repairing for a given company.

One aspect to establish the viability of shipbuilding on the Great Lakes is the availability of resources for both the currently operating yards and yards that are currently closed. The reality of the closed yards re-opening and becoming part of a future Great Lakes shipbuilding industry is dependent on the state of the facilities, proximity to rail, availability of outsource labor, availability of an industry supply base, and availability of engineering talent. All of these things need to be accounted for when evaluating the possibility of expanding shipbuilding.

One interesting fact that came out of the investigation of Great Lakes current shipyards was the disparity of consistent information between "sources" of shipbuilding statistics information. One example of this is the MARAD Report on Survey of U.S. Shipbuilding and Repair Facilities (21). This report defines Active Major Shipyards and Other Major Shipyards with Building Positions as:

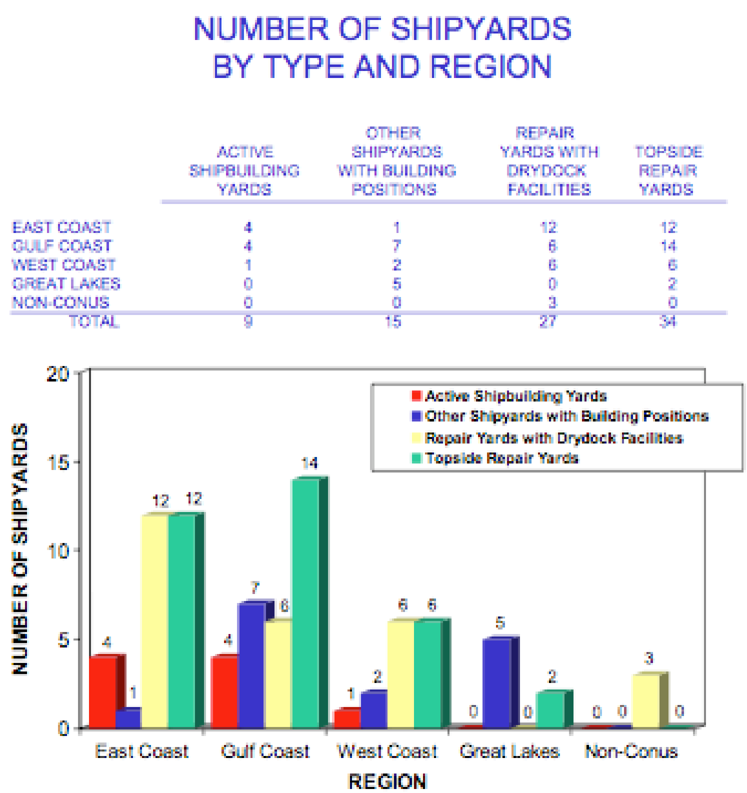
> **Active Shipbuilding Yards**
> The Active Shipbuilding Yards are comprised of privately owned U.S. shipyards that are open, having at least one shipbuilding position capable of accommodating a vessel 122 meters (400 feet) in length or over. In addition, these shipyards must own or have in place a long-term lease (1 year or more) on the facility in which they intend to accomplish the shipbuilding work, there must be no dimensional obstructions in the waterway leading to open water (i.e., locks, bridges), and the water depth in the channel to the facility must be a minimum of 3.7 meters. The Active Shipbuilding Base, as identified by the U.S. Navy and MARAD, consists of those shipyards identified as Active Shipbuilding Yards.
>
> **Other Shipyards with Building Positions**
> Other Shipyards with Building Positions are those privately owned shipyards/facilities that are open with at least one building position capable of accommodating a vessel 122 meters in length and over, and that have not constructed a naval ship or major oceangoing merchant vessel in the past two years.

The report also defines Medium and Small Size U.S. Shipyards as:

Boatbuilding and Repair Companies
Boatbuilding and Repair Companies are those privately owned shipyards capable of building and/or repairing maritime vessels less than 122 meters (400 feet) in length.

Vessel Repair Companies
Vessel Repair Companies are those facilities that only provide repair services, either repair with dry-docking or topside repair, to maritime vessels less than 122 meters (400 feet). These companies must have their own waterfront facilities.

The report states that the Great Lakes have zero active shipbuilding yards as seen in Figure 3.1. Marinette Marine is classified as a "Major" shipyard in this report. Marinette has built both Navy and Coast Guard vessels. Marionette's latest completion is the Navy's Littoral Combat Ship (LCS) vessel. The LCS is the Navy's next generation combatant with a length of 379 feet. The LCS's length is 11 feet smaller than the MARAD required 400-foot requirement. Does this 11-foot difference mean the Great Lakes is not an active shipbuilding region? Additionally if Marinette is constructing vessels under the 400-foot requirement but it can build ships up to 450 feet why is it not an active major shipbuilding yard? Other discrepancies were found within the MARAD report in addition to other errors in other Great Lakes shipbuilding reports.


NUMBER OF SHIPYARDS BY TYPE AND REGION

	ACTIVE SHIPBUILDING YARDS	OTHER SHIPYARDS WITH BUILDING POSITIONS	REPAIR YARDS WITH DRYDOCK FACILITIES	TOPSIDE REPAIR YARDS
EAST COAST	4	1	12	12
GULF COAST	4	7	6	14
WEST COAST	1	2	6	6
GREAT LAKES	0	5	0	2
NON-CONUS	0	0	3	0
TOTAL	9	15	27	34

Figure 3.1: Excerpt for MARAD Report (21)

3.1 A.A. Turner

A.A. Turner operated from 1866 to 1873. It was located in Trenton Michigan near Detroit.

3.1.1 Product Range

N/A

3.1.2 Number of Employees

N/A

3.1.3 Location Opportunities

N/A

3.1.4 Facilities and Dimensions

N/A

3.1.5 Condition of Facilities

N/A

3.1.6 Satellite Image

N/A

3.1.7 Building Practices

N/A

3.1.8 Production Organization

N/A

3.1.9 Performance

In the company’s existence of 7 years, it produced 36 ships.

3.1.10 Contact Information

N/A

3.2 Advance Boiler and Tank Company

Advance Boiler & Tank Company is currently open and functional.

3.2.1 Product Range

Advance Boiler & Tank Co. specializes in building ASME Pressure Vessels and plate fabrication. They also can solve power house/steam problems - drawing from experience on a variety of steam power equipment - marine, commercial, industrial, and utility types.

3.2.2 Number of Employees

The company has up to 50 employees, labor and management.

3.2.3 Location Opportunities

Because the yard is located in Milwaukee, there is a populated region for additional workers as well as technical universities for engineers and technical workers. Also in the area are many industrial supply companies.

3.2.4 Facilities and Dimensions

Advance Boiler & Tank Company was constructed in 1919.

Storage/Warehouse area: 31,000 sq. ft.
Total Shop Area: 52,700 sq. ft.
Shop Cranes - (2) 50T, (1) 25 T, several smaller auxiliary cranes (10/15T)

3.2.5 Condition of Facilities

Condition information not provided by company.

3.2.6 Satellite Image

Advance Boiler has a pier at the Port of Milwaukee. The pier is used for ship repair and transportation of its large pressure vessels via barge.

3.2.7 Building Practices

Information not provided by company.

3.2.8 Production Organization

Information not provided by company.

3.2.9 Performance

Information not provided by company.

3.2.10 Contact Information

Website:
http://www.advanceboiler.com

Contact:	Address:	
Inside sales/project manager	1711 S. Carferry Drive	P: 414-475-2120
rbauer@advanceboiler.com	Milwaukee, WI 53207	F: 414-475 2129

3.3 American Shipbuilding, Chicago

Before being named the American Shipbuilding Company, it was Chicago Shipbuilding, opening in 1891. The yard closed around 1920.

3.3.1 Product Range

Over its thirty-year existence, the yard produced steamships, barges, Lakers, and cargo ships.

3.3.2 Number of Employees

N/A

3.3.3 Location Opportunities

Located in Chicago, there are many industrial supply companies. It is a very populated region and has multiple technical universities in the area for engineers and technical workers. There is a large population for other additional workers.

3.3.4 Facilities and Dimensions

The shipyard closed around 1920.

(2) Graving Docks:	569 ft
	727 ft

3.3.5 Condition of Facilities

N/A

3.3.6 Satellite Image

The old docks and piers are used for bulk material offload locations, repair, and other industrial supply loading and offloading.

3.3.7 Building Practices

N/A

3.3.8 Production Organization

N/A

3.3.9 Performance

During its peak production, the shipyard was able to produce 22 cargo ships in 2 years.

3.3.10 Contact Information

N/A

3.4 American Shipbuilding, Detroit

American Ship Building Company in Detroit was formerly known as Detroit Shipbuilding, Detroit Dry Dock Company, and Campbell & Owen. The yard, then Campbell & Owen, began in 1852. The yard closed as American Ship Building Company after WWI in 1920.

3.4.1 Product Range

Over the life of this shipyard, it produced steamers, tugs, barges, ferries and freight ships.

3.4.2 Number of Employees

N/A

3.4.3 Location Opportunities

Being in Detroit, there are many industrial supply companies. There is a populated region for workers as well as technical universities in the area for engineers and technical workers.

3.4.4 Facilities and Dimensions

N/A

3.4.5 Condition of Facilities

N/A

3.4.6 Satellite Image

3.4.7 Building Practices

N/A

3.4.8 Production Organization

N/A

3.4.9 Performance

At Detroit Shipbuilding's peak, between 1918 and 1919, over 50 cargo ships at over 4,000 tons DWT were constructed.

3.4.10 Contact Information

Website:
http://www.coltoncompany.com/shipbldg/ussbldrs/prewwii/shipyards/inland/amshipdetroit.htm

Previous Address:
1801 Atwater
Detroit, MI 48207

3.5 American Shipbuilding, Lorain

Built in 1898, the Lorain Ohio shipyard served as the main facility of the American Shipbuilding Company after WWII. The yard closed in 1984 after a series of labor disputes. The land is now being redeveloped as an upscale housing development.

3.5.1 Product Range

N/A

3.5.2 Number of Employees

N/A

3.5.3 Location Opportunities

N/A

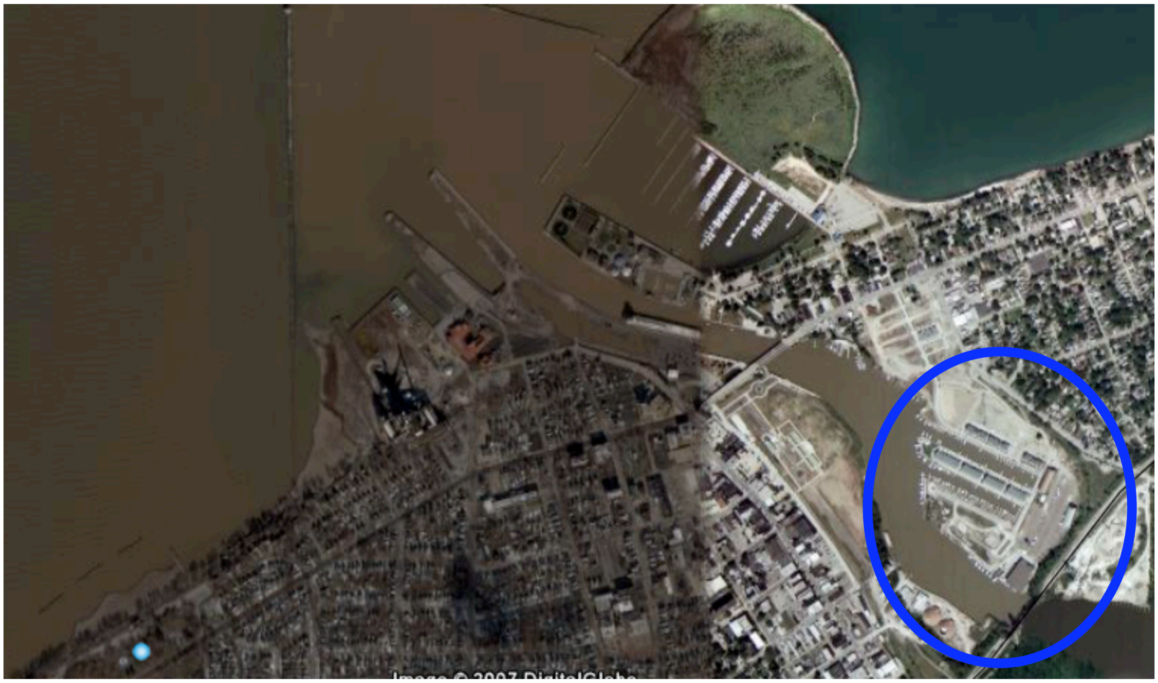
3.5.4 Facilities and Dimensions

During operation, the shipyard had (2) 1,000 ft dry docks.

3.5.5 Condition of Facilities

N/A

3.5.6 Satellite Image



3.5.7 Building Practices

N/A

3.5.8 Production Organization

N/A

3.5.9 Performance

The Lorain yard is credited with hundreds of launches including five of the 13 Great Lakes 1,000 ft ore carriers.

3.5.10 Contact Information

Previous Address:
400 Colorado Avenue
Lorain, OH 44052

3.6 Basic Marine

Basic Marine is currently open and operational.

3.6.1 Product Range

Basic construction such as barges and repair.

3.6.2 Number of Employees

Information not provided by company.

3.6.3 Location Opportunities

Because the yard is located in the Upper Peninsula of Michigan, there is not a populated region for more workers. Some industrial supply companies are in the area. There are technical universities in the area for local skilled engineers but they are at a distance.

3.6.4 Facilities and Dimensions

The following is information about facility dimensions and conditions of those facilities.

Total Covered Shop Area:	67,300 sq ft Includes: Fully equipped fabrication, shop and warehouse facilities
Building Docks/Berths:	1000 ft dock space 500 ft pier
Repair Docks:	160 ft x 65 ft - 2300 T floating dry dock

3.6.5 Condition of Facilities

Information not provided by company.

3.6.6 Satellite Image

3.6.7 Building Practices

Information not provided by company.

3.6.8 Production Organization

Information not provided by company.

3.6.9 Performance

Information not provided by company.

3.6.10 Contact Information

Website:
http://www.basicmarine.com/

Contact:
Info@basicmarine.com

Address:
440 North 10^{th} Street
Escanaba, MI 49829

P: 906-786-7120
F: 906-786-7168

3.7 Bay Shipbuilding Company (BSC)

Currently operational, Bay Shipbuilding Company is part of the Manitowoc Marine Group. This division of MMG specializes in large ship construction projects. Before its current name, BSC used to be Christy Corporation, which before named that was Leathem D. Smith Shipbuilding Company. BSC has a second shipyard very close to the first, previously named Peterson Builders.

3.7.1 Product Range

BSC is the U.S. builder of Great Lake Bulkers. It's product range includes OPA-90 vessels, dredges, dredging support equipment such as scows, deck barges, tugs, etc, and bulk cargo self unloading solutions.

3.7.2 Number of Employees

MMG employs 3500 people.
Employment for BSC is 632 and goes up in the winter to accommodate winter repair.

Management:	78
Production Workers:	554

3.7.3 Location Opportunities

Located in Sturgeon Bay, BSC has access to some industrial supply companies. Sturgeon Bay is a somewhat populated region and has one technical university. However, the city is close to Green Bay which has a large population for additional workers and many universities for engineers and technical workers.

3.7.4 Facilities and Dimensions

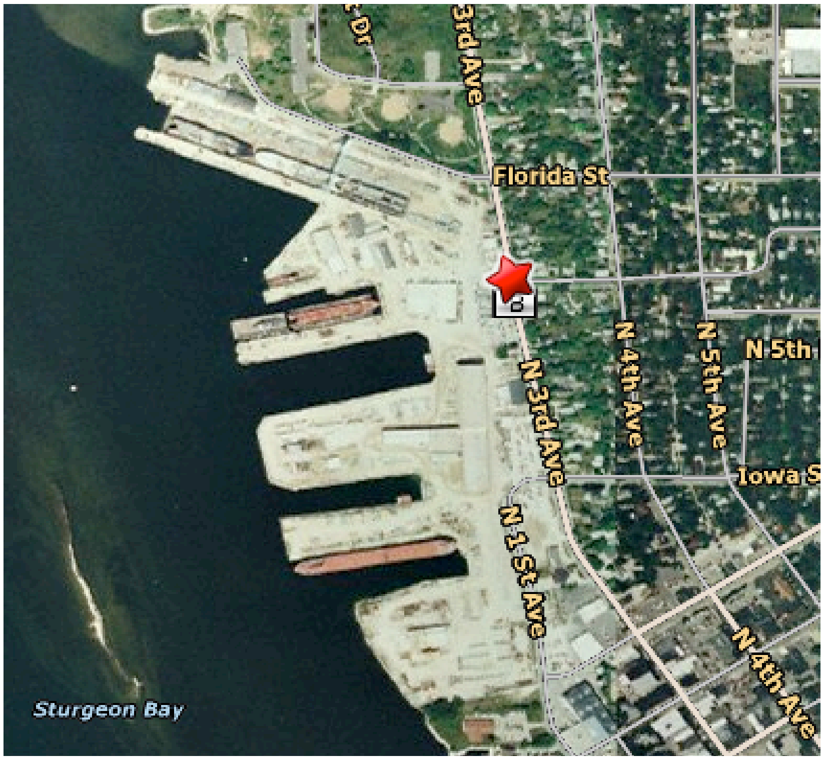
Bay Shipbuilding Company was reconstructed in 1968. Bay has a fully enclosed preparation and paint facility that can handle large sections in addition to automated blast and prime equipment for smaller plate and shape parts.

Total Area of Shipyard:	50 acres
Fabrication Shop Area:	95,515 sq ft
Machine Shop Area:	8,200 sq ft
Pipe Shop Area:	14,812 sq ft
Building & Repair Docks:	1,154 ft x 140 ft graving dock
	200 ft x 39 ft graving dock
	600 ft x 70 ft floating dock
Berth/Dock Crane:	200 T overhead gantry crane

3.7.5 Condition of Facilities

The shipyard looks newer than it is. The buildings are well maintained inside and out.

3.7.6 Satellite Image



3.7.7 Building Practices

Other than the lack of robotic use, this shipyard has a high building practice technology level. It uses Mitsubishi's shipbuilding software MATES and its own developed production control system based on ARTEMUS. Planning is manual. The total building time from start of fabrication until delivery is 15 months. For a new design, it is 2 years.

3.7.8 Production Organization

BSC's production approach utilizes block construction and advanced outfitting.

3.7.9 Performance

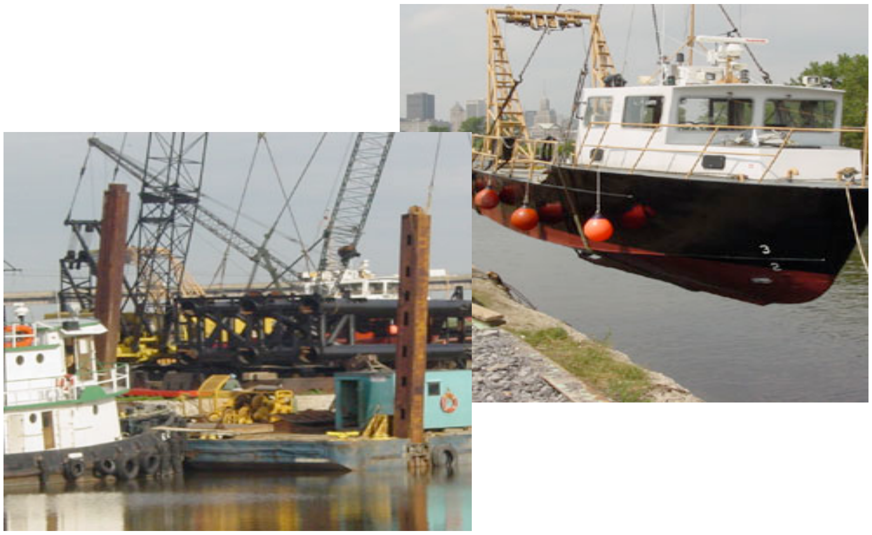
It is a very productive shipyard with productivity estimated to be 6 man hours/CGT.

3.7.10 Contact Information

Website:
www.manitowocmarine.com

Contact:	Address:	
Todd Thayse	605 N. 3rd Avenue	P: 920-743-5524
Manager - Contract Services	P.O. Box 830	F: 920-742-2371
todd@bscmmg.com	Sturgeon Bay, WI	

3.8 BIDCO Marine Group



The Buffalo Shipyard, a division of the BIDCO Marine Group, specializes in haul out service, new barge construction and ship repair. Previously, this shipyard used to be called Union Dry Dock Company as well as American Shipbuilding Company.

3.8.1 Product Range

Haul out service, new barge construction and topside repairs for ships, tugs, barges, tour boats and other floating structures.

3.8.2 Number of Employees

Information not provided by company.

3.8.3 Location Opportunities

Buffalo is a highly populated region which provides possibility of more workers. There are technical universities in the area which can provide technical workers and engineers. In the region, there are multiple industrial supply companies.

3.8.4 Facilities and Dimensions

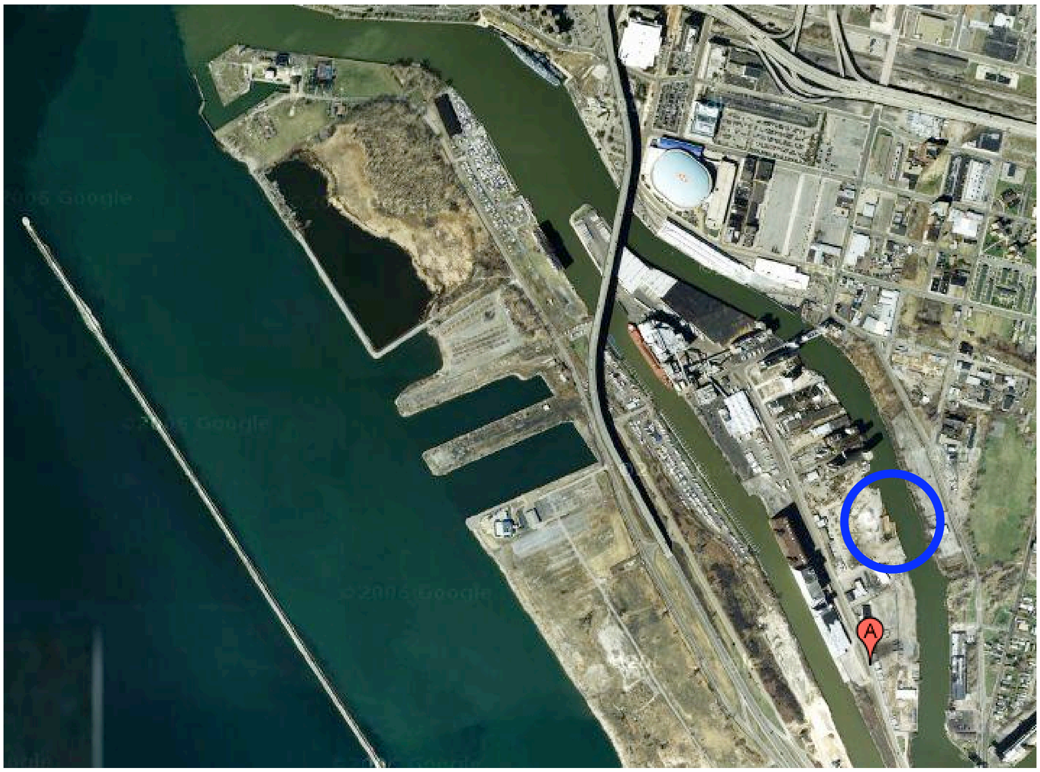
Because BIDCO Marine Group is made up of five divisions it is difficult to determine the actual dedicated ship production and ship repair facilities. What is known are the specifications of the past shipyard before it was purchased by the BIDCO group.

Total Previous Shipyard Area: 12 acres
As American Shipbuilding Company, this shipyard had three graving docks from 400 to 630 ft long.

3.8.5 Condition of Facilities

Information not provided by company.

3.8.6 Satellite Image



3.8.7 Building Practices

Information not provided by company.

3.8.8 Production Organization

Information not provided by company.

3.8.9 Performance

Information not provided by company.

3.8.10 Contact Information

Website:	Address:	
www.bidcomarine.com	201 Ganson Street	P: 716-854-1041
	Buffalo, NY 14203	

3.9 Burger Boat

Burger Boat is currently open and functioning.

3.9.1 Product Range

Burger Boat Company designs and builds custom motor yachts ranging in size from 100 to 200 feet.

3.9.2 Number of Employees

The company has almost 500 workers.

3.9.3 Location Opportunities

Manitowoc is a populated region which can provide workers. There are technical workers in the area which can supply engineers and technical workers. Industrial supply companies are plentiful in the region.

3.9.4 Facilities and Dimensions

- 36,000 sq ft covered building containing
  - 2 150 x 50 ft bays
  - 2 175 x 60 ft bays
- 42,000 sq ft covered building containing
  - 2 100 x 210 ft bays

Each of the above facilities have overhead bridge cranes full width and length of all bays
70 ft height at peak of 42,000 sq ft building

- 40,000 sq ft offsite facility
- 500 metric ton Marine Travel-lift
- 40,000 sq ft corporate headquarters

3.9.5 Condition of Facilities

Information not provided by company.

3.9.6 Satellite Image

3.9.7 Building Practices

Burger specializes in aluminum construction. Burger also has experience with ultra-high strength alloys, which require specialized manufacturing and engineering skill.

3.9.8 Production Organization

Information not provided by company.

3.9.9 Performance

Information not provided by company.

3.9.10 Contact Information

Website:
http://www.burgerboat.com/

Contact:	Address:	
info@burgerboat.com	1811 Spring Street	P: 920-684-1600
	Manitowoc, WI 54220	F: 920-684-6555

3.10 Cleveland Ship Repair

Cleveland Ship Repair is currently part of the Manitowoc Marine Group. Before its current ownership, Cleveland Ship Repair was called American Shipbuilding Company, Cleveland Shipbuilding Company, and Globe Iron Works.

3.10.1 Product Range

Cleveland Ship Repair specializes in all types of voyage and topside marine repair.

3.10.2 Number of Employees

MMG employs 3500 people.
Cleveland Ship Repair has a total of 13 employees.

Shipyard Total:	11
Management:	2
Design/Engineering:	1
Planning:	1
Production:	11
Use of Subcontractors:	Yes
Use of Design Agents:	Yes

Cleveland Ship Repair is a large repair shop, not much engineering and designing employment is needed. When it is, Bay Shipbuilding provides engineering support.

3.10.3 Location Opportunities

Located in Cleveland, Cleveland Ship Repair has access to many industrial supply companies. Cleveland is a very populated region and has multiple technical universities in the area for engineers and technical workers. There is a large population for other additional workers.

3.10.4 Facilities and Dimensions

Because it does not have an actual yard where they perform repairs, they rent pier / dock space or other facilities to perform these projects.

Total Area of Shipyard:	3 acres
Stockyard Area:	.25 acres
Total Covered Shop Area:	11,200 sq ft
Repair Dock:	400 ft
Shop Cranes:	(5) 5T, 3T
Berth/Dock Cranes:	35T mobile crane

3.10.5 Condition of Facilities

Information not provided by company.

3.10.6 Satellite Image

3.10.7 Building Practices

Information not provided by company.

3.10.8 Production Organization

Information not provided by company.

3.10.9 Performance

Because the yard is a repair yard, no ships are created. The annual tons of steel used is 3000.

3.10.10 Contact Information

Website:
http://www.manitowocmarine.com/Facilities/ClevelandShipRepair.asp

Contact:
Kyle Fries
General Manager
kfries.csc@sbcglobal.net

Address:
1847 Columbus Rd.
Cleveland, OH 44113

P: 216-621-9111
F: 216-621-4885

3.11 Edward E. Gillen Company, Inc.

Edward E. Gillen Company no longer builds or repairs ships.

3.11.1 Product Range

The company now designs and builds dock walls/structures, bluff stabilizations, breakwaters, and does dredging.

3.11.2 Number of Employees

Information not provided by company.

3.11.3 Location Opportunities

The location is suitable for shipbuilding.

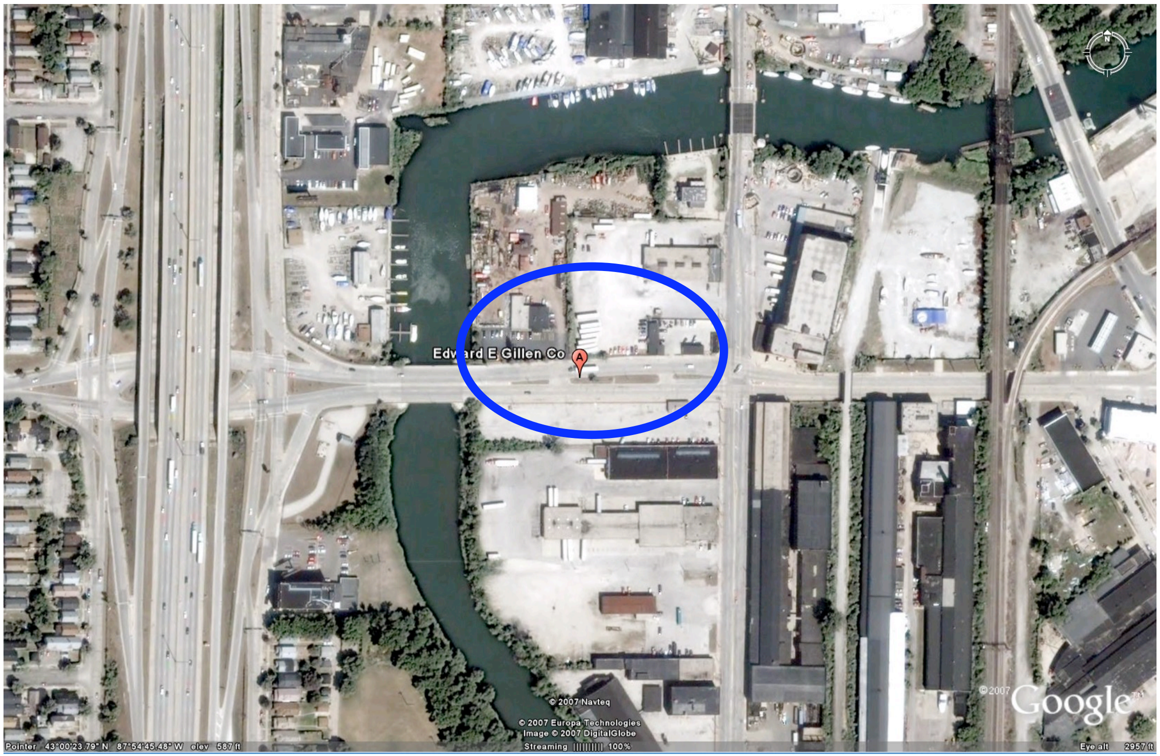
3.11.4 Facilities and Dimensions

Information not provided by company.

3.11.5 Condition of Facilities

Information not provided by company.

3.11.6 Satellite Image



3.11.7 Building Practices

Information not provided by company.

3.11.8 Production Organization

Information not provided by company.

3.11.9 Performance

Information not provided by company.

3.11.10 Contact Information

Website:	Address:	
http://www.gillenco.com/	218 W. Becher Street	P: 414-769-3120
	Milwaukee, WI 53207	F: 414-769-3135

3.12 Erie Shipbuilding


Erie Shipbuilding is currently open and a working facility. It was established in 2005. Prior to becoming Erie Shipbuilding, the facility was the Litton Industries Shipyard and Dry Dock, Erie Marine Enterprises, and Metro Machine Corp.

3.12.1 Product Range

The goal of Erie Shipbuilding is to engage in large scale general steel and aluminum fabrication and assembly with the intended purpose of building, converting, dry-docking and repairing ships. Erie's current projects consist of a dump scow and deck barges.

3.12.2 Number of Employees

Information not provided by company.

3.12.3 Location Opportunities

Erie is a populated region that may provide workers if needed. Also, there are technical universities in the area for engineers and technical workers. Many industrial supply companies are in this region.

3.12.4 Facilities and Dimensions

Total Area of Shipyard:	44 acres
Stockyard Area:	12 acres
Steel Processing Shop Area:	45,000 sq ft
Steel Fabrication Shop Area:	35,000 sq ft
Machine Shop Area:	3,000 sq ft
Pipe Shop Area:	3,000 sq ft
Storage/Warehouse Area:	32,000 sq ft
Total Covered Shop Area:	130,000 sq ft

Building and Repair Docks:	130 ft x 1,250 ft dry dock
	(2) 140 ft x 1150 ft piers with 4,000 ft pier space
Shop Cranes:	ranging 20T - 100T overhead
Berth/Dock Cranes:	ranging 20T - 450T

3.12.5 Condition of Facilities

Information not provided by company.

3.12.6 Shipyard Image

3.12.7 Building Practices

Maximum block size Erie Shipbuilding is capable of is 40’ x 90’ and maximum block weight can be up to 100 tons.

3.12.8 Production Organization

Information not provided by company.

3.12.9 Performance

Information not provided by company.

3.12.10 Contact Information

Website:
http://erieshipbuilding.com/index.html

Contact:
John Chapman
VP of Operations
chap@erieshipbuilding.com

Address:
220 E. Bayfront Parkway
Erie, PA 16507

P: 814-452-0330
F: 814-461-7225

3.13 Fraser Shipyards, Inc.

Fraser is currently open and functional. Before its current ownership as Fraser Shipyards Inc., the shipyard was called American Steel Barge Company and also Superior Shipbuilding Company.

3.13.1 Product Range

Fraser can and has designed and built all types of commercial ships, including bulk carriers, oil tankers, product tankers, car carriers, OBO's, dredgers, and ferries. Currently, the product range is bulk carriers, product carriers and special commercial marine equipment such as barges.

3.13.2 Number of Employees

Similar to other Great Lakes repair yards, the work force is seasonal; in the summer there is not a large available work force in the area and it would be difficult to increase their employment.

Shipyard Total:	varies 40 to 150
Management:	6
Design/Engineering:	2
Planning:	1
Production:	up to 140
Use of subcontractors:	Yes
Use of design agents:	Yes

3.13.3 Location Opportunities

Located in Superior, WI, there is a populated region for workers. There are universities in the area for engineers and technical workers. Industrial supply companies are in the area to provide services for the shipyard.

3.13.4 Facilities and Dimensions

The facilities were constructed in 1890.

Total Area of Shipyard:	60 acres
Steel Processing, Fabrication, Machine Shop, and Pipe Shop Area: 69,000 sq ft	
Storage/Warehouse Area:	16,000 sq ft
Total Covered Shop Area:	100,000 sq ft
Building Docks:	628 ft x 60 ft graving dock
	831 ft x 80 ft graving dock
Repair Berths:	(4)
Shop Cranes:	various
Berth/Dock Cranes:	(6) Heavy lifting cranes ranging from 44-175T

3.13.5 Condition of Facilities

The buildings are well maintained externally with no signs of deterioration.

3.13.6 Satellite Image

3.13.7 Building Practices

Information not provided by company.

3.13.8 Production Organization

Fraser Shipyards approach is to be as flexible as possible as it can respond to whatever opportunity arises. They have a very lean organization and simple approach.

3.13.9 Performance

The throughput is not consistent. Work consists mainly of repairing the Great Lakes bulk carriers and tugs. Fraser will build special craft such as the 70 foot double hull barge for the U.S. National Park Service (completed in 2004). Previous to that, however, the last new construction was a tug built in 1967.

3.13.10 Contact Information

Website:
frasershipyards.com

Contact:	Address:	
Trevor White	3rd and Clough Avenue	P: 715-394-7787
Vice President and General Manager	P.O. Box 997	F: 715-394-2807
twhite@frasershipyards.com	Superior, WI 54880	

3.14 Great Lakes Engineering Works

The yard in Ashtabula Ohio was started in 1912 and closed in 1960.

3.14.1 Product Range

Ashtabula created Lakers, cargo ships, tugs, ferries, bulkers, barges, and military ships.

3.14.2 Number of Employees

N/A

3.14.3 Location Opportunities

Located near Cleveland, there are many industrial supply companies and multiple technical universities in the area for engineers and technical workers.

3.14.4 Facilities and Dimensions

Graving Dock: 630 ft

3.14.5 Condition of Facilities

N/A

3.14.6 Satellite Image

N/A

3.14.7 Building Practices

N/A

3.14.8 Production Organization

N/A

3.14.9 Performance

N/A

3.14.10 Contact Information

Website:
http://www.coltoncompany.com/shipbldg/ussbldrs/postwwii/shipyards/inactive/inland/greatlakes.htm

3.15 Great Lakes Towing Shipyard

Great Lakes Towing is currently open and functioning. Great Lakes Towing Shipyard is part of The Great Lakes Group Company.

3.15.1 Product Range

The Great Lakes Towing Company specializes in all types of marine repair service for tugboats, supply boats, ferries, barges, cruise boats, large yachts, and many other types of vessels. GLT is also embarking on a new tugboat shipbuilding venture.

3.15.2 Number of Employees

Company Total:	125
Shipyard Total:	26
Management:	1
Design/Engineering:	2
Planning:	1
Production:	23
Use of Subcontractors:	Yes
Use of Design Agents:	Yes

3.15.3 Location Opportunities

Located in Cleveland, Great Lakes Towing has access to many industrial supply companies. Cleveland is a very populated region and has multiple technical universities in the area for engineers and technical workers. There is a large population for other additional workers.

3.15.4 Facilities and Dimensions

Rebuilt in November 2006 with future plans for a 40,000 sq ft building facility with a 300-ton Travelift.

Total Area of Shipyard:	over 5 acres
Total Covered Shop Area:	11,400 sq. ft.

Includes: Steel Processing Shop Area, Steel Fabrication Shop Area, Machine Shop Area, Pipe Shop Area, Storage/Warehouse Area

Building Docks/Berths:	300T floating dry dock

Repair Docks:	1000 ft of wet berth
Shop Cranes:	10T gantry
Berth/Dock Cranes:	45T crawler
	30T hydraulic

3.15.5 Condition of Facilities

New

3.15.6 Satellite Image

3.15.7 Building Practices

Basic block construction.

3.15.8 Production Organization

Information not provided by company.

3.15.9 Performance

Annual throughput is 2 tugs and 20 truckable barges.

3.15.10 Contact Information

Website:
http://www.thegreatlakesgroup.com/index.php

Joseph P. Starck, Jr.
Vice President - Engineering
jps@thegreatlakesgroup.com

Address:
4500 Division Avenue
Cleveland, OH 44113

P: 216-621-4854
F: 216-621-0069

3.16 H. Hansen Industries, Inc.

H. Hansen is currently open and functioning. The company is located in the Port of Toledo.

3.16.1 Product Range

Ship repair, fabrication, machining and propeller repair.

3.16.2 Number of Employees

Information not provided by company. MARAD lists 60 employees in 2004.

3.16.3 Location Opportunities

Being in Toledo there are many industrial supply companies. There is a populated region for possible workers as well as multiple technical universities in the area for engineers and technical workers.

3.16.4 Facilities and Dimensions

Machine Repair Shop with 20-ton crane
450 ft of total pier length

3.16.5 Condition of Facilities

Information not provided by company.

3.16.6 Satellite Image

3.16.7 Building Practices

Information not provided by company.

3.16.8 Production Organization

Information not provided by company.

3.16.9 Performance

Information not provided by company.

3.16.10 Contact Information

Bob Ossovicki,	Address:	
Superintendent	2824 Summit Street	P: 419-729-1621
Hansen_ind@msn.com	Toledo, OH 43611	F: 419-729-0715

3.17 Ironhead Marine Inc.

Before its current ownership, Ironhead Marine Inc. used to be called American Shipbuilding Company, Steelhead Marine Company, Toledo Ship Repair, Craig Shipbuilding Company, and Toledo Shipbuilding Company.

3.17.1 Product Range

Dry-docking and marine repair services.

3.17.2 Number of Employees

15-40 employees depending on season and workload

3.17.3 Location Opportunities

Being in Toledo, there is a highly populated region with many potential workers. There are also many technical universities in the area for engineers and technical workers. In Toledo, there are many industrial supply companies.

3.17.4 Facilities and Dimensions

Site: 14 acres

Graving Docks:	800 ft x 70 ft
	550 ft x 70 ft

Currently building 20,000 sq. ft. High Bay Fabrication shop.

3.17.5 Condition of Facilities

Other than the new high bay fabrication shop there are no other building on the site other than a 100 year old pump house.

3.17.6 Satellite Image

3.17.7 Building Practices

Information not provided by company.

3.17.8 Production Organization

Information not provided by company.

3.17.9 Performance

Information not provided by company.

3.17.10 Contact Information

Tony LaMantia
President of Company
tony@ironheadfab.com

Address:
2245 Front Street
Toledo, OH 43605

P: 419-698-8081
F: 419-698-9066

3.18 Marinette Marine Corporation

Marinette Marine Corporation is open and functioning as part of the Manitowoc Marine Group. It was founded in 1942 to meet the growing need for naval construction. MMC is a full service shipyard with in-house capabilities to design and construct complex vessels. It has earned an international reputation for its ability to build technologically advanced ships.

3.18.1 Product Range

Product range covers special purpose small technically advanced ships/platforms for the U.S. Government such as the USCG Icebreaker, USCG Buoy Tender, Mobile Landing Causeway, and the new monohull Littoral Combat Ship, as well as ferries like the Staten Island Ferry and tugs for private customers. MMC is currently looking at a car carrier in the 400 foot length range.

3.18.2 Number of Employees

MMG employs 3500 people. At MMC there are a total of 1000 workers. This is about the maximum available in the region around the shipyard.

3.18.3 Location Opportunities

Marinette is a populated area so workers could be available if needed. There are technical universities in the area to supply engineers and technical workers. Industrial supply companies are present in this region.

3.18.4 Facilities and Dimensions

MMC was constructed in 1942.

Total Area of Shipyard:	60 acres
Total Shop Area:	300,000 sq. ft.
Shop Cranes:	40 tons
External Cranes:	40 ton, 100 ton, and 275 ton
Side Launchways:	2,500 long ton and 450 ft limit
Ship Transport system:	ships or blocks up to 1,600 tons
Module movers:	160 ton

3.18.5 Condition of Facilities

Information not provided by company.

3.18.6 Satellite Image

3.18.7 Building Practices

MMC uses the block and advanced outfitting approach to production. They move as much work as possible as far up the production line. MMC can produce both steel and aluminum structures.

3.18.8 Production Organization

Ships are typically around 90% complete when launched. They have separate shops for steel processing, subassemblies, panels, bow, and stern blocks, block outfitting, and painting. Panel and block construction are all a fixed work station.

3.18.9 Performance

Since opening, MMC has built more than 1,300 vessels. MMC will build half an LCS, two tugs, and many parts of the mobile causeway in a year. If MMC was concentrating on small commercial ships they could build up their throughput to three ships per year.

3.18.10 Contact Information

Website:
http://www.manitowocmarine.com/Facilities/MarinetteMarine.asp

Contact:	Address:	
Floyd R. Charrier, Jr.	1600 Ely Street	P: (715) 735-9341 ext. 6528
Vice President Sales & Marketing	Marinette, WI	F: (715) 735-3516
fcharrier@marinettemarine.com	54143-2434	

3.19 MCM Marine Inc.


MCM Marine is currently open and operational.

3.19.1 Product Range

MCM Marine is capable of river and harbor improvements, environmental dredging and capping, maintenance dredging, break walls and retaining walls, sheet, steel and wooden pile driving, dock installation and repair, crane services, sandblasting, certified welding, marine construction, beach nourishment, dry docking and boat repair.

3.19.2 Number of Employees

Information not provided by the company.

3.19.3 Location Opportunities

Being in Sault Ste. Marie there are many industrial supply companies. There is a populated region for possible workers. However, technical universities are in the area for engineers and technical workers but at a distance.

3.19.4 Facilities and Dimensions

MCM Marine opened in 1984.

Build and Repair Berths/Docks: 2000 T floating dry dock

3.19.5 Condition of Facilities

Information not provided by the company.

3.19.6 Satellite Image

3.19.7 Building Practices

Information not provided by the company.

3.19.8 Production Organization

Information not provided by the company.

3.19.9 Performance

Information not provided by the company.

3.19.10 Contact Information

Website:
www.mcmmarine.com

Contact:	Address:	
jmccoy@mcmmarine.com	1065 East Portage Avenue	P: 906-632-4316
	Sault Ste. Marie, MI 49783	F: 906-6327766

3.20 Michigan Limestone Ship Repair Shop

Michigan Limestone Ship Repair Shop is no longer open and does not currently build or repair ships.

3.20.1 Product Range

N/A

3.20.2 Number of Employees

N/A

3.20.3 Location Opportunities

Being in Rogers City there are hardly any industrial supply companies. There is not a populated region for workers nor are there technical universities in the area for engineers and technical workers.

3.20.4 Facilities and Dimensions

N/A

3.20.5 Condition of Facilities

N/A

3.20.6 Satellite Image

3.20.7 Building Practices

N/A

3.20.8 Production Organization

N/A

3.20.9 Performance

N/A

3.20.10 Contact Information

Previous Address:
1035 Calcite Road
Rogers City, MI 49779

P: 517-734-2131
F: 517-734-4979

3.21 Nicholson Terminal and Dock Company

Nicholson Terminal is currently open and functional. Before its current ownership, this shipyard was known as Great Lakes Engineering Works.

3.21.1 Product Range

Nicholson Terminal & Dock Company offers vessel repair services including a small yet full functioning dry dock that can range from minor to major repair jobs. The yard regularly performs maintenance on tugs, barges, cargo handling vessels, and passenger carrying vessels. NT&D offers two shipyards, both with a variety of services including truck, rail car and barge loading/unloading, container stuffing and stripping, securing, cargo sorting, cargo assembly, and short and long term storage.

3.21.2 Number of Employees

Information not provided by company.

3.21.3 Location Opportunities

Being in Ecorse, MI, near Detroit, there are many industrial supply companies. There is a populated region for workers as well as technical Universities in the area for engineers and technical workers.

3.21.4 Facilities and Dimensions

Nicholson Terminal & Dock Company has two terminals: Detroit and Ecorse. The Detroit Terminal is for loading/unloading and storage; it has thirty forklift trucks with capacities of 5,000 - 80,000 lbs as well as two bobcat wheel loaders for transporting cargo. There is also a riverside rail system for load cranes.

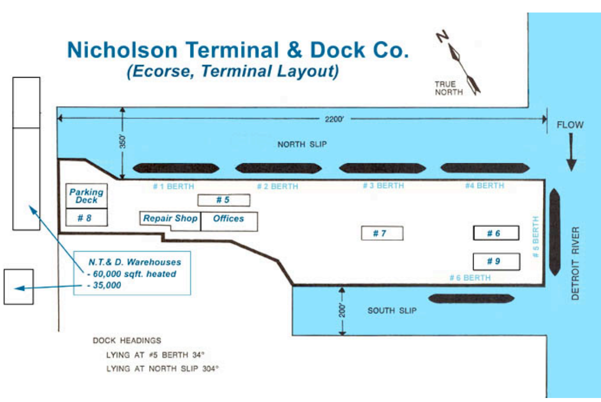
Storage/Warehouse Area:	50 acres, 185,000 sq ft covered
Repair Docks:	3,400 ft repair dock and a small floating dry dock
Shop Cranes:	(2) overhead 20-25 T

3.21.5 Condition of Facilities

Information not provided by company.

3.21.6 Satellite Images

The top screen shot is the Detroit Terminal. The lower shot is the Ecorse Terminal and Repair Shop.



3.21.7 Building Practices

Information not provided by company.

3.21.8 Production Organization

Information not provided by company.

3.21.9 Performance

Information not provided by company.

3.21.10 Contact Information

Website:
http://www.nicholson-terminal.com/

Contact:	Address:	
psutka@nicholson-terminal.com	P.O. Box 18066 River Rouge, MI 48218	P: 313-842-4300 F: 313-843-1091

3.22 Palmer Johnson Yachts

Palmer Johnson is currently open and producing vessels.

3.22.1 Product Range

Palmer Johnson builds semi-custom sports yachts between 120 feet and 150 feet in length. They are currently expanding their facilities through internal funds and state government support to be able to produce yachts up to 200 feet.

3.22.2 Number of Employees

Palmer Johnson's current workforce is 300 with an anticipated number of 500 when the new facilities are completed.

3.22.3 Location Opportunities

Located in Sturgeon Bay, Palmer Johnson has access to some industrial supply companies. Sturgeon Bay is a somewhat populated region and has one technical university. However, the city is close to Green Bay that has a large population for additional workers and many universities for engineers and technical workers.

3.22.4 Facilities and Dimensions

Current facility is 67,000 square feet. Palmer Johnson has secured funding through the Sturgeon Bay Shipbuilding Cluster Plan, which is currently building new facilities for Palmer Johnson. The new facilities consist of a 15,000 square foot expansion of the current facility, a 12,000 square foot paint facility and an additional 20,000 square foot production facility. The Shipbuilding Cluster Plan also includes a new boat launch system.

3.22.5 Condition of Facilities

New

3.22.6 Satellite Image

3.22.7 Building Practices

Since Palmer Johnson makes semi-custom vessels they are able to implement modular assembly and other advance manufacturing processes.

3.22.8 Production Organization

Information not provided by company.

3.22.9 Performance

Palmer Johnson should be able to produce 8-12 ships per year with the new facilities.

3.22.10 Contact Information

Website:
www.palmerjohnson.com

Contact:	Address:	
Mike Kelsey	128 Kentucky Street	P: 920-743-4412
mkelsey@itol.com	Sturgeon Bay, WI 54235	

3.23 T.D. Vinette

T.D. Vinette is not currently open and functional.

3.23.1 Product Range

This shipyard used to be a small repair shop, capable of docking Panamax size vessels.

3.23.2 Number of Employees

N/A

3.23.3 Location Opportunities

Because Escanaba is in Michigan's Upper Peninsula, there are limited resources available.

3.23.4 Facilities and Dimensions

N/A

3.23.5 Condition of Facilities

N/A

3.23.6 Satellite Image

N/A

3.23.7 Building Practices

N/A

3.23.8 Production Organization

N/A

3.23.9 Performance

N/A

3.23.10 Contact Information

Previous Address:
1212 19th North Avenue
P.O. Box 416
Escanaba, MI 49829

P: 906-786-1884
F: 906-789-1089

4.0 Factors That Impact Great Lakes Shipbuilding

There are several factors unique to the Great Lakes region that will impact the success or failure of shipbuilding and repair on the Great Lakes. These factors include:

- Saint Lawrence Seaway system constraints
- Labor considerations
- Facility and environmental considerations
- National Cost of Production considerations

Each factor has impact on the Great Lake's shipbuilding viability within certain markets as well as long-term sustainable shipbuilding business. Shipbuilding and repair is more than dry-docks and dreams. It is a heavy industrial manufacturing and engineering business that is no different than any other heavy industry. Volume, market, cost and other business metrics matter in all the same ways as in other heavy industry sectors.

4.1 Saint Lawrence Seaway

An important component to the maritime business within the Great Lakes is the Saint Lawrence Seaway. These seaways impact the maximum size of vessels that can transit in and out of the Great Lakes and thus impacting the market segments available for shipbuilding. Additionally the winter closures of the seaway system will impact the delivery schedule and capacity utilization of shipbuilders within the Great Lakes region as well as the volume of ships entering the Great Lakes.

The St. Lawrence Seaway is a system of canals that allows ocean-going vessels to travel from the Atlantic Ocean to the Great Lakes through the St. Lawrence River. To control flooding in the area and lake levels, there are a series of 19 locks along the longest route (14).

4.1.1 How the Locks Work

Used in rivers with a significant change in water level, locks provide a way for ships to travel through them by essentially creating a ship elevator. When a ship comes to a lock it goes into a watertight chamber connecting the two different heights of water. The ship is then raised or lowered to match the height of water it is traveling to; this occurs when water is pumped into the chamber to raise the ship or draining the water to lower it. Once the chamber holding the ship is the same water level as the river, the gates open and the ship continues on.

4.1.2 Lock Dimensions

Vessels allowed to travel through the St. Lawrence River are limited by the size of the locks which are 766 feet (233.5 m) long, 80 feet (24 m) wide, and 30 feet (9.1 m) deep. Therefore, the maximum size of a ship passing through must be slightly smaller at 740 feet (225.5 m) long, 78 feet (23.7 m) wide, 26.5 feet (8.08 m) draft, and 116.5 feet (35.5m) height above water; this is informally known as Seaway-Max. Larger vessels can be built inside the Great Lakes but cannot travel down the seaway. The size restriction does not eliminate the involvement of Great Lakes yard in the construction of large vessels. There are no reasons why able yards could not produce large sections of ships, such as deckhouses and engine rooms, and barge those sections to an integrating yard outside of the Great Lakes. A business practice like this is feasible and was done during the World Wars, but Great Lakes yards would find it difficult to provide value and savings in today's market. This type of business strategy is currently being done in Europe and Asia. Figure 4.1.2.1 below shows where the locks are located along the Seaway.

Figure 4.1.2.1: Map of Seaway Locks

4.1.3 Cost of Travel Through Seaway

By routing through Great Lakes ports, steel shippers save anywhere from $3-50 per ton. Transportation studies show that Great Lakes ports have lower port costs than competing ocean ports for the handling, wharfage, dockage, and stevedoring of grain, iron ore, steel coils, and machinery. Table 4.1.3.1 shows toll charges for different cargo measured in US $ per metric ton.

Table 4.1.3.1: 2007 Seaway Tolls (US $ per metric ton) (11,13)

Cargo Tolls	**Montreal**	**Welland**
Bulk Cargo	.958086	.634832
Grain	.588612	.634832
Coal	.565645	.634832
General Cargo	2.30851	1.01588
Steel Slab	2.08928	.727272
Containerized Cargo	.958086	.634832
Government Aid	0	0
GRT Charge	**Montreal**	**Welland**
Loaded Ballast -OR-	.092440	.150047
Vessel carrying new cargo or a vessel returning ballast after carrying new cargo	0	N/A
Minimum charge per ship per lock transited for full or partial transit of Seaway	23.9234	23.9234
Lockage Charge (per lock)	**Montreal**	**Welland**
Loaded Vessels -OR-	N/A	506.976
Vessel Charge per Gross Registered Ton (for a vessel carrying new cargo)	N/A	.149377
Ballast Vessels -OR-	N/A	374.574
Vessel Charge per Gross Registered Ton (for a vessel returning in ballast after carrying new cargo)	N/A	.109473

4.1.4 Duration of Travel Through Seaway

Getting through a lock takes about 45 minutes due to the incredibly quick dumping and filling of water which is approximately 24 million gallons in just 7 to 10 minutes per lock. The Welland Canal takes about 12 hours to completely travel through. The Montreal/Lake Ontario region takes about 5 hours.

Appendix A contains charts of Great Lakes port distances from each other and also to some overseas ports. The charts estimate an average sailing time of 12mph (10.4 knots).

4.1.5 Seaway Closing Information

The only entrance to the Great Lakes is through the Saint Lawrence Seaway, which due to ice can become dangerous and must be closed in multiple locations for a portion of the winter. The locks along the seaway are made up of the Welland Canal, Lake Ontario region, and Sault Ste. Marie region.

According to the Great Lakes St. Lawrence Seaway Notices (15) for the past 6 years, the locks at Sault Ste. Marie close on or around January 15, while the remaining areas close between December 20 and 29 depending on the severity of weather conditions for the year. The Sault Ste. Marie locks reopen on March 25, the others open between March 21 and 31. This is shown in Tables 4.1.5.1.

Winter closure impacts Great Lakes shipbuilding in two ways:

1. The closure of the seaway affects the shipyard required capacity needs as well as its new ship delivery schedule. Since the shipyard has a condensed new ship delivery schedule it will need to have additional capacity to maintain an equivalent throughput when compared to gulf coast yards. It will also need to negotiate with customers who would require delivery of a ship during the closure months. It may also be difficult to engage in the partial build scenario discussed earlier. The winter closure may cause scheduling and sequencing issues with the final vessel integrator.

2. The closure also affects ship repair opportunities by decreasing the number of ships that enter the Great Lakes as well as eliminating the opportunity of capturing possible repair work during the closure months. International short sea shipping possibilities are also lost due to the winter closure thus eliminating possible increase repair opportunities.

Table 4.1.5.1: Seaway Closings and Openings From 2001 – 2006 (15)

SEAWAY REGION 2001	DATE OPENED	DATE CLOSED
Welland Canal	3/23	12/24
Lake Ontario	3/23	12/20
Sault Ste. Marie	3/25	1/15

SEAWAY REGION 2002	DATE OPENED	DATE CLOSED
Welland Canal	3/26	12/24
Lake Ontario	3/26	12/20
Sault Ste. Marie	3/25	1/15

SEAWAY REGION 2003	DATE OPENED	DATE CLOSED
Welland Canal	3/31	12/24
Lake Ontario	3/31	12/20
Sault Ste. Marie	3/25	1/15

SEAWAY REGION 2004	DATE OPENED	DATE CLOSED
Welland Canal	3/23	12/26
Lake Ontario	3/25	12/20
Sault Ste. Marie	3/25	1/15

SEAWAY REGION 2005	DATE OPENED	DATE CLOSED
Welland Canal	3/23	12/26
Lake Ontario	3/25	12/20
Sault Ste. Marie	3/25	1/15

SEAWAY REGION 2006	DATE OPENED	DATE CLOSED
Welland Canal	3/21	12/26
Lake Ontario	3/23	12/20
Sault Ste. Marie	3/25	1/15

4.1.6 Transportation Options for Seaway Region

Having to go through a series of locks in the Saint Lawrence River slows the transit of a ship. However, depending on the destination, this path of travel may still be significantly faster than transporting cargo by railway, truck, or another mode of transportation.

4.2 Labor Considerations

A commonly expressed viewpoint shared by Midwest shipbuilders and owners is the difference between the labor environments in the Midwest compared to the Gulf Coast. The common belief is that labor rates, cost of living differences, labor practices, and union influences hinder Great Lakes shipyards ability to be competitive within the U.S. markets. This section will address those concerns.

4.2.1 Right to Work

All Great Lakes states are forced-unionism states while all southeastern states are right to work states, as shown in Figure 4.2.1.1. This translates to differences in average labor rates and labor practices between the regions. All states that do not force unions generally have lower and more competitive wages and thus lower ship prices than unionized states. The right to work issue may keep the Great Lakes from being as competitive as the Gulf Coast states.

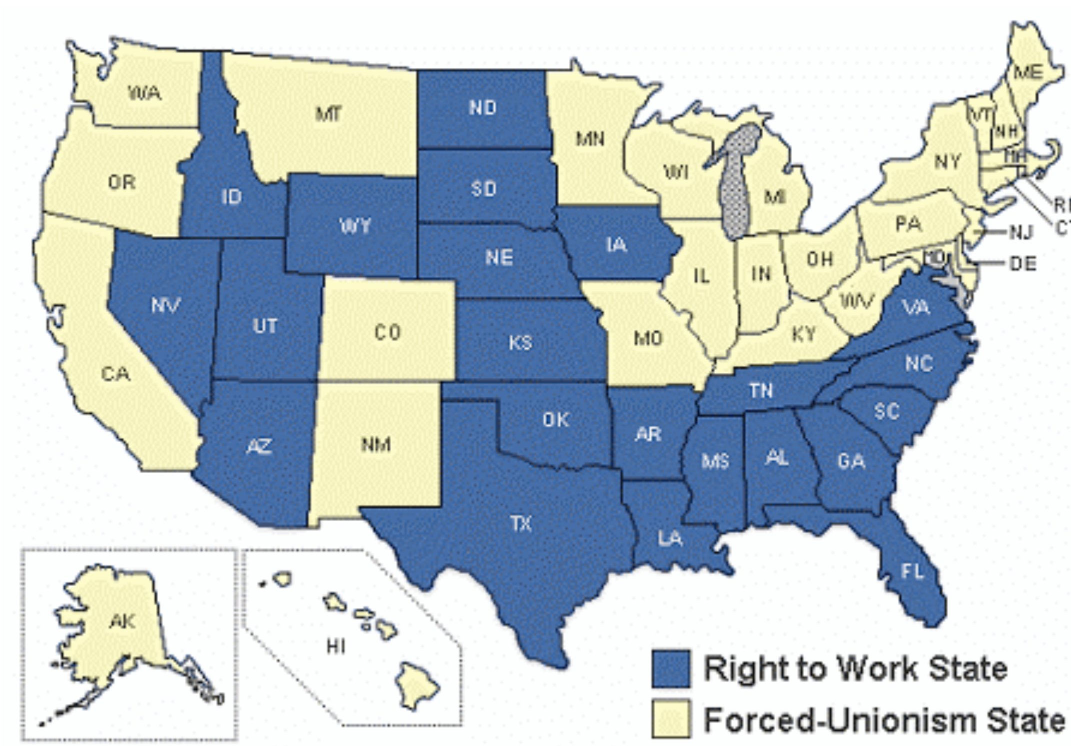


Figure 4.2.1.1: Right to Work and Unionized States

4.2.2 Wage rates comparison

Regional wage rate data was gathered from the U.S. Department of Labor Bureau of Labor Statistics (BLS) database system. The supporting information can be found at www.bls.gov.

The BLS splits the country into census divisional data. The three divisions evaluated and their included states are presented in Table 4.2.2.1 while the wage rates for each region are presented in Table 4.2.2.2.

Table 4.2.2.1: BLS Census Divisional Data

Census Divisions Name	States Included
East North Central Census Division (ENC)	Michigan, Ohio, Indiana, Illinois, Wisconsin
East South Central Census Division (ESC)	Kentucky, Tennessee, Alabama, Mississippi
West South Central Census Division (WSC)	Texas, Louisiana, Arkansas, Oklahoma

Table 4.2.2.2: Wage Rates for Each Region

Area	Occupation	Year	Hourly Rate
ENC	All occupations, excluding sales	2005	$19.09
ENC	White collar occupations	2005	$22.93
ENC	Blue collar occupations	2005	$16.83
ENC	Welders and cutters	2005	$16.15
ESC	All occupations, excluding sales	2005	$14.83
ESC	White collar occupations	2005	$18.51
ESC	Blue collar occupations	2005	$14.64
ESC	Welders and cutters	2005	$14.58
WSC	All occupations, excluding sales	2005	$16.62
WSC	White collar occupations	2005	$20.52
WSC	Blue collar occupations	2005	$13.78
WSC	Welders and cutters	2005	$13.87

The data gathered shows that the average blue-collar worker in the Midwest makes $2-$3 more per hour than the average blue-collar worker in the Gulf States. Additionally, white-collar workers in the Midwest make an average $2-$5 more per hour than white-collar workers in the Gulf States. Labor cost are a significant part of overall shipbuilding cost thus the labor differences between the Midwest and the Gulf is a barrier to the success of the Great Lakes shipbuilding business.

4.2.3 Cost of Living Comparison

For this study, the BLS Consumer Price Index (CPI) is used as the basis for comparing the cost of living difference between the different geographic regions. Even though the CPI is not a cost-of-living index it does measure the average change over time in prices paid by consumers in a region for a market basket of consumer goods and services. The cost of goods does correlate to the salary requirements needed to sustain a workforce within that region.

The CPI data presented is for two areas and three class sizes within those two areas. Class A population size class represents all metropolitan areas over 1.5 million; B/C represents mid-sized and small metropolitan areas (fewer than 1.5 million); and D, all non-metropolitan urban areas. The CPI values for different regions are presented in Table 4.2.3.1.

Table 4.2.3.1: CPI Data

Region	Consumer Type	CPI Value 2006
Midwest – Size Class A	Urban Wage Earners and Clerical Workers	188.5
Midwest – Size Class A	All Urban Consumers	194.0
Midwest – Size Class B/C	Urban Wage Earners and Clerical Workers	122.5
Midwest – Size Class B/C	All Urban Consumers	122.8
Midwest – Size Class D	Urban Wage Earners and Clerical Workers	185.2
Midwest – Size Class D	All Urban Consumers	187.1
South – Size Class A	Urban Wage Earners and Clerical Workers	194.8
South – Size Class A	All Urban Consumers	195.7
South – Size Class B/C	Urban Wage Earners and Clerical Workers	122.5
South – Size Class B/C	All Urban Consumers	123.5
South – Size Class D	Urban Wage Earners and Clerical Workers	195.2
South – Size Class D	All Urban Consumers	193.7

The CPI data disproves the belief that there is cost of living difference between the Midwest and Gulf Coast regions. Given certain cities within each region may have a higher or lower cost of living, in general the two geographic regions are the same with regards to buying power of residence in those regions.

4.2.4 Workforce Age Issues

In a recent RAND study (1) that investigated the reasons to why the cost of Navy ships have raised several national workforce issues were presented. The issues that exist in the naval construction shipyards also exist in the Great Lakes region. The two issues are the aging workforce and the "green labor". The national shipbuilding workforce is split between workers who are more than 45 years of age with more than 20 years of experience and workers who are less than 35 years of age with less than 5 years of experience (24).

What does this mean for Great Lakes shipbuilding? The consequence of this age gap is that the industry will see a large number of retirements within the next decade. This will leave rather inexperienced labor to take the place of the experienced labor. If you add the fact that shipbuilding is a challenging and tough work with unstable demand young potential laborers will most likely choose high-tech or other service industries with better compensation and better working conditions.

The southern region of the US has established industry, state, and federal funded shipyard labor development and outreach programs. If the Great Lakes region wanted to expand its shipbuilding base such ventures will be needed to create the needed workforce.

4.3 Facility and Environment Considerations

Environmental conditions impact shipbuilding in many ways ranging from speed of production, quality, and the introduction of advance manufacturing equipment. A 1974 National Shipbuilding Research Program (NSRP) study titled "Cost effectiveness study of weather protection for shipbuilding operations" concluded that in colder environments covered, heated working areas are cost effective and improve production times, quality and enable the introduction to advance manufacturing equipment. The study concluded that productivity improvements to cold weather shipyards ranged from 20% - 30%. Even though the referenced NSRP study is rather old, one could argue that the productivity savings today would be substantially greater given the reality of robotic welding and other automation technology that is now available compared to 1974. These types of equipment cannot be used unless they are placed in a temperature and weather controlled environment. The Great Lakes region is a cold environment. If new shipbuilding opportunities are going to take place, modern covered, environmentally controlled facilities will be needed.

4.4 Cost of production

For this study, the BLS Producer Price Index (PPI) will be used as the basis for evaluating the cost of producing ships within the United States. Since a large number of ships built within the US are governmental cost plus contracts the PPI is a good indicator of the relative cost of ship production given that the government sets the percentage of profit available to the producing ship yards.

Table 4.4.1: Producer Price Index

Business Sector	PPI in 2001	PPI in 2006	% Change
Ship and Boat Building	152.6	181.4	18.87%
Ship Building and Repairing	140.1	169.9	21.27%
Military New Construction		165	
Nonmilitary New Construction	160.9	211.9	31.70%
Ship Repair Military	146.2	174.2	19.15%
Ship Repair Nonmilitary	137	163.2	19.12%
Ship Building and Repairing Primary Products	141	171.5	21.63%
Boat Building	186.3	214.1	14.92%
Boat Building Outboard Motorboats, Commercial and Military	192.2	232.8	21.12%
Boat Building Inboard Motorboats, Commercial and Military	190.4	209.4	9.98%

The PPI data in Table 4.4.1 shows that the cost of shipbuilding has increase at a rate grater than inflation over the past 5 years. This is due to the large increase in raw material costs as well as energy cost over the past 5 years. Military vessel costs have increased an average annual rate of 10% per year for the last 50 years. The cost of vessel increase, must match the revenue opportunities of the ship owners. If revenue opportunities do not increase then new vessels created within the Great Lakes region will need to be sold at a rate that will limit the profit opportunities of the shipyard or may even require the shipyards to take a small loss.

5.0 Shipbuilding and Ship Repair Market Opportunities

In order to justify increasing the shipbuilding capacity within the Great Lakes one must look at the possible markets that will provide potential revenue to justify the investments. The industry of shipbuilding and ship repair is a worldwide market. To secure contracts and jobs that will keep its yards functional, the Great Lakes shipyards must be competitive with the rest of the nation and the world. Currently, the Great Lakes region is losing a lot of its market to other U.S. shipyards and to foreign countries. The Gulf of Mexico region has right to work laws, warmer environment, lower wage rates, and a similar cost of living and therefore have better opportunities to capture shipbuilding contracts due to the decreased labor costs and facility requirements. The U.S. has plans to increase both its military and commercial fleets but it will be difficult for the Great Lakes shipyards to get this business due to more appealing yards in other parts of the country. On the international scale, the U.S. has high labor costs that keep international business in foreign countries.

5.1 Short Sea Shipping Market

Short Sea Shipping (SSS) has many advantages including relieving highway and border congestion, and reducing greenhouse gas emissions. In the past decade, SSS in Europe has experienced significant growth and the European Commission wishes to transfer all freight growth in the coming years to non-highway modes.

SSS should be viewed as complementary to, rather than competing with, truck and rail. There are benefits of SSS for trucks and rail such as addressing driver shortages, helping retain drivers, or overcoming heavily congested corridors. Other benefits include financial advantages due to carrying more cargo at once, reduced energy consumption, fewer vehicle emissions, traffic accidents, and less need to build road and rail facilities. There will also be increased investment and employment in shipbuilding and inter-modal transportation services.

Expansion of SSS within the Great Lakes as well as from the east coast of North America through the seaway to Midwest ports should have positive impacts to the shipbuilding and repair business within the Great Lakes.

5.1.1 International Cargo

A Short Sea Shipping Market Study conducted by MariNova Consulting Ltd. (7), found that a short sea service based purely on international cargo is not financially viable. The MariNova study evaluated the scenario of a foreign ship that calls to the Port of Halifax, at the mouth of the St. Lawrence Seaway, and reloads onto a short-sea shipping vessel to travel into the Great Lakes at its final destination of Hamilton, past the majority of the locks.

Two major issues contributed to the study’s conclusions. The first issue dealt with winter service container and general cargo service. Due to the fact that the Saint Lawrence Seaway closes for a few months in the winter season, ships have no other option but to call to ports outside the Great Lakes and rail to their final destinations. If short sea shipping is to be successful, the industry must have a way of keeping their customers during these months. The possibility of providing the continuation of container shipping using truck or rail during the winter months is not possible. Shifting transportation methods is not advantageous to shippers. Shippers depend on predicable, dependable service. This type of service is guaranteed via long term contracts with rail companies and trucking companies. If shipping companies, especially container shippers, wanted to take advantage of the Seaway's time and cost savings the Seaway would need to be opened year round.

The second issue that led to the conclusions of the study is the restrictive Canadian and US policy and regulatory conditions that cause a barrier to entry. These barriers increase vessel construction and operational cost thus making the start-up phase when cargo is building not economically feasible.

An additional issue not addressed in the study is the lack of container terminal infrastructure within the Great Lakes region. Winter navigation is not solely a seaway lock issue but the shallow depths of some of the ports, lack of needed equipment to keep piers open during winter, and the lack of container infrastructure are also barriers to entry for short sea shipping. Either state and/or federal funds will be needed to remedy these constraints, or a unique ship type will be needed to work around the problem. Great Lakes self un-loaders are example of a ship type that provides an infrastructure workaround.

5.1.2 Domestic Cargo

Recent completed studies (6,18) evaluated domestic short sea shipping as a more viable option for the Great Lakes region compared to international cargo because it can be performed year round since it does not require access to the locks in the St. Lawrence Seaway. These studies concluded that there are two distinct markets for short sea shipping on the Great Lakes: the longer-distance bulk commodity market and the short-distance RO/RO market for trucks and containers. Table 5.1.2.1 shows the current Great Lakes domestic cargo-carrying ships.

Table 5.1.2.1: The Great Lakes Domestic Cargo-Carrying Ship Fleet (18)

Vessel Type	Number of Ships
Bulk Carriers	27
Self Unloaders	85
General Cargo Ships	15
Tankers	16
RO/RO Ships	2
Container Ship	0
Small-Cargo Vessel	11
Subtotal	**156**
Dry-Cargo Barges	53
Liquid-Cargo Barges	29
Tug Boats	412
Total	**650**

With the current Great Lakes domestic cargo-carrying ship fleet short sea shipping must, at least in the short run, focus on the bulk commodity market. Already existing, the bulk market requires changes in the form of smaller quantity shipments and reduced lockage fees for small vessels. While tugs and barges can be domestically supplied through re-builds, larger Ro/Ro ships capable of handling truck-competitive times may have to be imported from outside Canada and the U.S. These larger Ro/Ro ships may have to include passengers and automobiles to make the trips economical and to therefore offer a sufficient number of trips per day to be time-competitive.

Just like anywhere else, the conditions necessary for short sea shipping success on the Great Lakes include schedule reliability, fast loading/unloading and transshipment, and competitive times and costs.

5.1.3 Scenario London to Cleveland: Seaway vs. Train

When transporting goods into the U.S. that have a destination past the East Coast, the Great Lakes provide a quicker route to the middle of the country. There are two options when transporting goods to the Midwest region of the U.S. from overseas; ship from port to port through the St. Lawrence Seaway, or ship to coastal port and transport to final destination with rail. Table 5.1.3.1 shows the travel times between both scenarios.

Table 5.1.3.1: Ship vs. Ship & Train (12, 22)

Transportation	Start	End	Speed	Distance	Duration
Ship	London	Cleveland	16 knots*	3544 nautical mi	9d 6h
Ship &	London	Newark	20 knots	3224 nautical mi	6d 17h
Rail	Newark	Cleveland	Unknown	Unknown	7d 22h

* 20 knots estimated ocean going; through seaway, 10.4 knots is average (Seaway Facts). Appendix B & C have visuals for distance of both paths.

The table above shows that for quicker delivery it is beneficial to use the St. Lawrence Seaway; saving about 4 days of travel time, in addition to time spent unloading the ship and loading the train.

5.1.4 Scenario Madison to Detroit: Short Sea Shipping & Truck vs. Truck

When a body of water stands between your current location and destination, a method of quicker transportation is short-sea shipping that saves travel time. In this scenario, loaded trucks coming from Madison Wisconsin drive to Milwaukee Wisconsin where they load onto a Ro/Ro ship to Muskegon Michigan; from there they continue driving to their final destination Detroit Michigan. The other possibility is to truck from Madison to Detroit via highway.

Table 5.1.4.1: Truck vs. Ship & Truck (6)

Transportation	Start	End	Distance	Duration
Truck	Madison	Detroit	432 mi	9.5h
Truck & Ship & Truck	Madison Milwaukee Muskegon	Milwaukee Muskegon Detroit	Total: 303mi	Total: 7.5h

Shipping across Lake Michigan is faster than driving the entire way because the Ro/Ro allows the trucks to drive right into it at a quick loading and unloading rate. Avoiding the longer distance of driving around the lake saves 2 hours, excluding traffic delays, in this scenario as seen in Table 5.1.4.1

5.1.5 Benefits of Shipping in Great Lakes

A ship's typical capacity of 25,000 metric tons requires an equivalent of 225 rail cars and 870 trucks to carry the same amount of cargo. In this respect, keeping cargo onboard a ship as long as possible compared to removing cargo far from the final destination and continuing on rail or truck is more economical from an economy of scale perspective in addition to the additional economical advantage by the reduction of road damages. These advantages become more significant when you look at the heavily congested ports and highways in the east and west coast.

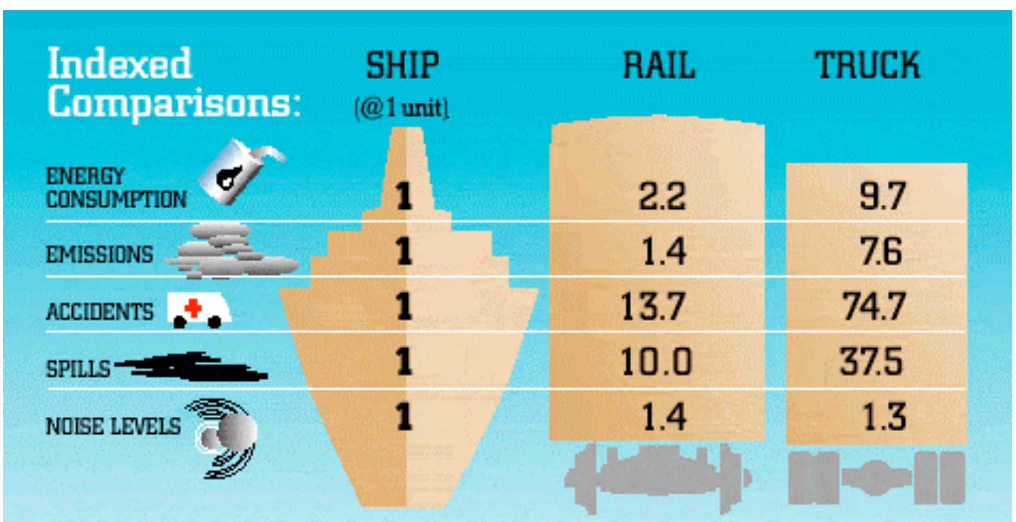


Figure 5.1.5.1: Transportation Method Comparison (10)

5.1.6 Most Economical

Carrying a ton of freight, a ship can travel 500 miles (800 km) on 1 gallon (4 liters) of fuel. In comparison, a train can bring the freight 62 miles (100 km) and a truck can go 19 miles (30 km), as shown in Figure 5.1.6.1.

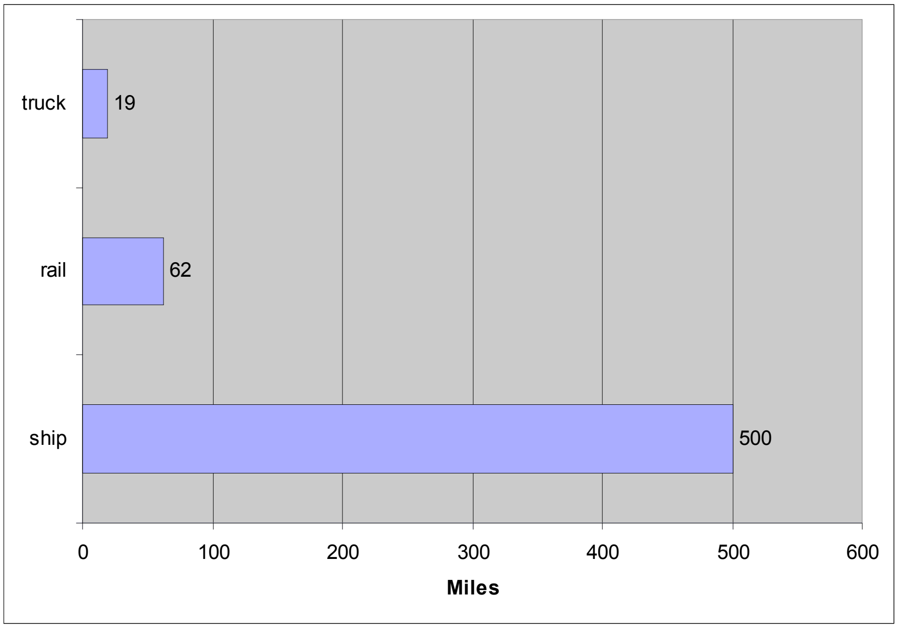


Figure 5.1.6.1: Miles Traveled on 1 Gallon of Fuel (10)

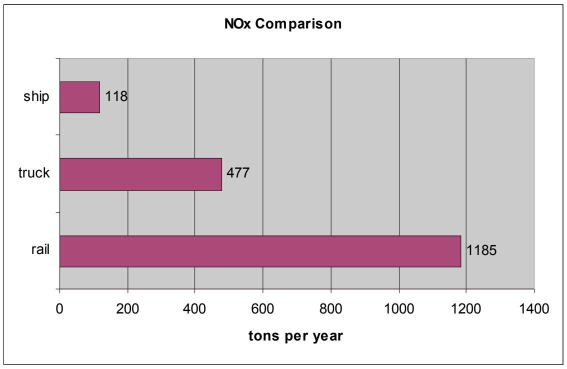
Marine transportation also is economical in the respect that it does not damage its waterways in the way that truck and trains destroy roads and rails. The Midwest states spend hundreds of millions of dollars annually to repair roads. This is due do weather wear and the large amount of truck traffic. Roads can take a finite amount of weight and use and once that is exceeded, they must be replaced. The same goes with railways, they can only take a certain amount of use and abuse before wearing. Water on the other hand, does not have a limit and can be used repeatedly and more economically than roads. One truck is equivalent to 10,000 – 20,000 cars with regards to pavement impact.

5.1.7 Environmental Impact

Of the three modes of transporting freight, ships have the superior fuel efficiency. Ships emit one-tenth the greenhouse gases of trucks and half that of trains. Therefore, ships are much better for the environment than other options of transportation.

A study done in 2004 (17) in the Cleveland Ohio region shows how marine transportation has far less emissions than trucks and rails carrying cargo from ships. The emissions evaluated in this study are: hydrocarbon (HC), oxides of nitrogen (NOx), carbon monoxide (CO), and particulate matter (PM listed as PM-10 and PM-2.5).

As seen in Figure 5.1.7.1, ships release much fewer harmful emissions than trucks and rail.



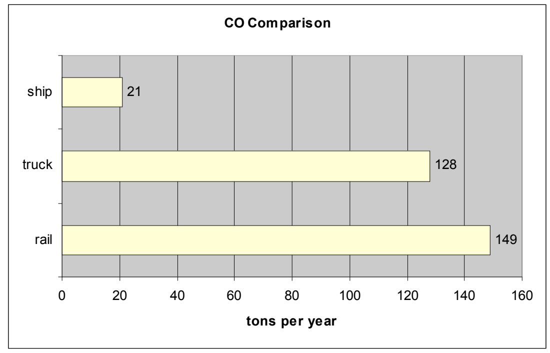


Figure 5.1.7.1: Annual Emission Comparisons Between Transportation Methods (17)

Many studies have repeatedly shown the environmental value of marine transportation. The major issue concerning US shipbuilders is how the environmental social value and saved roadway repair cost are translated to the shipbuilders and ship owners. Currently the European Union provides subsidies to shipbuilders and ship owners willing to enter the short sea shipping market. The large capital investment required to produce ships and moving cargo off the roads will require governmental incentives to make the business viable and profitable.

5.2 Current Great Lakes Markets

After a shipbuilding boom in the 1980's due to the Navy fleet buildup, American shipbuilding has declined in both domestic and international production (23). The Great Lakes region has lost a lot of its shipbuilding market to foreign countries and to U.S. Gulf Coast builders. In addition to the aging workforce and Jones Act requirements affecting the country, the Great Lakes shipbuilders have other production ailments and physical limitations when it comes to competing in the national and international shipbuilding markets.

Another issue that is unique to the Great Lakes is the fact that the Great Lakes are fresh water. This seems to be a trivial fact but ships that operate on the Great Lakes can last four to five times longer than an equivalent ocean going vessel. Currently Great Lakes ship owners are not replacing their vessels and have stated that they have no intention of replacing them in the future. To handle the increase in energy costs, ship owners are replacing the older, less efficient engines with modern efficient ones. Because of this, ship repair and conversion has a stable demand in the Great Lakes region and should increase in the coming years depending on changes in environmental regulations that may impact ship owners. The labor and technical skills within the GL region are well suited for this type of work.

5.2.1 Military

There is always need for military shipbuilding during wartime. However, after the mass amounts of ships are created, the industry demand plummets and the shipyards have much fewer contracts for new vessels. Additionally, the military tend to be conservative and will favor working with yards that they have worked with in the past. The exception is the current LCS vessel completed by Marinette Marine. The continuation of the LCS program is currently in negotiation within the Navy. Most news sources say that another LCS vessel will be unlikely.

5.2.2 Commercial

The commercial shipbuilding industry has faltered since government subsidies ended in 1981. Now, shipbuilders in the region are losing a big piece of their market with much of the foreign competition receiving subsidies averaging 30-35 percent of their construction costs. With low demand, and construction moving overseas to take advantage of cheaper labor, there is now a more stable future in ship repair. The exception has been in the luxury yacht building market. There are currently two major luxury yacht producers on the Great Lakes. The successful introduction of another in the region is low. A Jones Act tugboat is another potential opportunity for the Great Lakes. The issue is that the increased tugboat demand is being met and the GL shipbuilders would be late to entry in that market.

5.2.3 Current Ship Repair Opportunities on the Great Lakes

The need for ship repair is much greater than shipbuilding in the Great Lakes region, mostly because the Great Lakes ships have a far longer lifespan than ocean-going vessels. Corrosive salts in the ocean can make a vessel ineffective within 25 years. As a result, the demand for new ship construction has fallen, while demand for repair and refurbishing of the older vessels has risen. Additionally, repairs are done in the winter months on ships having to remain in the Great Lakes.

5.2.3.1 Military

The Great Lakes ship repair industry does not have the opportunity to work with military vessels with the exception of a few Coast Guard vessels. The repair business on the Great Lakes is only in commercial ship repair.

5.2.3.2 Commercial

Each winter, current shipyards are repairing and maintaining vessels that remain in the Great Lakes region or ones that are not able to travel out of the lakes due to freezing and seaway closings.

5.3 Gulf of Mexico Region Market

Much of the shipbuilding and repair jobs are being taken by Southern or Gulf of Mexico region shipyards, not leaving many options for the Great Lakes shipyards. Much of this has to do with the unionization law differences between the two regions, wage rates, easy of market entry due to better weather, proximity to the growing Gulf of Mexico oil industry (5,16), and congressional support.

5.4 National Market

The U.S. Market is much different than the Great Lakes market segment. In addition to the building of some commercial vessels, military contracts are important to the success of this industry.

A near problem for the country is an aging workforce. This does not provide a stable future for the American shipbuilding companies. The current nationwide average age of shipyard production workers is 42.1 years and large volumes of replacement workers are not readily available (1).

Although the present state of both military and commercial shipbuilding looks stagnant, there are plans to put new ships in the waters in military and commercial markets. This will be achieved through the MARAD Title XI program funding and the new Title IV of the Transportation Energy Security and Climate Change Mitigation Act of 2007 funding for domestic shipbuilding increase as well as an increased budget for military shipbuilding.

5.4.1 Military

In the 1980's, the U.S. shipyards thrived during the Navy fleet buildup. Since the need for Navy ships has declined lately, shipbuilders have had fewer new vessel contracts. However, new military projects are underway. All in the beginning stages of construction are the 300 Ship Navy as well we the Coast Guard Integrated Deepwater System (26).

The Navy plans to build 280 new vessels between 2007 and 2036. The Congressional Budget Office estimated the Navy would spend about $21 billion to carry out this plan. Table 5.4.1.1 shows how many of each type of ship will be built in each upcoming year. This will provide U.S. shipbuilders an increase in business.

Table 5.4.1.1: Long Range Naval Vessel Construction Plan (8)

	Near Term					Mid Term									Far Term															
Type/Class	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Aircraft Carrier		1				1				1					1				1				1					1		
Surface Combatants	2		1	1	2	1	2	1	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Littoral Combat Ships	2	3	6	6	6	6	5	6	6	5														1	3	2	3	6	6	6
Attack Submarines	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	1	2	1	2	1	2
Cruise Missle Submarines																														
Ballistic Missle Submarines																1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Expeditionary Warfare Ships	1	1		1								1			1	1	1	2	1	1	2	2	1	2	1	1	1			1
Combat Logistics Force	1	1										1		1	2	2	2	2	3	3	2	1								
Mine Warfare Ships																														
Maritime Perpositioning Force (Future)			2	2	4	2	1																							
Support Vessels			1	1	1	1	2	2	1	1					1	2	3	2		1	1		1	2						
Total New Construction Plan	7	7	11	12	14	13	12	11	11	10	4	6	4	5	9	10	11	11	10	10	10	8	7	10	8	8	8	12	10	11

The Coast Guard's Integrated Deepwater System is a multi-year program to modernize and replace the Coast Guard's aging ships and aircraft, and improve command and control and logistics systems. It is an $11 billion contract which covers both marine and air vessel construction. The bulk of the ship construction is awarded to Northrop Grumman's Ingalls and Avondale shipyards. Subcontract work for smaller vessels will go to Bollinger Shipyards and Halter Marine. This benefits several Gulf Coast shipyards, providing no scheduled work for the Great Lakes shipyards.

When complete, the Integrated Deepwater System will include three classes of new cutters and their associated small boats, a new fixed-wing manned aircraft fleet, and combination of new and upgraded helicopters, and both cutter-based and land-based unmanned air vessels. All of these highly capable assets are linked with Command, Control, Communications and Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) systems, and are supported by an integrated logistics regime.

The five types of cutter ships the shipbuilding industry will be constructing include Fast Response Cutter, National Security Cutter, Offshore Patrol Cutter, Long Range Interceptor, and Short Range Prosecutor.

5.4.2 Commercial

The national U.S. commercial market is limited by the Jones Act, which requires all vessels operating between U.S. ports are U.S. owned, built, and operated. This causes difficulties among the international commercial market, having operated exclusively in a protected domestic market; the U.S. shipbuilding industry has not implemented the best commercial processes necessary to compete in the international arena. Even though international shipbuilding is not a huge market for the U.S., there are hundreds of national commercial ship deliveries every year, as shown in Table 5.4.2.1 below.

Table 5.4.2.1: U.S. Commercial Vessel Deliveries, 2000-2006 (3)

Vessel Type	2000	2001	2002	2003	2004	2005	2006	Totals
Oceangoing Tankers	0	1	1	1	2	2	3	10
Oceangoing Cargo Ships	1	0	0	3	1	2	1	8
Large Tank Barges	0	1	11	11	9	6	10	48
Large Dry Cargo Barges	1	3	2	0	4	1	3	14
Semi-Submersible Drill Rigs	1	0	2	0	2	0	0	5
Jack-Up Drill Rigs	1	1	1	1	2	1	1	8
Offshore Service Vessels	27	22	31	34	32	15	14	175
Crewboats	19	20	22	19	11	19	15	125
Tugs	22	18	20	20	20	16	23	139
Towboats	13	21	15	16	25	21	42	153
Ferries & Other Passenger	10	11	13	21	20	12	12	99
All Other Self-Propelled	3	3	5	2	1	7	4	25
Subtotals	98	101	123	128	129	102	128	809
Commercial Fishing Vessels	95	113	71	14	5	1	0	299
Totals	193	214	194	142	134	103	128	1108

As a positive opportunity for the commercial market, legislation that would provide enough federal monies in loan guarantees to generate $2 billion worth of domestic shipbuilding over the next four years was voted out of the House Transportation and Infrastructure Committee. This provision was part of Title IV of the Transportation Energy Security and Climate Change Mitigation Act of 2007 (H.R. 2701). Introduced by Rep. James Oberstar (D-MN), the legislation would better integrate domestic short sea shipping (also known as America's Maritime Highway) into the nation's overall inter-modal transportation system. The overall aim of the bill is to reduce global warming through greater transportation efficiencies and conservation initiatives. Other maritime provisions in the final version that passed the House committee pertain to tax incentives to stimulate the use of U.S.-flag vessels in an effort to reduce congestion in the rail and highways systems. Other objectives focus on port and shipyard pollution. The actual amount devoted to loan guarantees is $100 million. Economic studies indicate that every $1 allotted for loan guarantees generates $20 worth of shipbuilding work.

5.4.2.1 OPA-90

A future opportunity for U.S. shipyards is the passing of OPA-90; enacted following the 1989 Exxon oil spill disaster (4). This legislation requires that all vessels carrying petroleum products in U.S. waters must be replaced with double-hulls by 2015. In addition to preventing and controlling oil spills, it will also control and prevent other hazardous substances. There are currently a large number of these smaller barges that will not meet the OPA-90 requirements and have to be replaced in the near future and could cause a U.S. shipyard capacity problem. Although the schedule for the new regulations has already been delayed several years and there is no precise implementation date released, it is the next logical progression and cannot be put off any longer. OPA-90 barge conversions and new building is a strong active business with the Great Lakes with Bay Shipbuilding leading the effort. They have invested in advance manufacturing capabilities that has enabled them to obtain a high level of productivity.

5.5 International Market

The U.S. shipbuilding industry is the world's largest in terms of sales volume due to Navy contracts, yet remains uncompetitive in the international shipbuilding market. The U.S. shipbuilding industry is responsible for only one percent of international shipbuilding as shown in Figure 5.5.1. Of that one percent, a huge portion is Jones Act vessels.

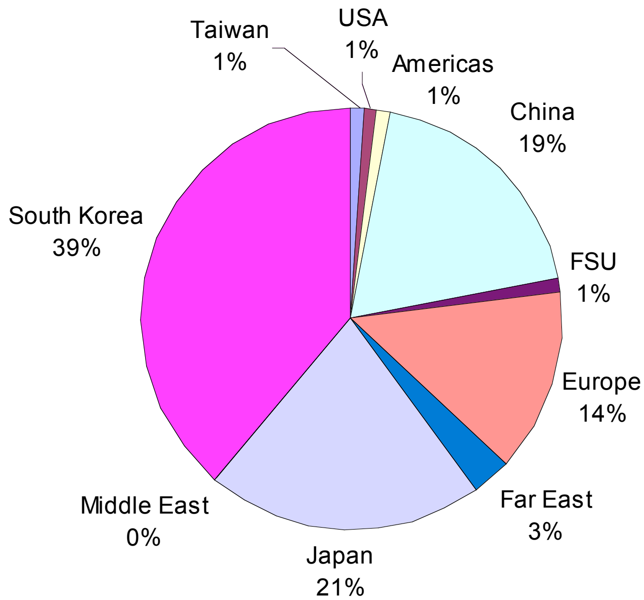


Figure 5.5.1: International Orders by Country of Build (As of 16 Aug. 2006) (3)

U.S. shipbuilding has been examined repeatedly in recent years with general agreement about the major findings. From the shipbuilders' perspective, the major problem is that too few large ships are being ordered and built; and from the perspective of buyers, the major problem is that large U.S. built ships cost too much. There is no consensus, however, about what can, or should, be done about the major problems nor about the relative importance of many related issues.

Historically, many vessels have been built at foreign yards, which have a cost advantage over U.S. shipyards because of lower wages, more innovative manufacturing techniques and government subsidies.

The commercial outlook for U.S. shipbuilders is poor. It is difficult to compete on the international commercial market due to high material and labor costs as well as lower productivity when compared to highly automated European and Asian yards. Additionally, U.S. labor issues such as union resistance to employee cross-training keeps labor costs high.

5.6 Non-Traditional Approach: Creation of Market Through High End Engineering; The Austal Model

Austal Limited, an Australian company, commenced operations in 1988 with a vision to build high quality commercial vessels for the international market. By the company's fifth anniversary, Austal had become the world's leading manufacturer of 40 meter passenger catamarans and the dominant supplier to Asia.

It was in Hong Kong as early as 1993, that Austal introduced gas turbine propulsion and the first two installations of the Austal developed motion control system. The success in Asia and the introduction of a range of sophisticated, large vehicle-carrying fast ferries were the springboard for ongoing growth in Europe, the Mediterranean and the Asia-Pacific.

Today, Austal is the world's largest builder of fast ferries and is proud to list amongst its customers many of the world's leading fast ferry and shipping operators.

Austal listed on the Australian Stock Exchange in December 1998 and has diversified its product base through acquisitions of local shipbuilders and the establishment of a new US shipyard in Mobile, Alabama.

In 1998 Austal entered the patrol boat market securing an order for eight Bay Class vessels for the Australian Customs Service. Sizeable orders from other Australian and International agencies, including the Royal Australian Navy, have cemented the company's place among the world's elite patrol vessel builders.

In 2001, Austal became the first company to supply the U.S. military with a high speed vessel, the Theatre Support Vessel (TSV).

In 2004, the US Department of Defense awarded a final design contract for the US Navy's Littoral Combat Ship (LCS) project to prime contractor Bath Iron Works, a General Dynamics company. Austal is the LCS seaframe designer and builder. The first order for a US $223 million prototype was successfully awarded to the General Dynamics/Austal Littoral Combat Ship Team in October 2005. A second order was received in late 2006.

The US Navy LCS is based on the same 127 meter trimaran hullform of a revolutionary fast ferry delivered in 2005 that not only provided full scale validation for the LCS proposal but, by showing increased passenger comfort in operation, adds a further impetus to the already strong interest being shown in trimarans by ferry and defense operators.

There is little doubt, Austal provides one of the most substantial product bases of any shipbuilder worldwide. This includes passenger and vehicle-passenger ferries, coastal combat ships, high speed military support vessels, patrol boats, cruise vessels, live-aboards, offshore crew/supply boats and private vessels.

Austal's success in aluminum ship building is based on the fact that Austal is a high skilled engineering company that builds high technology vessels, **not** a shipbuilder who supports itself through in-house engineering.

5.6.1 Austal Model for the Great Lakes

Advanced materials such as composites, thin steel and aluminum are the future of advanced shipbuilding for maritime markets. To work with these materials highly skilled and highly technical engineers, as well as highly skilled blue-collar workers, are required. Advanced materials also require advance manufacturing facilities, technology, and equipment.

If year round short sea shipping between eastern coastal ports and ports within the Great Lakes become a reality then a possible market could be created for a high performance, Great Lakes specific, multi-cargo vessel. Historically, the uniqueness of the Great Lakes has forced innovations, such as self-unloading bulk cargo vessels. These “Lakers” are unique to the Great Lakes. Similar innovation is needed today if shipbuilding is going to increase on the Great Lakes.

The Great Lakes region needs to design and build an advanced vessel that would be part of the total GL inter-modal supply chain. This vessel should be made of thin steel or aluminum. The Great Lakes region needs to create an engineering and manufacturing base to support the development, production, and servicing of such a product. Once the GL market is realized and the expertise are developed within the region then Great Lakes shipbuilding could compete in the global shipbuilding and military market. Pieces of this structure currently reside within the region but a unified plan and support is needed to put the pieces together.

5.7 Market Opportunity Summary and Potential Economic Impacts

In summary, the current and potential markets available to the Great Lakes are varied. Except for in a few cases where expansion of current businesses are justified, there is little reason to expand the shipbuilding base on the Great Lakes. Things could change if new markets are created. If short sea shipping, as part of an inter-modal component of the Great Lakes supply chain, becomes a reality then investing in new shipbuilding base with the region becomes viable. Even with a potential new market, competition between the Great Lakes region and Gulf Coast is a real problem and must be taken into consideration. A summary of the markets and the relative value to the Great Lakes shipbuilding are listed below:

1) Repair
    a) The Great Lakes should see an increased demand for repair and conversion for ships that operate within the Great Lakes. Due to winter closure of the Seaway non-Great Lakes ships will not seek repair in the Great Lakes unless an emergency occurs.
    b) The Great Lakes labor force is suited for this type of work.
    c) Current facilities and labor are sufficient for the increase.

2) General Commercial
    a) Except for the luxury and possibly tugboat markets, general commercial vessels are not sufficient for sustained industry unless a new market is created.
    b) Current competition within the US as well as international competition may be too large for the Great Lakes to overcome.

3) Jones Act Traditional (Standard Ship Types)
    a) Short term possibility due to increased demand
    b) Late market entry compared to other shipyards such as Aker American Shipping who builds traditional Jones Act ships in its Philadelphia Pennsylvania shipyard. It will be difficult for Great Lakes shipyards to catch up and gain market share.

4) Military
   a) Low probability for large Navy contracts given the history of the LCS program and the Navy acquisition practice.
   b) Coast Guard is currently doing work on Great Lakes and will most likely want to diversify risk by providing business to other US shipyards. Additionally the issues with the Deepwater Project will most likely cause the Coast Guard to focus on the traditional Navy shipbuilding shipyards.
   c) Not viable for industry growth due to inconsistent demand.

5) OPA-90
   a) High volume of work.
   b) Good short-term opportunity for existing Great Lakes facilities.
   c) Does not increase GL competitiveness since a large majority of OPA90 volume are double-hulled barges. The ability to build barges does not mean a company can build ships. A company that can build ships can also build barges and in most cases will build them efficiently.

6) Austal Model
   a) High risk due to the large number of unknowns.
   b) High potential if successful.
   c) The Great Lakes region has a large heavy industrial base which will provide the needed technical resources to make this venture a reality.
   d) Long term viability if successful since it is based on a new market, short sea shipping, and high technology requirement. The Austal model could not only create a new shipbuilding and naval architecture industry within the Great Lakes but a new shipping market as well.
   e) Large government funding, policy changes, and seaway operations changes are needed.
   f) A new shipyard with new facilities could also provide an opportunity to create new level-land facilities which are more efficient than traditional graving dock facilities.

6.0 Conclusions

This study has presented an overview of the history of shipbuilding on the Great Lakes, information concerning past shipyards and currently active shipyards, a study of the factors that impact shipbuilding on the Great Lakes and an analysis of potential shipbuilding and ship repair markets available to the Great Lakes.

The Great Lakes has had a rich history of shipbuilding but has never reached the critical mass that other areas of the country has with regards to shipbuilding volume and number of employees. There are many contributing factors that include seaway limits, labor issues, and facility challenges.

Twenty-three shipbuilding locations, which include past and present, have been identified. A major issue that the researchers faced when completing this task concerns the accuracy of public documents. Many inconsistencies were found in local and federal documents that are used to describe current shipbuilding facilities. Other inconsistencies were found within the companies themselves. Some shipyards provide information to this study that was inconsistent when compared to the company's own websites. These discrepancies have been addressed to the appropriate agencies and companies.

A market study was completed as part of this research study. The study concluded that there is sufficient capacity within the Great Lakes region for the existing demand. Local governments such as the ports of Toledo Ohio and Door County Wisconsin have invested large sums to improve the shipbuilding and ship repair businesses in those regions. It was not the goal of this study to evaluate those decisions but the assumption is that those investments are justified. Even though local areas have invested in additional shipbuilding and ship repair businesses it is the conclusion of the researchers that there is little proof that a large scale increase in Great Lakes shipbuilding would be justified. Competition within the U.S. presents an impressive barrier to the Great Lakes. Unless new markets are created or large productivity investments are made, an increase in Great Lakes shipbuilding is unrealistic. On the other hand the Great Lakes ship repair business should see an increase in the future.

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Appendix A: The Great Lakes / Seaway System - serving the world

The Great Lakes / Seaway System – serving the world

Sailing distances from Seaway ports to overseas destinations (statute miles)

	Antwerp	Bremen	Copenhagen	Helsinki	Le Havre	Lisbon	London	Marseilles	Naples	Rotterdam	Tangier	Tunis
Chicago	4858	4918	5178	5666	4644	4567	4817	5716	6047	4864	4305	5840
Cleveland	4141	4201	4461	4949	3927	3850	4100	4999	5330	4147	3588	5123
Detroit	4225	4285	4545	5033	4011	3934	4184	5083	5414	4231	3672	5207
Duluth	4951	5011	5271	5759	4737	4660	4910	5809	6140	4957	4398	5933
Green Bay	4732	4792	5052	5540	4518	4441	4691	4590	5921	4738	4179	5714
Hamilton	3959	4019	4279	4767	3745	3668	3918	4817	5148	3965	3406	4941
Indiana	4873	4933	5193	5681	4659	4582	4832	5731	6062	4879	4320	5855
Lorain	4154	4214	4474	4962	3940	3863	4113	5012	5343	4160	3601	5136
Milwaukee	4793	4853	5113	5601	4579	4502	4752	5651	5982	4799	4248	5775
Monroe	4241	4301	4561	549	4027	3950	4200	5099	5430	4247	3688	5223
Ogdensburg	3733	3793	4053	4541	3519	3442	3692	4591	5922	3739	3180	4715
Oshawa	3897	3957	4217	4705	3683	3606	3856	4755	5086	3903	3344	4879
Oswego	3841	3901	4161	4649	3627	3550	3800	4699	5030	3847	3288	4823
Thunder Bay	4829	4889	5149	5637	4615	4538	4788	5687	6018	4835	4276	5811
Toledo	4218	4278	4538	5026	4004	3927	4177	5076	5407	4224	3665	5200
Toronto	3929	3989	4249	4737	3715	3638	3888	4787	5118	3935	3376	4911
Valleyfield	3617	3677	3937	4425	3403	3326	3576	4475	4806	3623	3064	4599
Windsor	4225	4285	4545	5033	4011	3934	4184	5083	5414	4231	3672	5207

Approximate sailing distances between Great Lakes ports (statute miles)

	Chicago	Cleveland	Detroit	Duluth	Green Bay	Hamilton	Indiana	Lorain	Milwaukee	Monroe	Ogdensburg	Oshawa	Oswego	Thunder Bay	Toledo	Toronto	Valleyfield	Windsor
Chicago																		
Cleveland	7 17																	
Detroit	633	84																
Duluth	808	810	726															
Green Bay	126	591	587	682														
Hamilton	899	182	266	992	773													
Indiana	15	732	648	820	279	94												
Lorain	704	13	71	816	578	195	719											
Milwaukee	65	652	568	743	180	834	80	639										
Monroe	617	100	39	765	491	282	632	87	552									
Ogdensburg	1125	408	492	1218	999	224	1140	421	1060	508								
Oshawa	961	244	331	1054	835	62	976	257	896	34	164							
Oswego	1045	380	412	1110	891	166	1032	313	952	400	108	56						
Thunder Bay	686	688	684	195	560	870	701	694	621	635	1096	932	968					
Toledo	640	77	62	733	514	259	655	64	575	23	485	321	377	611				
Toronto	929	212	256	1022	803	30	944	225	864	312	196	32	88	900	289			
Valleyfield	1241	524	608	1334	115	342	1256	537	1176	624	116	280	224	121	601	312		
Windsor	633	84	0	726	507	264	648	71	568	16	492	328	384	604	39	296	608	

Percent of world ocean fleet able to use the St. Lawrence Seaway

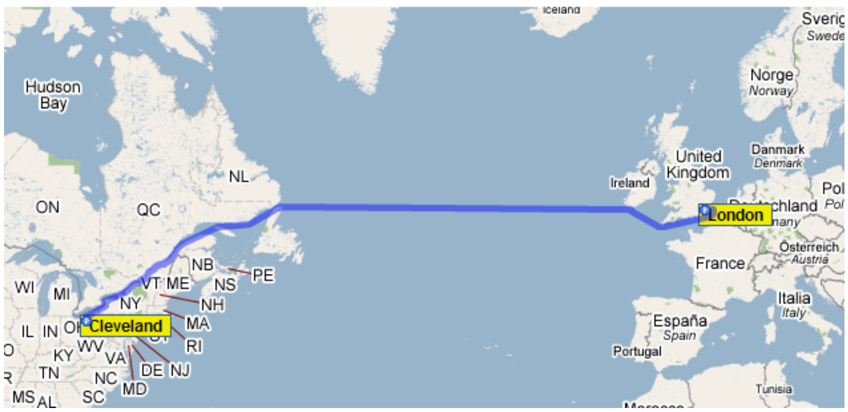
Based on Length (L) Beam (B) and Draft (D)

	L-B-D	L-B
All ships	44.4%	69.0%
Freighters	61.2%	88.8%
Bulkers	9.2%	39.0%
Tankers	38.9%	49.7%

Appendix B: Water transit London – Cleveland

Calculation results

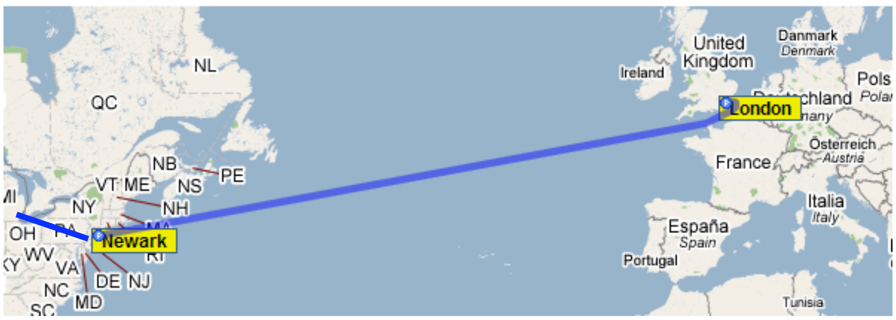
Port of loading: London, GB
Port of discharge: Cleveland, US
Distance: 3544 nautical miles
Vessel speed: 16 knots
Time: 9 days 6 hours



Appendix C: Water transit London - Newark & Train Newark – Cleveland

Calculation results

Port of loading: London, GB
Port of discharge: Newark, US
Distance: 3224 nautical miles
Vessel speed: 20 knots
Time: 6 days 17 hours



Service Schedules
Shipment Transit Times

Origin City, State:	NEWARK, NJ
Interchange Carrier:	
Destination City, State:	CLEVELAND, OH
Interchange Carrier:	CSXT
Service Date:	7/24/2007
Service Time:	00:01

Show Reverse Trip

Shipping Instructions Release Date	Shipping Instructions Release Cut-off Time	Delivery Date	Delivery Time	Total Time from Release to Delivery
Mon 7/23/2007	20:45	Tue 7/31/2007	18:30	7 days, 22 hours

Great Lakes Maritime Research Institute

A University of Wisconsin - Superior and University of Minnesota Duluth Consortium

The Effect of Long-Term Cold Storage on Biodiesel Blends

Final Report

Daniel N. Pope — Department of Mechanical and Industrial Engineering, University of Minnesota Duluth

November 26, 2007

University of Minnesota Duluth
Department of Mechanical and Industrial Engineering
105 Voss-Kovach Hall
1305 Ordean Court
Duluth, MN 55812-3042

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Executive Summary

The current project consists of two parts; the identification of the potential issues involved with the shipboard use of biodiesel blends, and the development of a long-term cold storage test and subsequent testing of biodiesel blends. The two parts of the project were conducted concurrently and in collaboration with fuel suppliers and carriers.

A review of typical diesel-powered ship systems was performed. In general, long-term cold storage of biodiesel blends is a concern in the following shipboard systems.

- Hatch/Deck Crane – This system has a low fuel turnover rate and is exposed to the external environment.
- Lifeboat Power Pack – This system has a low fuel turnover rate and is exposed to the external environment.
- Fuel Bunker and Main Engines – Even if heavy fuel oil (IF 280) is used as the primary fuel in the main engines, one fuel bunker is generally filled with no. 2 diesel near the end of the shipping season. Test results indicate that particulates may form in the fuel if a high percentage biodiesel blend (greater than B20) is used during winter lay up.

A long-term cold storage test was developed and results were presented for two different temperature ranges (23-25°F and 30-32°F). The test covered a period of four weeks and included a storage tank test for density variation via hydrometer testing of top and bottom tank samples, and the use of small samples to visually check for preferential gelling of the biodiesel component. The results of the long-term cold storage test indicate the following.

- The hydrometer tests indicated no measureable density difference between the top and bottom tank samples and thus no separation of the biodiesel component. This result was consistent for both temperature ranges.
- Particulate formation and settling was observed for a B50 blend in both the small sample and the bottom tank sample. This result was consistent for both temperature ranges.
- Blends up to B20 exhibited good cold storage characteristics for both temperature ranges.
- The flash point and viscosity of the small samples in the 23-25°F cold storage test were determined at the end of the test. All of the samples met the required fuel specifications.

An additional test to determine the effect of a common cold flow additive on biodiesel blends was also conducted. The test utilized small samples of no. 2 diesel, B5, B10, B20, B50, and B100 both with and without the additive. Sample temperatures were varied from 45°F to -9°F in 3°F increments. The samples were kept at each new temperature for a minimum of 24 hours to achieve thermal equilibrium. Visual inspection of the small samples and a review of the results established the following.

- The additive had a noticeable effect on the temperature at which a given biodiesel blend begins to gel. This was particularly evident for the B100 sample.
- The relatively simple procedure employed for this test yielded results for the B10, B5, and no. 2 diesel samples that appear to be inconsistent with the average cloud point of no. 2 diesel (3°F).
- Additional testing of a more quantitative nature could be undertaken to identify the appropriate mixture fraction of additive for each biodiesel blend.

There were several observations made during the tests that merit further investigation. The following additional work is therefore recommended to provide more detailed information.

- The chemical composition of the particulates formed in the B50 sample during the cold storage test should be determined.
- A filtration test using the samples from the cold storage test should be performed to check for particulates that could potentially plug fuel filters.
- A quantitative test to determine the appropriate mixture fraction of cold flow additive for each biodiesel blend should be performed. The test would consist of measuring the cloud point, pour point, and cold filter plugging point of biodiesel blends with varying mixture fraction of additive.

1. Introduction

The shipboard use of biodiesel blends presents some unique challenges due to the wide range of operating environments experienced by diesel-powered ship systems. Legislative and industrial efforts point to the use of up to 20% biodiesel blends for both on-road and off-road applications in the near future. These efforts are primarily driven by the advantages associated with the use of biodiesel. However, biodiesel also has some undesirable properties that can lead to operational problems. A majority of the potential problems are associated with the increase in cold flow properties associated with the use of biodiesel. Ship systems that utilize biodiesel blends instead of straight diesel fuel are more susceptible to fuel gelling when exposed to cold weather environments. Of particular concern is the long-term cold storage of fuel during the two-month winter layup period when fuel turnover is low and preferential gelling and separation of the biodiesel component in a blend is possible. The goals of this project were to identify potential problems associated with the use of biodiesel blends in diesel-powered ship systems, and to develop a long-term cold storage test for biodiesel blends.

The properties of, and testing procedures for, pure biodiesel (B100) are described in the international standard ASTM D 6751 [1]. B100 may be used as the primary fuel, or as part of a blend (e.g. B20, a blend of 20% biodiesel and 80% distillate fuel). There are several advantages associated with the use of biodiesel:

- Biodiesel is a renewable energy source, and its use reduces our dependence on foreign oil.
- Biodiesel can be used in current diesel engines with little to no change in performance. Biodiesel and no. 2 diesel have similar density and kinematic viscosity, resulting in comparable fuel delivery characteristics. In addition, the energy content of B100 is only slightly less than that for no. 2 diesel. Thus the use of biodiesel has little impact on engine torque, power, and fuel economy.
- Biodiesel has better lubricity than diesel fuel which reduces wear on fuel system parts such as injectors and pump bearings. Biodiesel could be used as an additive to ultra low sulfur diesel which suffers from low lubricity.
- Biodiesel combustion produces fewer harmful emissions than no. 2 diesel. A summary of "average" emissions results [2, 3] shows that the use of biodiesel and biodiesel blends reduces most regulated emissions. Total unburned hydrocarbons (THC), carbon monoxide (CO), and particulate matter (PM) emissions decrease significantly with biodiesel usage, while oxides of nitrogen (NOx) emissions increase moderately.
- Biodiesel is nontoxic and biodegrades faster than diesel fuel, reducing fuel handling requirements.

The increase in cold flow properties (tendency to gel) associated with biodiesel is quantified using cold filter plugging point, cloud point, and pour point tests. The cloud point, which is the temperature at which solid crystals first appear, has an average value of 3°F for no. 2 diesel and 32 to 40°F for B100. Therefore, B100 is not suited for use in cold climates if fuel system components are exposed to the environment. However, tests have shown that the cloud point for a B20 blend with no. 2 diesel is approximately 7°F. Thus, blends as high as B20 can be used as a direct replacement for no. 2 diesel under most conditions. Even if a low percentage blend such as B20 is employed, more frequent checking and cleaning of the fuel filters should initially be performed.

A complete review of diesel-powered ship systems is beyond the scope of the present work since these systems vary from ship to ship. Tours of the M/V Mesabi Miner, operated by Interlake Steamship Co., and the R/V Blue Heron, operated by UMD's Large Lakes Observatory, were undertaken to determine "typical" systems that utilize diesel fuel. Fuel turnover is rapid during the shipping season; however, during the two-month winter lay up period there is a long-term cold storage concern for systems exposed to the external environment. In general, if a high percentage biodiesel blend is used in any of the systems, the fuel system components should be checked to make sure that they are compatible with B100. Typical diesel-powered ship systems that were identified include the main engines, diesel generator sets, boilers, emergency generators, hatch/deck crane, and the lifeboat power pack.

Larger vessels utilize heavy fuel oil (IF 280) or no. 2 diesel as the primary fuel for the main engines which are supplied by fuel bunkers via a heated day tank. Even when heavy fuel oil is the primary fuel, one fuel bunker is filled with no. 2 diesel near the end of the shipping season. The main engines are then run on no. 2 diesel at the end of the season, and also at the start of the next shipping season. Thus, at least one fuel bunker contains no. 2 diesel during the winter lay up period. Since portions of the fuel bunker are in contact with the external environment, either above or below the waterline, long-term cold storage becomes a potential concern if a biodiesel blend is used. Other systems that are exposed to the external environment and that have a low fuel turnover rate during winter lay up include the hatch/deck crane, and the lifeboat power pack.

The potential problems associated with the long-term stability of biodiesel blends in cold weather have not been addressed in the literature. Current stability tests address both the thermal [4] and oxidation [5, 6] stability. These tests use a slightly elevated temperature to simulate long-term storage (greater than 4 to 6 months). This is unlikely to be a problem with vessels on the Great Lakes, which refuel often. The exception to frequent refueling occurs during the winter lay up period (2 months), when the portions of the main fuel tank below the waterline are at approximately 0°C and portions above the waterline may be at temperatures slightly below freezing. Auxiliary systems may also have components exposed to below freezing temperatures. The available stability tests do not address this potential cold weather problem.

1.1 Project Description

The current project consisted of two parts; the identification of the potential issues involved with the shipboard use of biodiesel blends, and the development of a long-term cold storage test and subsequent testing of biodiesel blends. The two parts of the project were conducted concurrently and in collaboration with fuel suppliers and carriers. The issues involved with the shipboard use of biodiesel blends was addressed earlier in the Introduction.

The development of the current long-term cold storage test was based in part on a test for stratification discussed in the 2004 Biodiesel Handling and Use Guidelines [7]. The characteristics of the testing procedure given in the original proposal were as follows.

- The test would check for density variation and preferential gelling of biodiesel in blends.

- Density variation would be determined via hydrometer measurements of samples from the top, middle, and bottom of a tank in cold storage.
- Blends tested would vary from 0% to 20% biodiesel.
- Gelling of the biodiesel component would be determined via visual inspection.
- The duration of the test would be approximately 2 months.
- The storage temperature used in the test would be between the cloud point of no. 2 diesel (approximately 3°F) and the cloud point of pure biodiesel (approximately 32°F to 40°F).

The following changes to the proposed test were made based on initial test results.

- Density variation was determined via hydrometer measurements of samples from the top and bottom of a tank in cold storage.
- B5, B10, B20, and B50 blends were tested. Some additional tests using no. 2 diesel and B100 were also performed.
- In addition to the storage tanks, small glass sample bottles were used in the cold storage test to visually check for gelling of the biodiesel component.
- The duration of the test was 4 weeks. The original two month time frame was deemed unnecessary, as the results did not change between the second and fourth week of the test.
- Two temperature ranges were used for the long-term cold storage test: 23-25°F and 30-32°F. Ranges were used instead of exact temperatures due to the nature of the cold storage test apparatus that was constructed.

Some additional tests were also conducted that went beyond the scope of the original proposal. These included viscosity and flash point tests of cold storage samples, and a cold flow additive test. A detailed discussion of the equipment, procedure, and results, for the long-term cold storage test and the additional tests that were performed is provided in the remaining sections of the report.

There are no direct economic impacts associated with the experimental work presented in this project. However, the expected increase in the shipboard usage of biodiesel blends that has motivated this research does have a potentially large impact as discussed in a previous report co-authored by the current PI [8]. The previous report [8] indicates that increased biodiesel usage, which includes maritime usage, could provide a large boost to local economies through the construction of biodiesel plants. An increase in biodiesel usage would also extend to agricultural markets since soybean oil is generally used in the production process. In addition, proactively identifying potential problems with biodiesel usage may contribute to reduced maintenance costs if higher percentage biodiesel blends are mandated in the future.

Portions of the results presented in this report were incorporated in two separate presentations, one given at a meeting of the Northeast Clean Energy Resource Team (CERT) held at UMD on March 23rd, 2007, and one given at the GLMRI University Affiliates Meeting held in Duluth, MN on September 28th, 2007. A seminar for the faculty and students in the Department of Mechanical and Industrial Engineering at the University of Minnesota Duluth is also planned for December 10th, 2007.

2. Long-Term Cold Storage Test

A long-term cold storage test was designed and tests were conducted for two different temperature ranges. Initial testing was geared toward simulating the two month winter lay up period, with samples held at a reduced temperature over an extended time period. There were no changes in the test results between the second and fourth week, thus, the final length of the test was set at four weeks. Each cold storage test included both a storage tank test and a small sample test with biodiesel blends of B5, B10, B20, and B50. An additional small sample test to determine the effect of a common cold flow additive was also conducted.

2.1 Cold Storage Test Apparatus

The various tests presented in the present work required the construction of a test apparatus to maintain the samples within a specified temperature range over extended periods of time. The apparatus consisted of a freezer with an external temperature controller. Figure 1 shows the Kenmore model #16082, 19.9 cubic foot capacity freezer used in the tests. The internal control system for the freezer has a temperature range of -10 to 10°F. An external temperature controller was constructed to extend the range of the controllable temperatures.

Figure 1: Freezer used in cold storage test apparatus.

Figure 2 shows the external temperature control unit. The unit consists of an AutomationDirect TC33-2010-AC temperature controller, an AutomationDirect QL2N1-A120 electro-mechanical relay, an AutomationDirect SQL08D relay socket, an Omega 5TC-TT-J-24-36 “J” type thermocouple, a Radio Shack model 274-670 8-position, dual row terminal strip, a six ft. AC power cord, an electrical outlet and wiring box, and associated wiring. The thermocouple input to the temperature controller sensed the temperature in the interior of the freezer, and the temperature controller energized the outlet that provided power to the freezer. On/off control with a 2°F hysteresis was used to avoid excessive cycling of the freezer’s compressor. The assembled apparatus is capable of providing a controlled temperature environment within 2°F ranging from room temperature to -10°F.

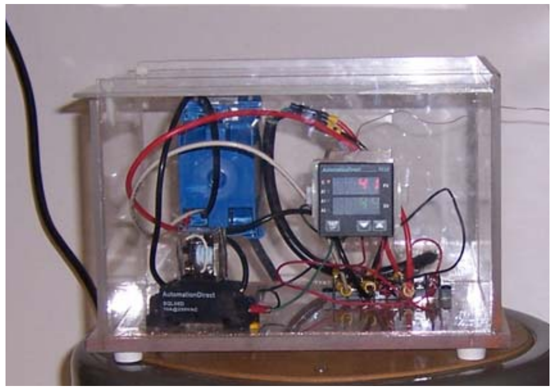

Figure 2: Temperature controller unit.

2.2 Cold Storage Test

Each cold storage test was conducted over a period of four weeks, and consisted of both a storage tank test and a small sample test. The storage tank tests were used to check for separation and gelling of the biodiesel component in B5, B10, B20, and B50 blends. Any separation of the biodiesel component would result in a density difference between the top and bottom of the storage tank. Top and bottom samples of the storage tanks were taken in two week intervals, and a hydrometer test was performed to check for density variations. A visual inspection for crystallization (cloudiness) of the fuel was performed using the small samples. The general procedure for the test is as follows.

1. Set the desired temperature for the cold storage test on the cold storage test apparatus. Ensure that the apparatus has reached the desired temperature prior to the start of the test.
2. Prepare the storage tank blends.
    a. Extract small samples of the diesel fuel and the B100 used to prepare the blends.
    b. Perform hydrometer tests on the diesel fuel and the B100 small samples.
3. Extract an initial representative sample and a small sample from the storage tanks prior to the start of the test.
    a. Perform hydrometer tests on the initial representative samples of B5, B10, B20, and B50.
4. Place the storage tanks and small samples in the cold storage test apparatus (freezer).
5. After two weeks of cold storage:
    a. Visually inspect the small samples for crystallization.
    b. Extract top and bottom samples from the B5, B10, B20, and B50 storage tanks.
    c. Allow samples to reach room temperature and perform hydrometer tests on the top and bottom samples.
6. After four weeks of cold storage:
    a. Visually inspect the small samples for crystallization.
    b. Extract top and bottom samples from the B5, B10, B20, and B50 storage tanks.
    c. Allow samples to reach room temperature and perform hydrometer tests on the top and bottom samples

Individual aspects of the general procedure are addressed in more detail below.

2.2.1 Tanks and Sample Preparation

The storage tanks used in the test consisted of 6+ gallon (23.2 L) self-venting gas cans. Each blend (B5, B10, B20, and B50) was mixed in 22 L batches and placed in a storage tank. Table 1 shows the volume fractions used in the preparation of each storage tank. A 1000±10 ml graduated cylinder was used to measure the fuel volumes. Thorough mixing was ensured via manual agitation (shaking) of each tank for a period of three minutes. The storage tanks were placed in the test apparatus as shown in Figure 3.

Sample	Vol. B100 (L)	Vol. #2 Diesel (L)
B5	1.1	20.9
B10	2.2	19.8
B20	4.4	17.6
B50	11.0	11.0

Table 1: Storage tank sample preparation.

Figure 3: Storage tank placement in test apparatus.

Step 3 in the general testing procedure calls for extracting a small sample from the storage tank prior to the start of the test. Each small sample consists of 400 to 450 ml of biodiesel blend placed in a 16 oz. glass sample bottle. Figure 4 shows the placement of a B5, B10, B20, B50, and B100 small sample in the test apparatus.

Figure 4: Small sample placement in test apparatus.

2.2.2 Bi-Weekly Tank Samples

Top and bottom samples are taken from each of the storage tanks at two weeks and four weeks after the start of the test. The top sample is taken first, in accordance with the guidance set forth in ASTM D 4057 [9], in order to avoid cross contamination of the samples. Samples volumes were 400 to 450 ml and were stored in 16 oz. glass sample bottles. The samples were extracted from the storage tanks using the hand-operated, stainless steel drum pump (Cole-Parmer model number EW-07079-20) shown in Figure 5.

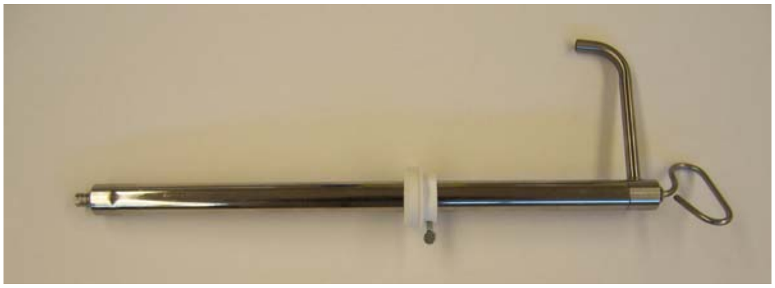

Figure 5: Stainless-steel drum pump.

2.2.3 Hydrometer Test

The specific gravity of the initial representative samples, the B100 and diesel fuel used in the sample preparation, and the bi-weekly tank samples was measured using a hydrometer in accordance with ASTM D 1298 [10]. An SG 60/60°F hydrometer with a range of 0.800 to 0.910 and divisions of 0.001 was used to measure the specific gravity of each sample. The samples were allowed to reach room temperature and were manually agitated prior to the hydrometer test. Figure 6 shows a B100 sample, the hydrometer cylinder, and the hydrometer. Initial and final sample temperatures were taken during the hydrometer test, and the resulting specific gravity was corrected to 60°F.

Figure 6: Hydrometer, cylinder, and B100 sample.

2.3 Test Results

The storage tank and small sample tests were conducted for two temperature ranges 23 – 25°F and 30 – 32°F. These temperatures were selected based on expected winter lay up operating conditions and average fuel properties. The higher temperature range is based on a fuel bunker in contact with the waterline which should exhibit minimum temperatures near freezing during winter lay up. The lower temperature range represents a conservative temperature that is slightly above the average cloud point of B50. High sulfur no. 2 diesel and soy-based biodiesel were used to prepare the sample blends. Some additional tests were also performed on a limited number of samples by an outside testing facility. The raw data and corrected hydrometer readings for the two temperature ranges are included in the appendices.

2.3.1 Results: 23 – 25°F

The hydrometer tests showed no measureable density variation between the top and bottom tank samples (see Appendix A for data). The specific gravity of a particular blend was also within the readability (0.001) of the hydrometer for all of the samples tested over the four week test period.

A small amount of particulate matter was observed in the B50 bottom samples taken at both the two week and four week point. The exact nature of the particulate matter formed is not known at this time, but it appears to be consistent with the formation of wax crystals described in ASTM D 2500 [11]. Additional tests to determine the chemical composition would be required to classify the particulate matter.

Visible cloudiness was observed in the B10, B20, and B50 small samples at both the two week and four week point. The cloudiness in the B10 and B20 samples disappeared when the samples were allowed to reach room temperature at the end of the test. Particulate matter was observed in the B50 small sample, which is consistent with the results obtained from the B50 storage tank bottom sample. The B100 small sample included in this test was completely solid since the temperature is well below the cloud point of biodiesel (32 to 40°F).

Two additional tests were conducted on the small samples at the conclusion of the cold storage test. The kinematic viscosity and flash point of the samples were determined in accordance with ASTM D 445 [12] and ASTM D 93 [13], respectively. The tests were performed by personnel at the Superior Refinery of Murphy Oil USA, Inc using a Koehler K23400 constant temperature viscosity bath and a Herzog HFP 360 Pensky-Martens closed cup flash point tester. Allowable ranges for these fuel properties are given in ASTM D 6751 [1] for B100, and ASTM D 975 [14] for no. 2 diesel. B100 has an allowable range for kinematic viscosity (at 40°C) of between 1.9 and 6.0 mm^2/s and a minimum flash point of 130°C. No. 2 diesel has an allowable range for kinematic viscosity (at 40°C) of between 1.9 and 4.1 mm^2/s and a minimum flash point of 52°C. Table 2 shows the test results. All of the samples met the required fuel specifications.

Sample	Viscosity (mm^2/s)	Flash Point (°C)
B100	4.031	138
B50	2.927	78
B20	2.425	72
B10	2.264	73
B5	2.200	68
#2 Diesel	2.132	65

Table 2: Kinematic viscosity and flash point results.

2.3.2 Results: 30 – 32°F

The test results at this higher temperature range were similar to the results obtained at the lower temperature range. Hydrometer tests showed no density variation between the top and bottom samples and particular blends showed no measureable density differences over the period of the test (see Appendix B for data). The B10 and B20 small samples did not exhibit cloudiness at this higher temperature. However, the presence of particulates in the B50 storage tank bottom sample and the B50 small sample was once again noted.

3. Cold Flow Additive Test

A test to determine the effect of a common cold flow additive (Polar Power manufactured by FPPF Chemical Co. Inc.) on biodiesel blends was also conducted. Small samples (450 ml) of no. 2 diesel, B5, B10, B20, B50 and B100 both with and without the additive were placed in the cold storage test apparatus. The manufacturer's recommended amount of 1 part additive to 1000 parts fuel by volume was used in the samples that included the additive. The manufacturer claims that this fraction of additive will lower the cold-filter plugging point of diesel by 10°F. The starting temperature for the test was 45°F, the temperature was decreased by 3°F per day, and the ending temperature was -9°F. Recall that the cold storage test apparatus uses a 2°F hysteresis loop, thus a setting of 45°F corresponds to a temperature range of 43-45°F. A visual inspection of the samples was performed each day and the following observations were made.

- At 36°F
  - A small amount of particulates were present in the B100 samples both with and without the additive
- At 33°F
  - The B100 sample without the additive exhibited significant gelling throughout the sample
  - The B100 sample with the additive exhibited some gelling at the base of the sample container
  - A small amount of particulate was present in the B50 samples both with and without the additive
- At 30°F
  - The B100 sample without the additive was almost completely gelled
  - The B100 sample with the additive exhibited significant gelling at the base of the sample container
- At 27°F
  - The B100 sample without the additive was completely gelled (solid)
  - The B100 sample with the additive exhibited significant gelling in the lower half of the sample container
  - The B50 sample without the additive had a small amount of particulate at the bottom of the sample and appeared cloudy throughout the sample
  - The B20, B10, and B5 samples both with and without the additive exhibited some cloudiness at the bottom of the samples
- At 9°F
  - The B50 sample without the additive had a slush-like appearance and was almost completely gelled
  - The B50 sample with the additive had a significant increase in particulates at the bottom of the sample
- At -3°F
  - The B20 sample without the additive had crystal-like formations dispersed throughout the sample
- At -6°F
  - The B20 sample without the additive had a slush-like appearance throughout the sample

- The B20 sample with the additive exhibited some crystal-like formations in the bottom of the sample
- At -9°F
  - The B20 sample with the additive had a slush-like appearance in the bottom third of the sample

A review of the above observations shows that the additive had a noticeable effect on the temperature at which a given biodiesel blend begins to solidify. This was particularly evident for the B100 sample that contained the additive which exhibited no additional solidification when the temperature was lowered from 27°F to -9°F. There may be a more appropriate mixture fraction of additive to use for each biodiesel blend than the one suggested by the manufacturer.

An unexpected result was obtained for B10, B5, and no. 2 diesel samples at low temperatures. As noted above, the B10 and B5 samples began to exhibit cloudiness near the sample bottom at a temperature of 27°F. The cloudiness in the B10 and B5 samples did not appear to increase as the temperature was further decreased. This was not expected since the cloud point of no. 2 diesel has an average value of 3°F. One would expect that the B10, B5, and no. 2 diesel samples would exhibit significant cloudiness and/or gelling at the lowest temperature of -9°F. This unexpected result may reflect the limitations of the testing method employed in this section; the method is inexact since it relies solely on visual observation. Additional testing to determine the cloud point [11], pour point [15], and cold filter plugging point [16] could be done to quantify the appropriate additive mixture fraction for each blend.

4. Conclusions and Recommendations

The potential issues involved with the shipboard use of biodiesel blends were identified. Typical diesel-powered ship systems include the main engines, diesel generator sets, boilers, emergency generators, hatch/deck crane, and the lifeboat power pack. Long-term cold storage of fuel is a potential concern in the hatch/deck crane and the lifeboat power pack due to their low fuel turnover rate and exposure to the external environment. In addition, storage of high percentage biodiesel blends (greater than B20) in one or more fuel bunkers during the winter lay up period may lead to particulate formation within the fuel.

A cold storage test apparatus was constructed and the procedure for a long-term cold storage test was developed. The test consisted of maintaining tanks and small samples of B5, B10, B20, and B50 blends within a specified temperature range for a period of four weeks. Top and bottom samples were taken from the tanks at bi-weekly intervals and a hydrometer test was performed to check for density variation. A visual inspection of the small samples was also performed bi-weekly to check for gelling of the fuel. Test results were obtained for two different temperature ranges (23-25°F and 30-32°F). The hydrometer test results showed no measurable difference between the density of the top and bottom samples. However, there was some particulate formation observed in the B50 bottom tank sample and small sample. In general, blends of up to B20 exhibited good cold storage characteristics. The flash point and viscosity of the blends at the conclusion of the cold storage test were within the required fuel specifications.

The effect of a common cold flow additive on biodiesel blends was also investigated. Small samples of no. 2 diesel, B5, B10, B20, B50, and B100 both with and without the additive were placed in the cold storage test apparatus and the temperature of the samples was slowly decreased from 45°F to -9°F in 3°F increments. Visual inspection of the small samples showed that the additive lowered the temperature at which a given biodiesel blend started to gel. The presence of the additive kept the B100 sample from completely gelling, even at the lowest temperature. There was no observable gelling of the B10, B5, and no. 2 diesel samples, which is inconsistent with average cloud point of no. 2 diesel (3°F). The dependence of the test on visual observation, as opposed to quantifiable measurement, may be the cause of these unexpected results.

In light of the current observations and test results, the following additional testing is recommended. The characteristics of the particulates formed in the B50 sample are presently unknown. A test to determine the chemical composition of these particulates should be performed. Samples from the cold storage test should also be filtered to check for the formation of small particulates that could potentially plug fuel filters. Finally, the appropriate mixture fraction of cold flow additive for each biodiesel blend should be determined using quantifiable tests such as the cloud point, pour point, and cold filter plugging point.

References

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[9] ASTM D 4057, "Standard Practice for Manual Sampling of Petroleum and Petroleum Products", ASTM International.

[10] ASTM D 1298, "Standard Test Method for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method", ASTM International.

[11] ASTM D 2500, "Standard Test Method for Cloud Point of Petroleum Products", ASTM International.

[12] ASTM D 445, "Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity", ASTM International.

[13] ASTM D 93, "Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester", ASTM International.

[14] ASTM D 975, "Standard Specification for Diesel Fuel Oils", ASTM International.

[15] ASTM D 97, "Standard Test Method for Pour Point of Petroleum Products", ASTM International.

[16] ASTM D 6371, "Standard Test Method for Cold Filter Plugging Point of Diesel and Heating Fuels", ASTM International.

Appendix A

Results for Cold Storage Test
Temperature Range: 23 to 25°F

Date 6/26/07
Initial Representative Sample Hydrometer Tests
SG 60/60°F Hydrometer
Scale: 0.800 to 0.910

Fluid	Starting Temperature (°F)	Hydrometer Reading	Ending Temperature (°F)	Corrected Hydrometer Reading
B100	71.0	0.880	71.5	0.881
B50	73.0	0.857	73.0	0.858
B20	73.0	0.845	73.0	0.846
B10	72.0	0.841	72.0	0.842
B5	71.0	0.839	71.0	0.840
#2 Diesel	71.0	0.838	71.0	0.839

Date Samples Taken 7/10/07
Date of Hydrometer Test 7/17/07
Hydrometer Tests after 2 weeks cooling
SG 60/60°F Hydrometer
Scale: 0.800 to 0.910

Fluid	Sample	Starting Temperature (°F)	Hydrometer Reading	Ending Temperature (°F)	Corrected Hydrometer Reading
B50	Top	76.0	0.857	76.0	0.858
	Bottom	76.5	0.857	76.5	0.858
B20	Top	76.5	0.844	76.5	0.845
	Bottom	76.5	0.844	76.5	0.845
B10	Top	76.0	0.840	76.0	0.841
	Bottom	76.0	0.840	76.0	0.841
B5	Top	76.5	0.838	76.5	0.839
	Bottom	76.5	0.838	76.5	0.839

Date Samples Taken 7/24/07
Date of Hydrometer Test 8/3/07
Hydrometer Tests after 4 weeks cooling
SG 60/60°F Hydrometer
Scale: 0.800 to 0.910

Fluid	Sample	Starting Temperature (°F)	Hydrometer Reading	Ending Temperature (°F)	Corrected Hydrometer Reading
B50	Top	80.5	0.855	80.5	0.857
	Bottom	80.5	0.855	80.5	0.857
B20	Top	80.5	0.843	80.5	0.845
	Bottom	80.5	0.843	80.5	0.845
B10	Top	80.5	0.839	80.5	0.841
	Bottom	80.5	0.839	80.5	0.841
B5	Top	80.5	0.837	80.5	0.839
	Bottom	80.5	0.837	80.5	0.839

Appendix B

Results for Cold Storage Test
Temperature Range: 30 to 32°F

Date 8/14/07
Initial Representative Sample Hydrometer Tests
SG 60/60°F Hydrometer
Scale: 0.800 to 0.910

Fluid	Starting Temperature (°F)	Hydrometer Reading	Ending Temperature (°F)	Corrected Hydrometer Reading
B100	71.5	0.880	71.5	0.881
B50	71.5	0.866	71.5	0.867
B20	71.5	0.859	71.5	0.860
B10	71.5	0.857	71.5	0.858
B5	71.5	0.850	71.5	0.851
#2 Diesel	71.0	0.839	71.0	0.840

Date Samples Taken 8/28/07
Date of Hydrometer Test 9/4/07
Hydrometer Tests after 2 weeks cooling
SG 60/60°F Hydrometer
Scale: 0.800 to 0.910

Fluid	Sample	Starting Temperature (°F)	Hydrometer Reading	Ending Temperature (°F)	Corrected Hydrometer Reading
B50	Top	76.0	0.866	76.0	0.867
	Bottom	76.0	0.866	76.0	0.867
B20	Top	76.0	0.859	76.0	0.860
	Bottom	76.0	0.859	76.0	0.860
B10	Top	76.0	0.857	76.0	0.858
	Bottom	76.0	0.857	76.0	0.858
B5	Top	76.0	0.851	76.0	0.852
	Bottom	76.0	0.851	76.0	0.852

Date Samples Taken 9/11/07
Date of Hydrometer Test 9/17/07
Hydrometer Tests after 4 weeks cooling
SG 60/60°F Hydrometer
Scale: 0.800 to 0.910

Fluid	Sample	Starting Temperature (°F)	Hydrometer Reading	Ending Temperature (°F)	Corrected Hydrometer Reading
B50	Top	72.0	0.867	72.0	0.868
	Bottom	72.0	0.867	72.0	0.868
B20	Top	72.0	0.860	72.0	0.861
	Bottom	72.0	0.860	72.0	0.861
B10	Top	72.0	0.858	72.0	0.859
	Bottom	72.0	0.858	72.0	0.859
B5	Top	72.0	0.851	72.0	0.852
	Bottom	72.0	0.851	72.0	0.852

Great Lakes Maritime Research Institute

A University of Wisconsin - Superior and University of Minnesota Duluth Consortium

Structure of Bacterial Communities Associated with Accelerated Corrosive Loss of Port Transportation Infrastructure

Final Report

Randall E. Hicks
Tel: 218-726-8438
Email: rhicks@d.umn.edu

November 21, 2007

University of Minnesota Duluth
Department of Biology
1035 Kirby Drive, SSB 207
Duluth, MN 55812

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Executive Summary

Steel sheet piling material used for docks, bridges and bulkheads in the Duluth-Superior harbor has been reported to be corroding at an accelerated rate. Corroded areas on steel sheet pilings in this harbor have an orange rusty appearance characterized by blister-like, raised tubercles on the surface. These tubercles vary in diameter from a few millimeters to several centimeters and when removed, large and often deep pits are revealed. This pattern of corrosion is consistent with the appearance of microbiologically influenced corrosion (MIC). Using a community DNA fingerprinting method called T-RFLP, we demonstrated that bacterial communities on corroded steel sheet pilings in the most affected part of this harbor were different from bacterial communities on these structures at a less affected area just outside the harbor. *Siderooxidans lithoautotrophicus*, a microaerophilic chemotrophic bacterium that oxidizes Fe^{2+} to Fe^{3+}, was repeated isolated from the corroding structures. Sequencing the 16S rDNA gene of bacterial clones indicated that the majority of bacteria on the surfaces of steel pilings at the corroded sites examined were from three bacterial phyla, the β- and α-Proteobacteria, and Cyanobacteria. This clonal analysis also indicated the presence of a bacterium most similar to an iron-reducing bacterium (*Rhodoferax ferrireducens*), which can grow well at the low temperatures (4°C) seasonally encountered in this harbor. Although we cannot provide conclusive evidence that these iron bacteria are the causative agents of the accelerated corrosion in this harbor, our preliminary results indicate that the corroding steel structures are covered by complex microbial biofilms that contain bacteria of the type responsible for corrosion of steel in other environments.

Introduction

Steel sheet piling material used for docks, bridges and bulkheads in the Duluth-Superior harbor (DSH) has been reported to be corroding at an accelerated rate (Marsh et al. 2005). To date accelerated corrosion of this character and speed has not been observed by dive inspectors or reported by authorities at other ports and harbors in the Great Lakes. The increased rate of corrosion appears to have begun in the late 1970's in the DSH and will require expensive replacement if the cause and possible remedies cannot be identified. About 20 kilometers of steel sheet piling appear to be affected in the DSH, which may cost more than $100 million to replace (Marsh et al. 2005). The US Army Corps of Engineers, the Duluth Seaway Port Authority, and the Minnesota and Wisconsin Sea Grant Programs convened an expert panel in September 2004 to examine this corrosion issue (see Marsh et al. 2005). This panel made several recommendations including further analysis to check for microbiologically influenced corrosion (MIC) in the harbor.

The steel sheet piling reported to be corroding at an accelerated rate has an orange rusty appearance characterized by blister-like, raised tubercles on the surface. These tubercles vary in diameter from a few millimeters to several centimeters and when removed, large and often deep pits (6 to10 mm) are revealed in the sheet piling, which is sometimes perforated. This pattern of corrosion is consistent with the appearance of corrosion caused by iron-oxidizing bacteria (Hamilton 1985). However, microbiologically influenced corrosion is rarely caused by a single microbial group, but more often by consortia of microbes including sulfate-reducing and iron-oxidizing bacteria (Hamilton 1985, Rao et al. 2000, Starosvetsky et al. 2001). The corrosion in this harbor appears similar to accelerated low water corrosion (ALWC) reported during the past decade on marine steel pilings in the United Kingdom and Baltic Sea (Christie 2001, Graff and Seifert 2005), which is thought to be accelerated by the action of sulfate-reducing bacteria.

The Lake Superior corrosion problem is primarily seen in the lower part of the Duluth-Superior harbor (Marsh et al. 2005). Most of the corrosion is confined to the first 1.5 meters below the surface and decreases from 1.5 to 3 meters below the surface. Extensive zebra mussel colonization occurs on these pilings from about 3 meters to the bottom of the sheet pile where little or no corrosion is observed (Chad Scott, AMI Consulting Engineers, pers. comm.). Less corrosion has been found on steel sheet pilings at the Oliver Bridge in the upper harbor near the mouth of the St. Louis River and on pilings exposed to Lake Superior water (Chad Scott, pers. comm.). Thus, there appears to be a dual gradient of corrosion from the upper harbor on one side and Lake Superior on the other side towards the middle of the DSH where the most extensive corrosion is seen. We examined microbial communities attached to sheet pilings at two corroded areas and one less affected site to determine if differences in microbial communities between these sites may indicate the participation of bacteria in this accelerated corrosion process.

The specific objectives of this project were to:

1. Sample microbial biofilm communities on steel pilings at two or more sites severely affected by corrosion in the Duluth-Superior harbor and at least one site where corrosion is minimal.
2. Extract DNA from these microbial biofilm communities

3. Compare the molecular diversity of bacterial biofilm communities on corroded and unaffected steel sheet pilings using a community DNA fingerprinting method (T-RFLP) to identify differences in biofilm communities at corroded and less affected sites.

Methods

Samples were collected from the surfaces of steel pilings in the Duluth-Superior harbor in August and September 2006, and again in July and August 2007. Samples collected in 2007 are still being analyzed and information in this report is derived from the analysis of samples collected in 2006. Microbial community biofilm samples were collected from corroded structures (Fig. 1) by a commercial diver approximately 1 m below the waterline at Hallett Dock 5 (Aug. 1 and Sept. 14), Midwest Energy (Aug. 15), and the Duluth Entry (Sept. 15) during 2006 using a syringe brush sampler (Ksoll et al. 2007). Portions of these samples were examined using epifluorescence microscopy and DAPI staining (Porter and Feig, 1980), used to inoculate gradient tubes to isolate iron-oxidizing bacteria, and to extract DNA for bacterial community fingerprinting and cloning analyses.

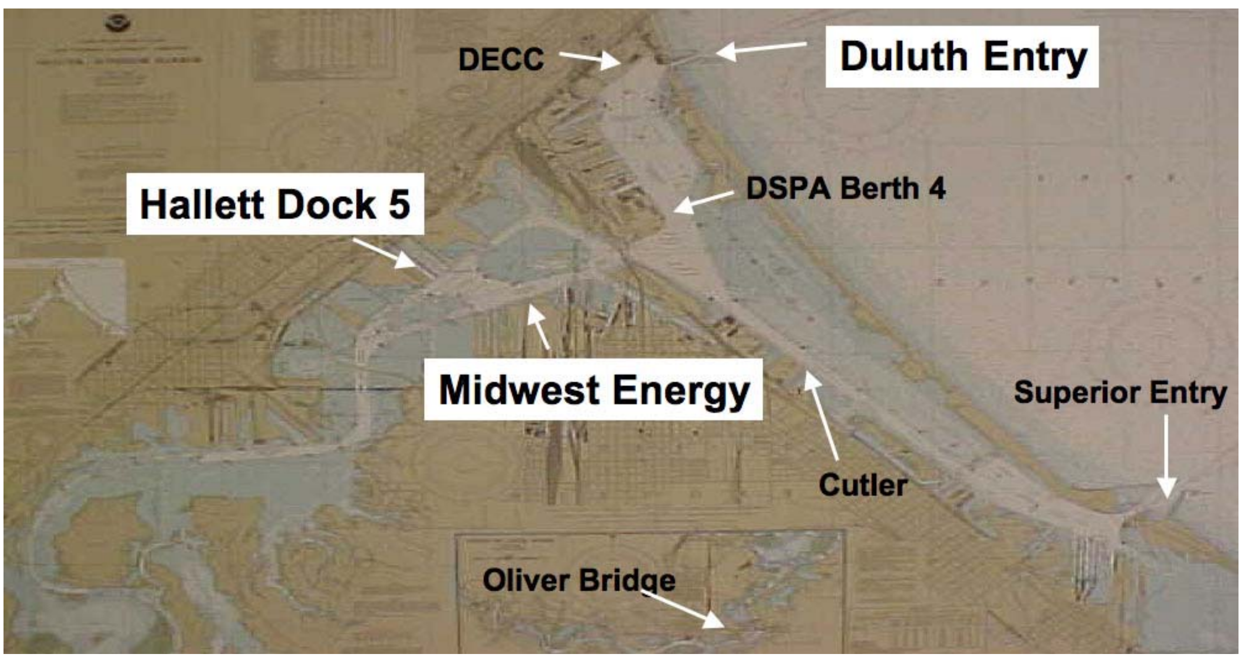

Fig. 1. Map of the Duluth-Superior harbor. Sites that were sampled during summer in 2006 and 2007 are shown in white boxes.

Enrichment and isolation of iron-oxidizing bacteria –
Iron-oxidizing bacteria were enriched and isolated using a gradient tube culturing technique (Emerson and Moyer 1997). Enrichments were carried out in opposing gradients of oxygen and Fe^{2+} that were established in Hungate tubes. The tubes had a plug of either FeS or $FeCO_3$ overlaid with modified Wolfe's mineral medium (MWMM), a semisolid mineral salts bicarbonate-buffered medium and a headspace of air. The tubes were inoculated with 10 µl of suspension

collected with the syringe sampler by removing the top of a gradient tube, inserting a pipette tip containing the inoculum to the bottom agarose plug, and expelling the contents as the pipette tip was withdrawn from the gradient tube. After 14 to 21 days of growth, sterile pipette tips were used to remove samples from individual bands that had formed in the gradient tubes. These band samples were placed in different sterile microcentrifuge tubes. A portion of some samples was preserved in 2% formaldehyde and examined by epifluorescence microscopy after the cells had been stained with DAPI (Porter and Feig, 1980). DNA was extracted from another portion of each sample using a MoBio UltraClean Soil DNA Kit following the instructions of the manufacturer. The 16S rDNA gene was amplified using bacteria-specific PCR primers (27F, 1492R) using a BioRad DNA Engine thermal cycler (see conditions below). These 16S rDNA fragments were sequenced on an ABI DNA sequencer at the University of Minnesota BioMedical Genomics Center and the partial sequences compared to sequences of known bacteria in the GenBank public database using the BLASTn tool.

Microbial community DNA extraction –

Total DNA extracted directly from microbial biofilm samples was used for 16S rDNA-based T-RFLP analysis, and cloning and sequencing the 16S rRNA gene to identify bacterial members of these microbial communities. Total DNA was extracted using an UltraClean Soil DNA Kit (MoBio Laboratories, Inc.) following the instructions of the manufacturer. Nucleic acid concentrations and purity were determined spectrophotometrically by measuring absorbance with a Nanodrop spectrophotometer.

T-RFLP community DNA fingerprinting –

Terminal restriction fragment length polymorphism (T-RFLP) analysis, a community DNA fingerprinting technique, was used to distinguish bacterial communities collected from different sites based on the size of terminal fragments of 16S rRNA genes following restriction endonuclease digestion (Braker et al. 2001, Moeseneder et al. 1999). We used a PCR primer set (27F, 1492R) specific for the Bacteria domain (Lane 1991, Reysenbach et al. 1994) to directly amplify the 16S rDNA gene in DNA extracted from microbial biofilms on corroded surfaces. The forward primer was labeled on the 5’ end with 6-carboxyfluorescein (6-FAM). All oligonucleotide primers were synthesized by Integrated DNA Technologies (IDT). DNA samples were amplified using puReTaq Ready-To-Go PCR beads and 25 pmol of each primer with a BioRad DNA Engine thermal cycler. The reaction conditions were 35 cycles of: 94°C for 1.5 min, 60°C for 1.5 min, and 72 °C for 2 min. After 35 cycles, the samples were cooled to 4°C until further analysis. DNA from *E. coli* was used as a positive bacterial control. In addition to blanks (containing no DNA template), DNA from *Sulfolobus solfataricus* (ATCC 35091), an archaeal microorganism, was used as a negative control. PCR reaction mixtures containing bacterial rDNA products of the expected size (~ 1,500 base pairs, visualized on 1.5% agarose gels) were cleaned with a MoBio UltraClean PCR Clean-Up Kit. Cleaned PCR products (200 ng) were then digested at 37°C for at least 3 hours with *Hae*III or *Rsa*I. The restriction fragments were precipitated, dried, and redissolved in 10 µl of sterile, nuclease free water. The sizes of the terminal restriction fragments in these digests were determined on an ABI DNA sequencer in the GeneScan mode at the University of Minnesota BioMedical Genomics Center. The pattern of terminal restriction fragments from each sample was imported into the BioNumerics statistical software package (Anonymous 2005). The molecular weights (in base pairs) of peaks in individual samples were normalized to internal molecular weight standards (ROX-1000 standard).

Afterwards, dendrograms comparing differences in the bacterial biofilm communities at the different sites in the harbor were constructed using Pearson correlations and the UPGMA clustering method. Similarities between different samples were calculated based on Pearson correlations of terminal restriction fragment patterns between 47 and 946 base pairs in size.

Bacterial clones –

A small bacterial clone library (fifty-seven partial 16S rDNA sequences) was created to identify the major bacterial groups associated with corroded steel piling materials in the Duluth-Superior harbor. Bacterial 16S rDNA was amplified in four microbial community samples from the Hallett Dock 5 site (collected on Aug 1 and Sept 14) and two samples from the Midwest Energy site (collected on Aug 15). We used the same bacterial PCR primers, materials, and PCR conditions as described above except the forward PCR primer was not labeled with 6-FAM. PCR reaction mixtures containing bacterial rDNA products of the expected size (~ 1,500 base pairs) were chosen for cloning using an Invitrogen TOPO-TA cloning kit (Keough et al. 2003, Jones et al. 2007). Twenty randomly selected transformant colonies appearing on selective media from each sample (except the Aug 1 sample from Hallett Dock 5) were isolated and screened by whole cell PCR. All colonies (n=110) were grown overnight in LB broth amended with 75 µg/ml ampicillin at room temperature. Cells from these cultures were frozen at -80ºC in glycerol stocks. Cloned 16S rDNA fragments from all the transformant cell lines were amplified using the primers M13F and M13R (included in the cloning kit), and then purified and concentrated using a MoBio UltraClean PCR Clean-Up Kit prior to sequencing. Inserts from clones were sequenced at the University of Minnesota BioMedical Genomics Center. These inserts were partially sequenced with the 27F primer to verify that the amplicons were 16S rDNA-like sequences (57 of 110 sequences). The partial 16S rDNA sequences of the clones were compared to 16S rDNA sequences in the public database GenBank using the BLASTn tool (www.ncbi.nlm.gov/BLAST/) to identify the closest bacterial relative.

Results and Discussion

Scrapping samples from the corroded steel surface at Hallett Dock 5 demonstrated that complex microbial biofilms composed of filamentous algae, diatoms, and various bacteria cover the steel surfaces and corrosion tubercles (Fig. 2). Iron-oxidizing bacteria were cultivated from materials collected from corroding steel pilings at Hallett Dock 5 and Midwest Energy (Fig. 3A) but not the Duluth Entry site. 16S rDNA from some bacteria isolated from both sites was most similar (96%) to 16S rDNA from *Siderooxidans lithoautotrophicus*, a microaerophilic γ-proteobacterium that oxidizes Fe^{2+} to Fe^{3+} (Fig. 3B and C).

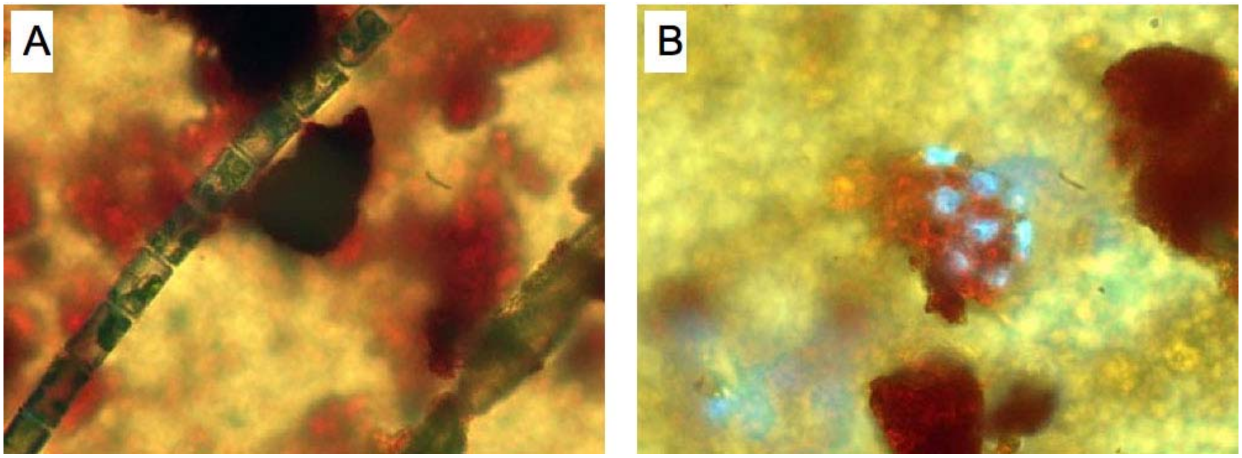

Fig. 2. Light photomicrographs of corrosion tubercle materials from the Duluth-Superior harbor. Note filamentous algae (A) and bacteria (blue color) on the surface of orange corrosion products (B). [photomicrographs by R. E. Hicks/UMD]

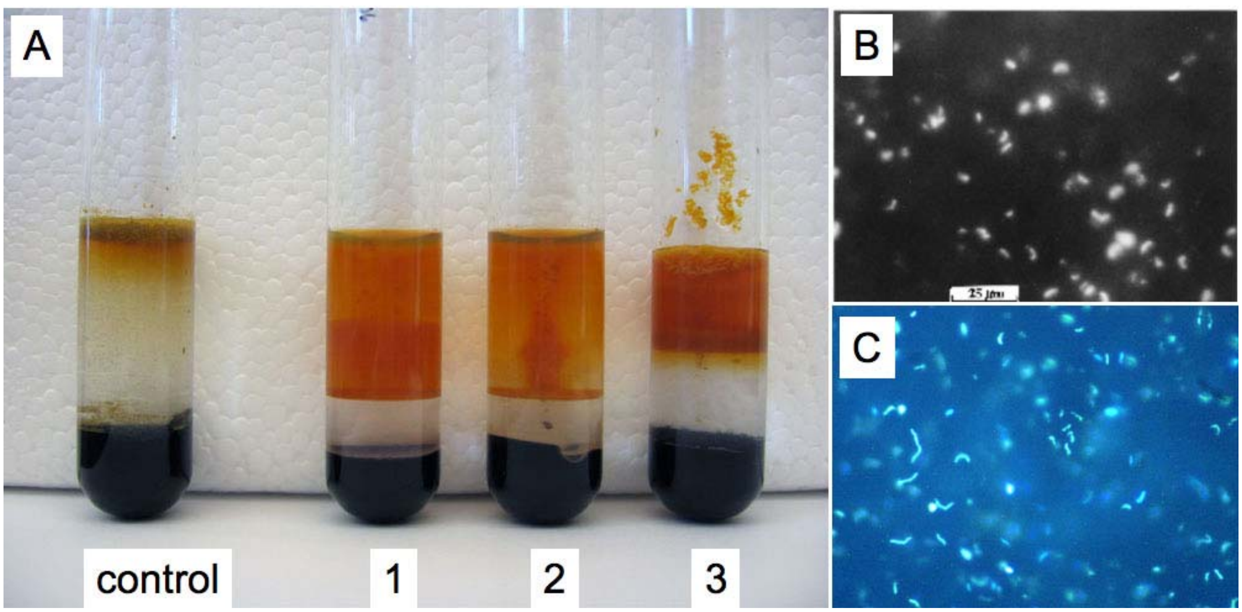

Fig. 3. Iron-oxidizing bacteria. (A) FeS gradient culture tubes inoculated with corrosion materials from Hallett Dock 5 collected on Sept. 14, 2006. (B) Photomicrograph of *Siderooxidans lithoautotrophicus* isolated by Emerson and Moyer (1997). (C) Photomicrograph of bacterial cells in the tube 2 band in panel A, whose 16S rDNA is 96% similar to *S. lithoautotrophicus*.

Community DNA fingerprints based on T-RFLP analysis indicated that bacterial communities on corroding steel pilings in the most affected part of the Duluth-Superior harbor were different from bacterial communities on steel sheet piling at the Duluth Entry (Fig. 4). At Hallett Dock 5, the composition of bacterial communities associated with corrosion tubercles was different than bacterial communities on adjacent areas of the steel sheet piling where tubercles were not present (Fig. 5).

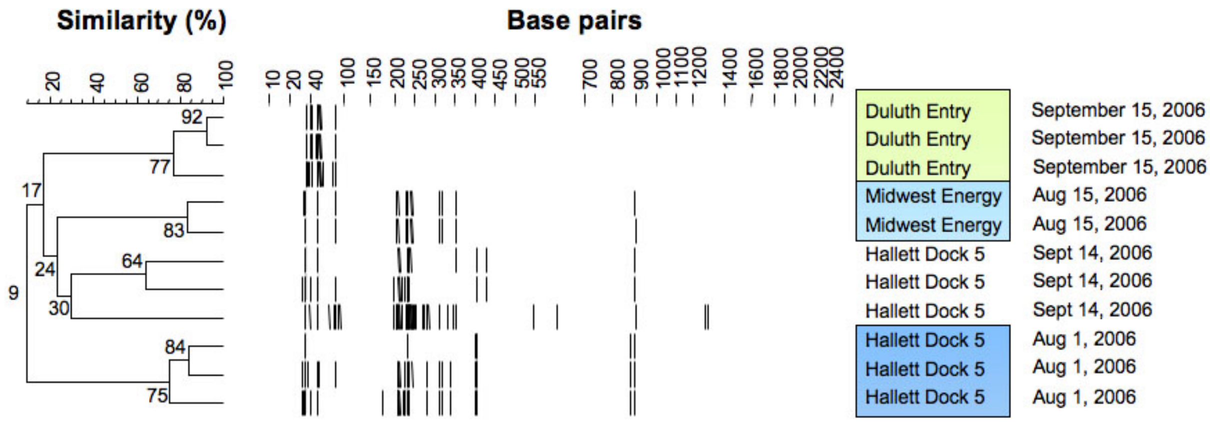

Figure 4. Similarity of bacterial biofilm communities at corroded sites (Hallett Dock 5, Midwest Energy) and a less affected area (Duluth Entry) in the Duluth Superior harbor during 2006. T-RFLP analysis of *Hae*III digests of bacterial 16S rDNA PCR products. Similarities are based on Pearson correlations of terminal restriction fragment patterns between 47 and 946 base pairs in size.

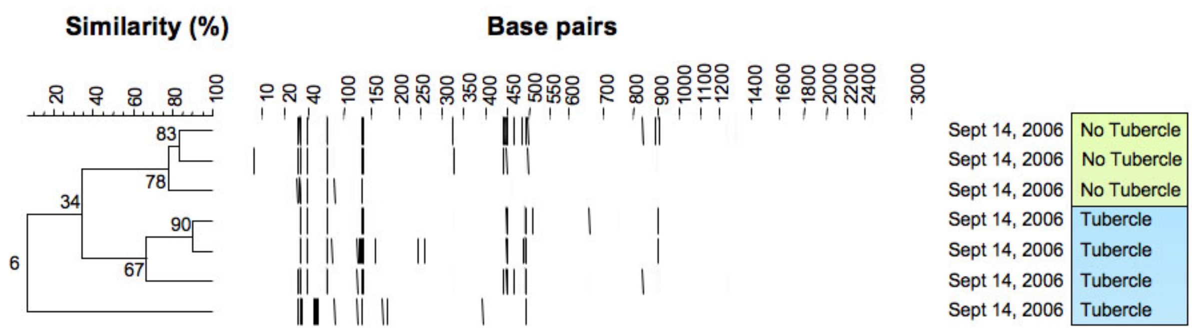

Fig. 5. Similarity of bacterial biofilm communities on corrosion tubercles and adjacent areas on steel sheet piling at Hallett Dock 5, September 14, 2006. T-RFLP analysis of *Rsa*I digests of bacterial 16S rDNA PCR products. Similarities are based on Pearson correlations of terminal restriction fragments patterns between 47 and 946 base pairs in size.

The bacterial clone library (57 clones) developed from 16S rDNA fragments amplified from Hallett Dock 5 and Midwest Energy community DNA samples demonstrated that most bacteria associated with the corroded steel surfaces were from three bacterial phyla, the β- and α-Proteobacteria, and Cyanobacteria (Fig. 6). One 16S rDNA clone from the β-Proteobacteria group was most similar to *Rhodoferax ferrireducens*. This iron-reducing bacterium grows well at low temperatures (~4°C) that are seasonally encountered in this harbor (Finneran et al. 2003).

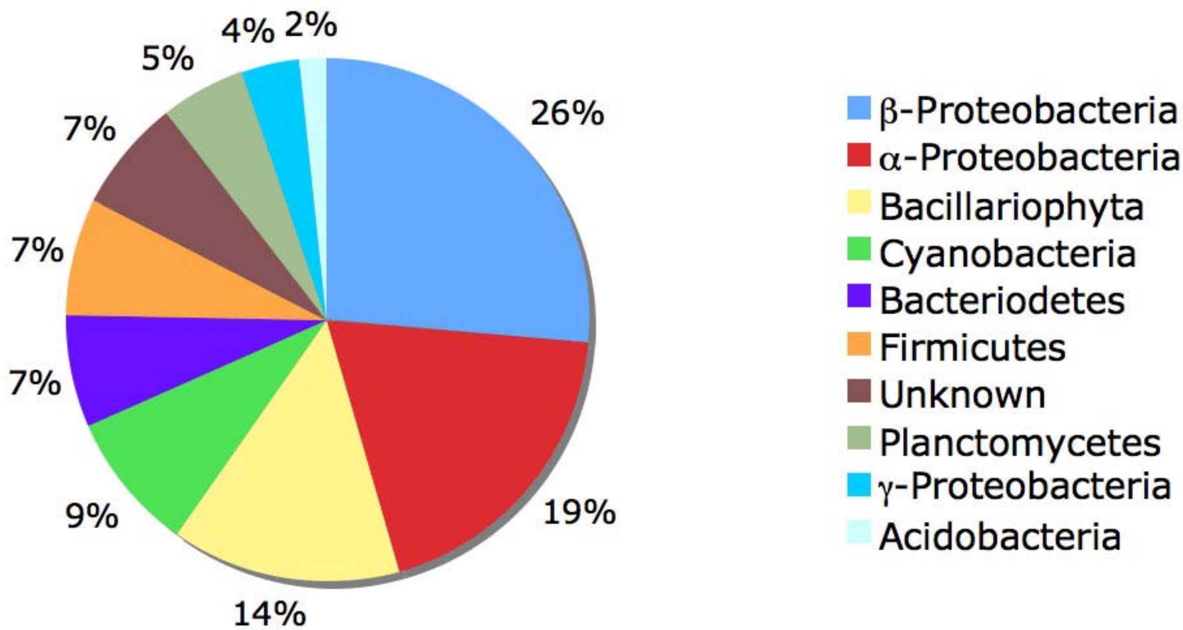

Fig. 6. Proportion of 16S rDNA clones from the Hallett Dock 5 (Aug 1, Sept 14) and Midwest Energy (Aug 15) in 2006 that are from different bacterial phyla (except the Bacillariophyta, which represent 16S rDNA clones from are eukaryotic diatom chloroplasts).

Conclusions –

- Corroded steel sheet piling surfaces and corrosion tubercles are covered by complex microbial biofilms.
- The diversity of bacterial biofilm communities is different on steel pilings at corroded and less affected sites.
- The composition of bacterial communities is different on corroded and uncorroded areas of steel sheet piling at Hallett Dock 5.
- The majority of bacteria on the surfaces of steel pilings at the corroded sites examined were from three bacterial phyla, the β- and α-Proteobacteria, and Cyanobacteria.
- Iron-oxidizing (*S. lithoautotrophicus*) and iron-reducing (*R. ferrireducens*) bacteria are present on corroding steel pilings in the Duluth-Superior harbor. Although we cannot provide conclusive evidence that these iron bacteria are causative agents of the accelerated corrosion of steel pilings in this harbor, our preliminary results indicate that the corroding steel structures are covered by complex microbial biofilms that contain bacteria of the type responsible for corrosion of steel in other environments.

Potential Economic Impacts of the Research Results

Coating steel pilings is only a temporary solution and the best coatings may only prevent or reduce corrosion in this environment for 5 to 10 years (Chad Scott, AMI Consulting Engineers; pers. comm.). The upper portion of sheet pilings is frequently abraded by ice scouring during the winter months in this harbor. Corrosion similar to that seen on unprotected steel surfaces rapidly appears on coated sheet pilings after they are scratched or abraded. Thus, it is important to understand the mechanisms and agents responsible for this accelerated corrosion. Understanding the cause should be helpful in designing and testing mitigation practices, which could lead to improved control and remediation efforts.

Shipping through the Duluth-Superior harbor, the largest port by total cargo volume in the Laurentian Great Lakes, has a $200 million dollar annual impact on Minnesota's economy. Solving this accelerated corrosion issue should enhance the economic vitality of many companies whose 15 major cargo terminals ship ore, coal, and grain from this port. The results of this research should be valuable to the U.S. Army Corps of Engineers, the Duluth Seaway Port Authority, individual companies that have docks and slips in this harbor, and engineering and construction firms hired to repair or replace failing steel piling structures. A more thorough understanding of this accelerated corrosion process in Minnesota will be invaluable because preliminary inspections indicate that corrosion problems similar to the one observed in the Duluth-Superior harbor may be present in other ports on Lake Superior and possibly other Laurentian Great Lakes.

Dissemination of Study Results

1. Publications

   Hicks, R. E., J. M. Bergin, J. Ohaju, and B. Little. Association of *Siderooxidans lithoautotrophicus* with corroding steel pilings in a freshwater aquatic environment. Journal of Biofouling: in preparation.

2. Presentations

   Hicks, R. E., J. M. Bergin, J. Ohaju, and J. L. Kish. 2007. Microbial Aspects of Steel Sheet Piling Corrosion in the Duluth-Superior Harbor. Corrosion Issue Meeting-Army Corps of Engineers, Duluth, MN. May 22, 2007 (oral presentation)

   Hicks, R. E., J. M. Bergin, J. Ohaju, and J. Bostrom. 2007. Microbial Aspects of Steel Sheet Piling Corrosion in the Duluth-Superior Harbor. City of Duluth Harbor Technical Advisory Committee meeting, Duluth, MN. September 5, 2007 (oral presentation)

   Hicks, R. E., J. M. Bergin, J. Ohaju, and J. Bostrom. 2007. Microbial Aspects of Steel Sheet Piling Corrosion in the Duluth-Superior Harbor. GLMRI University Affiliates Meeting, Duluth, MN. September 28, 2007 (oral presentation)

   Hicks, R. E., J. M. Bergin, J. Ohaju, and J. L. Kish. 2007. Microbial Aspects of Sheet Steel Piling Corrosion in the Duluth-Superior Harbor. Making a Great Lake Superior conference, Duluth, MN. October 29-31, 2007 (poster presentation)

3. Other

   Bostrom, J. Microbial influenced corrosion of steel structures in a freshwater port (tentative title). M.S. Thesis, Integrated Biosciences Graduate Program, University of Minnesota Duluth (in progress)

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We thank Chad Scott (AMI Consulting Engineers) for help collecting samples from corroding structures in the Duluth-Superior harbor. This work was supported by grants from the Great Lakes Maritime Research Institute, the Duluth Seaway Port Authority, the University of Minnesota Center for Urban and Regional Affairs, and the Minnesota Sea Grant College Program, NOAA Office of Sea Grant, United States Department of Commerce.

Title: Building Sustainable Solutions to the Issue of Ballast Water Treatment: Testing Relationships between Propagule Pressure and Colonization Success of Invasive Species.

Type of Report: Interim

PI Name	Donn K. Branstrator University of Minnesota Duluth Department of Biology 1035 Kirby Drive Duluth, MN 55812 Phone: 218-726-8134 E-mail: dbranstr@d.umn.edu
Co-PI Name	Matthew C. TenEyck University of Wisconsin-Superior Lake Superior Research Institute PO Box 2000 Superior, WI 54880 Phone: 715-394-8160 E-mail: mteneyck@uwsuper.edu

Date of Report October 31, 2007

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List of Tables, Figures, and Appendices

Executive Summary

This multi-year project addresses the issue of ballast water treatment by examining the efficacy of the standards that will be applied concerning permissible levels of biological pollution. The main objective of this project is to measure relationships between propagule pressure and colonization success of zooplankton in the Duluth-Superior Harbor and St. Louis Estuary through dose-gradient experiments that bracket International Maritime Organization standards.

The objective of this first year of work was to characterize the density and diversity of crustacean zooplankton in the Duluth-Superior Harbor and St. Louis Estuary, a first step in developing the experiments. Twelve locations were selected for sampling. These reflected a random, geographic distribution spanning from the Oliver Bridge to the Duluth Entry. On each of 10 dates between April and October, 2007, the 12 locations were sampled during day time for crustacean zooplankton and a variety of physical and chemical variables. The same set of locations will be sampled again on 10 dates in 2008.

Preliminary data analysis indicates strong gradients in temperature, water clarity and primary productivity across the 12 sampling locations, but little variation in dissolved oxygen concentration. Densities of individual species of zooplankton peak during midsummer which may be explained in part by seasonal variation in water temperature. Zooplankton composition and density show spatial gradients that may be the result of mixing with Lake Superior, but may also reflect variation in the degree of ballast water exchange from ships. Additional data and data analysis will permit us to test this hypothesis. A second year of sampling and analysis will permit us to develop a solid picture of the spatial and temporal characteristics of the zooplankton assemblage in the Duluth-Superior Harbor and St. Louis Estuary. This will provide the context necessary to carryout the other objectives of this project.

Introduction

During the past century the use of ballast water by commercial ships has inadvertently created a highly efficient, global transfer mechanism for non-native species. Foreign ships arriving in U.S. ports discharge in excess of 70 million metric tons of liquid ballast annually, fostering an ongoing transfer of non-native aquatic species into the country (Minton et al. 2005).

In an effort to prevent further biological pollution through ballast water exchange (Grigorovich et al. 2003), the U.S. Congress passed and reauthorized legislation in the 1990s that requires vessels to manage their ballast water in one of two ways. Ships are required either to carryout Ballast Water Exchange (BWE) by flushing ballast tanks in the open ocean or to perform Ballast Water Treatment (BWT) by proactive decontamination. Although BWE has been widely adopted by the shipping industry, it has a number of limitations as a preventative measure. As a result, there is a growing need for research, testing and implementation of BWT technologies.

Effectiveness standards of BWT technologies will be guided by standards agreed upon by the International Maritime Organization (IMO). Recognizing that no BWT technology can be expected to perform with 100% effectiveness all of the time, the IMO standards are meant to reduce the risk of biological pollution. Specifically, IMO standards are a set of permissible, post-treatment concentration limits that vary according to organism body size and taxonomic affiliation. It has been suggested that for organisms of >50 µm body length (e.g., crustacean zooplankton), a density of up to 10 living individuals per cubic meter will be permissible in post-treatment discharge (Global Ballast Water Management Programme, 1997).

There is a significant lack of understanding among ecologists regarding the quantitative relationships between propagule pressure (the size and frequency of founding populations) and colonization success of non-native organisms. The available evidence strongly implicates propagule pressure as a determinant of colonization success in terrestrial plants (Von Holle and Simberloff 2005) but evidence from aquatic ecosystems is limited (Bohonak and Jenkins 2003, Colautti et al. 2006). Examples of recent invasive zooplankton species that have colonized the Great Lakes–St. Lawrence Seaway System through ballast water exchange include zebra mussel larvae (*Dreissena polymorpha*) and the spiny waterflea (*Bythotrephes longimanus*). In neither case was it known how many invasive propagules, or founding events, precipitated the colonization event.

Hence, despite the intended outcomes of the IMO post-treatment standards, there have been no systematic evaluations of the relationships between permissible post-treatment concentration limits (propagule pressure) and the colonization success of aquatic species to which the standards will apply.

This project has three interrelated objectives. 1) Describe the density and diversity of zooplankton in the Duluth-Superior Harbor and St. Louis Estuary. The results will be used to develop the natural communities used to seed mesocosms (see objective 3 below). 2) Couple the results of objective 1 with information on ship traffic and ballast discharge (volume, port of origin) to evaluate the relationship between propagule pressure and colonization success of zooplankton in the Duluth-Superior Harbor and St. Louis Estuary. 3) Measure relationships between the size and frequency of founding populations of zooplankton (propagule pressure) and their colonization success. This interim report addresses data collected under objective 1 which was the focus of the 2007 work plan.

Report body

During the past century the use of ballast water by commercial ships has inadvertently created a highly efficient, global transfer mechanism for non-native species. In an effort to eliminate ballast water as a viable vector, the U.S. Congress passed and reauthorized legislation in the 1990s that requires vessels to manage their ballast water in one of two ways. Ships are required either to carryout Ballast Water Exchange (BWE) by flushing ballast tanks in the open ocean or to perform Ballast Water Treatment (BWT) by proactive decontamination. There has been no systematic evaluation of the relationships between permissible post-treatment concentration limits (propagule pressure) and the colonization success of non-native species. This project will eventually evaluate the quantitative relationship between the size and frequency of founding populations of zooplankton and their colonization success. Those experiments will be conducted in land-based mesocosms. As a first step in this process, surveys of the density and diversity of zooplankton in the Duluth-Superior Harbor are being conducted to help define the natural communities used to seed the experimental mesocosms. Furthermore, by coupling survey results with information on ship traffic and ballast discharge (volume, port of origin) we will test relationships between propagule pressure and colonization success of zooplankton in the Duluth-Superior Harbor.

The three objectives of this project and the basic approach to each are described below. The first year of this study (2007) concentrated on the collection of data under objective 1. This interim report presents the data collected and some preliminary analysis of those data.

1. **Measure the seasonal density and diversity of zooplankton at the species level in the Duluth-Superior Harbor and its connected waters including the St. Louis Estuary and Lake Superior adjacent to the Duluth-Superior Harbor.** Zooplankton collections will be made biweekly from April-October for 2 consecutive years with standard Puget-Sound style zooplankton nets. Associated measurements including temperature, dissolved oxygen, conductivity, pH, fluorescence, photosynthetic active radiation and water clarity will be taken.

2. **Test the hypothesis that seasonal density and diversity of zooplankton in the Duluth-Superior Harbor (a measure of colonization success) as determined under objective 1, is temporally and spatially correlated with seasonal shipping traffic and ballast discharge (volume, port of origin) statistics which is an index of propagule pressure.** Information on seasonal shipping traffic and ballast discharge will be collected. Starting in 2005, Masters were required to report all ballast transfers on the Great Lakes and Seaway. The information is stored at the National Ballast Information Clearing House, Smithsonian Environmental Research Center. Coupled with data about the seasonal density and diversity of zooplankton in the Duluth-Superior Harbor (objective 1), these data will provide a means to test for relationships in-situ between colonization success and propagule pressure.

3. **Measure the relationships between propagule pressure and colonization success of zooplankton in the Duluth-Superior Harbor and St. Louis Estuary through dose-gradient experiments that bracket International Maritime Organization (IMO) standards.** Experiments will be conducted in replicated mesocosms (1 cubic meter volume) in a typical dose-gradient design. Mesocosms will be located at a laboratory on the shores of the Duluth-Superior Harbor and contain native assemblages of bacteria, phytoplankton and zooplankton. Different levels of propagule pressure (inocula concentrations) will be applied that bracket IMO guidelines. Propagule pressure will be manipulated by adjusting independently the density of a 'model' invasive zooplankton species and the number of inoculating events. Candidate 'model' invasive species will include a least one phytoplanktivorous species (e.g., *Daphnia retrocurva*) and one carnivorous species (e.g. *Bythotrephes longimanus*). Quantitative relationships between propagule pressure and colonization success of a species are likely to be context specific and influenced by both biotic and abiotic factors of the recipient system. This will be experimentally tested as resources permit.

The completion of objective 1 required the initial identification of sampling sites within the study grid of the Duluth-Superior Harbor and St. Louis Estuary (Figure 1). Three zones within the grid were defined as follows: 1) Upstream of Spirit Lake, 2) Spirit Lake, and 3) Harbor adjacent to Lake Superior. The selection of our sampling sites within the grid was guided by an electronic-map program developed by the U.S. Environmental Protection Agency. The program was employed to identify 12 random locations within the grid, weighted by the area of each zone. The program identified 1 site in zone 1, 4 sites in zone 2, and 7 sites in zone 3. Sampling sites by name, number and zone are listed in Table 1. General locations of the sampling sites by zone are found in Figure 1.

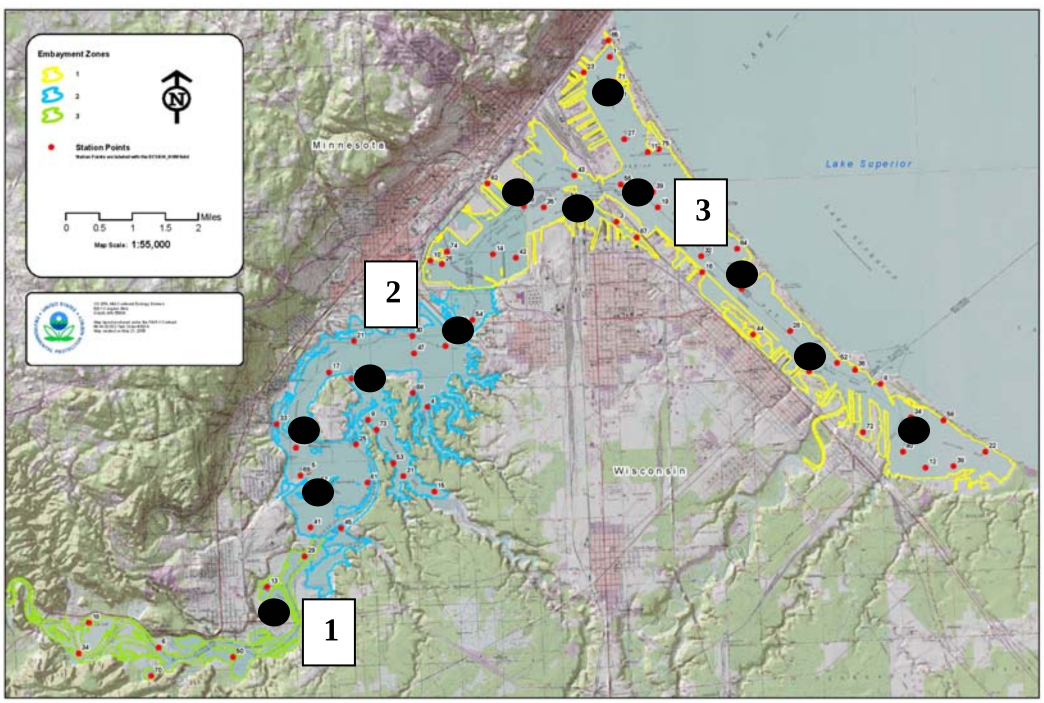

Figure 1. Distribution of the 12 sampling sites (black circles) within the three zones of the Duluth-Superior Harbor and St. Louis Estuary

Samples were collected on 10 dates, approximately biweekly, from 20 April 2007 to 20 October 2007. All 12 stations were sampled on 9 of the 10 dates. On the first sampling date (20 April 2007) 4 of 12 stations were not sampled due to mechanical problems with equipment.
Work was conducted from a 16' Lund boat during daylight hours. At each location on each date the following information was collected.

Table 1. Sampling site name, reference number, and geographic zone of site as given in Figure 1. Rows marked with 'Y' indicate that seasonal data are included in the Appendices of this report.

Site Name	Ref. number	Zone	Phys-Chem	Zooplankton
Riverside Marina	49	2	Y	
Oliver Bridge	50	1	Y	Y
Duluth Entry	51	3	Y	
Hog Island	52	3	Y	
Clough Island	53	2	Y	
Billings Park	54	2	Y	
High Bridge	55	3	Y	
Allouez Bay	56	3	Y	Y
Spirit Lake	57	2	Y	
DMIR	58	3	Y	
Midwest Energy	59	3	Y	Y
Barker's Island	60	3	Y	

Zooplankton were collected with a Puget-Sound style zooplankton net. The net had a mouth opening of 0.5-m diameter, an aspect ratio (opening:length) of 1:3, and nitex mesh of 100 µm aperture. The net was lowered to near the sediment and retrieved to the surface until at least 1,000 L were filtered. This required between 2 to 6 casts per location. Collections were preserved in 75% Ethanol (final volume).

Physical and chemical information was collected at meter intervals through the water column with three different instruments manufactured by YSI Incorporated. The physical and chemical variables included Temperature (ºC), pH, Conductivity (µS), Fluorescence (µg L^{-1}), Dissolved Oxygen (mg L^{-1}), and Turbidity (NTU). In addition, irradiance (foot-candles) at meter intervals was collected with a Protomatic meter. Three Secchi disk measurements were taken per location. Data were entered into an Excel spread sheet.

In the laboratory, zooplankton collections were diluted, split with a Folsom-style plankton splitter, and re-suspended to known volume. Two or more subsamples were scored under a Leica MZ125 dissecting microscope. Summing all dates, the equivalent of at least 100 L of original volume of collection was searched. Zooplankton counts were converted to number m^{-3}. Zooplankton collections on all dates (9 or 10) for 3 of 12 stations were completed by the time of this interim report.

Zooplankton data as well as physical and chemical data were entered into Excel spreadsheets and appear in Appendices 1 and 2, respectively, of this report.

Zooplankton

The crustacean zooplankton assemblage is dominated in number and diversity by copepods (Appendix 1). This pattern of composition strongly reflects the makeup of crustacean zooplankton in Lake Superior. Lake Superior is overwhelmingly dominated by calanoid copepods (e.g., *Diaptomus*) that aggregate in and above the metalimnion during summer (Watson and Wilson 1978, Megard et al. 1997, Zhou et al. 2001, Brown and Branstrator 2004). In Lake Superior, episodic outbreaks of cladoceran zooplankton (e.g., *Daphnia*) occur predominantly nearshore and in offshore surface regions seasonally, but cladocerans are usually present in substantial numbers only in the summer and autumn and are a minor biomass component in comparison to copepods lakewide. As in Lake Superior proper, at the 3 sampling locations analyzed thus far in this study, cladoceran zooplankton express strong seasonality, with highest densities achieved during July and August for most species.

There is a signal in the data that suggests species richness is greater in zone 3 (contiguous with Lake Superior, locations 56 and 59) than zone 1 which is upstream of Spirit Lake (location 50). This may reflect exchange with Lake Superior assemblages of zooplankton through the Duluth and Superior entries but may also reflect variation in the degree of ballast water exchange from ships. This hypothesis will be tested when more data have been analyzed. Aside from one outstanding specimen that will require more taxonomy, there were no individuals at any of the three sites analyzed that would be considered non-native to the region.

Water temperature ranged widely during the sampling campaign. Spring and autumn temperatures were generally in the range of 8-10°C while peak summer temperatures ranged from 23-29°C. The effect of temperature on controlling zooplankton growth in Lake Superior has been studied (Watson and Wilson 1978). Not surprisingly, temperature is an excellent predictor of zooplankton abundance because zooplankton are ectothermic and their growth rate is determined to a large extent by enzyme activity (Vijverberg 1980, Shuter and Ing 1977).

Significant correlations between zooplankton abundance and epilimnetic water temperature have been observed in Lake Superior at the correlation level of 69% (Watson and Wilson 1978) and 54% (Zhou et al. 2001). A correlation of 92% has been reported for several North American large lakes (Patalas 1990). Thus, epilimnetic temperature is certainly an important parameter to consider in variation in zooplankton composition and density. Owing to temperature controls on growth rates, invasive species of crustacean zooplankton may be more likely to establish when water temperatures are warmest. Hence, summer months present a vulnerable period for the Duluth-Superior Harbor and St. Louis Estuary in terms of establishment success of inocula of non-native species.

Physical Chemical

The physical and chemical data (Appendix 2) reveal noteworthy gradients from zone 1 to zone 3 in some variables such as temperature, chlorophyll fluorescence, turbidity and transparency but not in others such as dissolved oxygen.

Dissolved oxygen concentrations were generally uniform from surface to sediment with little indication of gradients in concentration. At no location or time did we detect anoxic or even hypoxic (< 2 mg L^{-1} dissolved oxygen) conditions at the sediment surface. These data indicate that benthic species and the benthic life stages of species will find sufficient oxygen conditions in the Duluth-Superior Harbor and St. Louis Estuary at all depths to complete their life cycles.

Surface temperatures were generally warmer upstream (zone 1) than downstream (zone 3). Gradients in chlorophyll fluorescence and turbidity were in the same direction, while water transparency (Secchi disk) increased from zone 1 to zone 3. Despite this general trend, there was tremendous variation in turbidity and transparency among sites in zone 3 owing to the fact that some sites are quite shallow and strongly influenced by riverine inputs (e.g., Allouez Bay, Location 56) whereas others are flushed more continuously with Lake Superior (e.g., Duluth Entry, Location 51).

In conclusion, there appears to be large gradients in the physical and chemical composition of the pelagic habitats from headwaters to outlets in the Duluth-Superior Harbor and St. Louis Estuary. Our analysis of 3 of 12 crustacean zooplankton samples reveals trends that suggest variation in composition and density from zone to zone, as well as strong seasonality in density. The latter may be governed in part by water temperature. A second year of sampling and analysis will permit us to develop a valuable picture of spatial and temporal variation in the zooplankton assemblage of the Duluth-Superior Harbor and St. Louis Estuary that can be used to complete objectives 2 and 3 of this multi-year project.

Potential Economic Impacts of the Research Results

This project will ultimately provide basic and applied results on relationships between propagule pressure and colonization success of invasive species. Results and reports emanating from this project will include a data-based risk assessment model of invasion success in relation to propagule pressure.

This research will provide a scientific basis for guiding the development of IMO standards as they relate to the effectiveness of BWT technologies. A broad set of professionals should be interested in this research including people in areas of policy, environmental law, research and development of BWT technologies, population biology, invasive species, and limnology.

There is a significant lack of understanding among ecologists regarding the quantitative relationships between propagule pressure and colonization success of dispersing organisms. This in turn presents a serious impediment for identifying specific standards (either concentrations or per-ship discharge) for ballast water management of invasive species. This project fulfills both an important information gap in the discipline of invasion ecology and a specific information gap regarding IMO standards. The Duluth-Superior Harbor has long been recognized as a globally important ecosystem from the perspective of maritime traffic volume and ballast water issues. This research project is basic and applied, as well as timely and geographically significant.

Dissemination of Study Results

This project is providing the basis for the Ph.D. degree sought by Matthew C. TenEyck through the University of Minnesota Water Resources Science Graduate Program. The results of this research will be published in peer-reviewed journals and it is anticipated that this will begin as soon as the completion of the 2008 field season. We anticipate that the first paper will define the spatial and temporal variation in zooplankton community structure within the Duluth-Superior Harbor and St. Louis Estuary and compare and contrast that to physical and chemical gradients as well as gradients and patterns in shipping traffic and ballast discharge.

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APPENDIX 1

Vertical Net Counts

Vertical Net Counts										
Oliver Bridge (location 50)										
#/m3										
Date	20-Apr-07	9-May-07	1-Jun-07	14-Jun-07	5-Jul-07	29-Jul-07	16-Aug-07	29-Aug-07	23-Sep-07	20-Oct-07
Bosmina longirostrus	70.9	44.2	67.0	165.8	348.6	1403.1	527.2	7602.0	302.3	81.2
Chydorus sp.	240.9	10.2	63.8	25.5					398.5	81.2
Alona sp.	14.2	20.4	44.6	63.8	8.5			25.5	89.3	162.4
Ceriodaphnia sp				63.8	11.9	95.7	807.8	357.1		
Diaphansoma sp.		23.8		17.0	149.7	561.2	646.3	535.7	34.4	
D. retrocurva						31.9	280.6	1275.5	61.8	
D. g. mendota						6.4	34.0			
D. thomasi male	42.5								6.9	
D. thomasi female	34.0									
A. vernalis male	8.5			4.3						
A. vernalis female	2.8									
E. agilis male				8.5					6.9	
E. agilis female	5.7	10.2		8.5						
T. mexicanus male										
T. mexicanus female	19.8	3.4								
D. sicillodies male	11.3									
D. sicillodies female	2.8									
D. orgenensis male	2.8									
D. orgenensis female										
D. sicilis male		3.4								
D. sicilis female										
Eurytemora male										
Eurytemora female										
Epischura male										
Epischura female										
Harpacticoid male										
Harpacticoid female	2.8	6.8		4.3						
Leptodora				4.3		12.8	110.5			
N auplii	522.0	602.0	172.2	761.1	352.0	548.5	8044.2	6326.5	96.2	121.8
Cyclop copepidids	272.1	224.5	95.7	250.9	35.7		3979.6	2959.2	130.5	609.0
Mesocyclop copepidids	11.3	3.4					8.5			
Tropocyclop copepidids	11.3									
Diaptomus copepidids	5.7	6.8		4.3	98.6		8.5	25.5		
Harpactacoid copepidids	62.4	47.6	3.2							
Eury copepidids						25.5				
Epischura copepidids										

Vertical Net Counts										
Allouez Bay (Location 56)										
#/m3										
Date	20-Apr-07	9-May-07	1-Jun-07	14-Jun-07	5-Jul-07	29-Jul-07	16-Aug-07	29-Aug-07	23-Sep-07	20-Oct-07
Bosmina longirostrus		372.2	1820.4	9235.7	995.2	7006.4	5254.8	16162.4	6608.3	410.7
Chydorus sp.										
Alona sp.										
Ceriodaphnia sp				106.2			159.2	636.9	318.5	
Diaphansoma sp.		97.1		3131.6	3861.5	5414.0	4697.5	3901.3	636.9	9.9
D. retrocurva		48.5		2282.4	1950.6	1672.0	1592.4	1433.1	3503.2	19.9
D. thomasi male		841.4	60.7	159.2	159.2	79.6			79.6	3.3
D. thomasi female		258.9		265.4	119.4	79.6			79.6	
A. vernalis male							79.6			
A. vernalis female										
E. agilis male				53.1						
E. agilis female										
T. mexicanus male							159.2		79.6	
T. mexicanus female							79.6			
M. edax male		40.5		1327.0	4657.6	636.9	1751.6	238.9	318.5	
M. edax female		40.5		265.4	3065.3	79.6	557.3	159.2	79.6	
D. sicillodies male										
D. sicillodies female				106.2	79.6					
D. orgenensis male				477.7	318.5	238.9	3343.9	3025.5	2070.1	9.9
D. orgenensis female				530.8	437.9	398.1	2229.3	2547.8	2149.7	16.6
D. sicilis male		16.2							79.6	16.6
D. sicilis female										26.5
Eurytemora male				743.1		238.9				3.3
Eurytemora female				159.2	79.6	79.6				3.3
Epischura male										
Epischura female					39.8					
Harpacticoid male										
Harpacticoid female										
Lepto				796.2	119.4	79.6		79.6		
Holopedium					39.8					
N auplii		1731.4	33798.5	11995.8	19187.9	21178.3	63216.6	47929.9	19426.8	414.0
Cyclop copepidids		2936.9	10012.1	11518.0	3941.1	11305.7	11305.7	14092.4	3025.5	215.3
Mesocyclop copepidids		137.5		3821.7	3423.6	11465.0	14729.3	4140.1	955.4	
Tropocyclop copepidids							159.2	318.5		
Diaptomus copepidids		210.4	182.0	1008.5	2189.5	3742.0	18232.5	6926.8	6210.2	46.4
Harpactacoid copepidids										
Eury copepidids				6316.3	1512.7	2388.5		3105.1	1433.1	79.5
Epischura copepidids				53.1					159.2	
Veligers					10589.2	1273.9				

Vertical Net Counts										
Midwest Energy (Location 59)										
#/m3										
Date	20-Apr-07	9-May-07	1-Jun-07	14-Jun-07	5-Jul-07	29-Jul-07	16-Aug-07	29-Aug-07	23-Sep-07	20-Oct-07
Bosmina longirostrus	111.0	336.2	2039.7	4726.1	15095.5	59872.6	12314.2	5573.2	10327.2	273.2
Chydorus sp.	252.1	47.8	28.3							16.6
Alona sp.	16.2	55.7	61.4	51.0	42.5					58.0
Ceriodaphnia sp		15.9		12.7	31.8		1141.2	159.2	243.9	
Diaphansoma sp.		8.0	4.7	12.7	382.2	4670.9	9660.3	3980.9	162.6	
D. retrocurva				51.0	244.2	1114.6	5520.2	4140.1	2032.9	91.1
D. thomasi male	44.0	55.7	37.8	25.5	31.8	53.1	238.9	716.6	243.9	
D. thomasi female	37.0	79.6	80.3		31.8	212.3	132.7	79.6	203.3	
A. vernalis male	4.6									
A. vernalis female	11.6									
E. agilis male	6.9				21.2		159.2	398.1		
E. agilis female	9.3				21.2		159.2	477.7		
T. mexicanus male									40.7	
T. mexicanus female		8.0							81.3	
M. edax male							106.2	636.9		
M. edax female	2.3					53.1		238.9		
D. sicillodies male		31.8		25.5						
D. sicillodies female	2.3	8.0								
D. orgenensis male					21.2	159.2			81.3	
D. orgenensis female					21.2		132.7		203.3	
D. sicilis male	32.4	15.9						79.6		
D. sicilis female	2.3							79.6		
Eurytemora male			14.2	89.2	21.2	159.2	159.2			
Eurytemora female			28.3	165.6	21.2			79.6		
Epischura male				12.7			53.1	79.6		
Epischura female				51.0			79.6	79.6		
Harpacticoid male	4.6									
Harpacticoid female	18.5	15.9						79.6		
Lepto				25.5	31.8	159.2	79.6			
Holopedium							26.5	79.6		
N auplii	1192.7	3837.6	2285.2	3535.0	4203.8	3343.9	4617.8	16879.0	10611.8	49.7
Cyclop copepidids	508.9	4808.9	1383.4	777.1	3620.0	4564.8	5838.6	6767.5	8213.0	256.7
Mesocyclop copepidids	48.6	39.8			42.5	159.2	106.2	79.6		
Tropocyclop copepidids	9.3									
Diaptomus copepidids	6.9	167.2	42.5	51.0	276.0	424.6	1512.7	1751.6	691.2	24.8
Harpactacoid copepidids	101.8	31.8	28.3							
Eury copepidids			75.5	815.3	350.3	265.4	212.3	238.9	203.3	
Epischura copepidids				993.6	658.2	1857.7	1035.0	3025.5	528.6	
Veligers						16135.9	5944.8	5812.1	162.6	

APPENDIX 2
Physical and Chemical Data

Oliver Bridge		Sample Date:									
Site 50	Temp (C)	20-Apr-07	9-May-07	1-Jun-07	14-Jun-07	5-Jul-07	25-Jul-07	16-Aug-07	29-Aug-07	23-Sep-07	20-Oct-07
Depth (m)	0	7.7	17.2	19.9	22.2	23.7	29	24.3	21.7	16	10.29
	1	7.6	16.8	19.6	22	23.7	27.8	24.2	21.3	15.5	1.28
	2	7.6	16.5	19.1	22	23.6	26.1	24.1	21.1	15.2	10.28
	3	7.5	16.2	19	21.5	22.8	25.3	24.1	21	15.1	10.28
	4	7.5	14.8	18.8	21	22.5	24.9	24	20.9	15	10.26
	5	7.5	14.7	18.8	20.9	22.3	24	23.8	20.8		10.26
	6				20.8	22.1		23.5			10.26
	7				20						10.27
	DO(mg/L)										
	0	12.6	10.58	9.05	8.32	7.7	8.39	7.9	8.68	10.54	13.12
	1	12.6	10.4	9.08	8.33	7.59	8.43	7.76	8.41	10.23	13.33
	2	12.6	10.49	8.87	8.2	7.58	8.24	7.64	8.26	9.72	13.12
	3	12.5	10.28	8.9	8.15	7.02	7.85	7.5	8.27	9.81	12.76
	4	12.5	10.27	8.85	8.04	7.06	7.35	7.38	8.01	9.85	12.58
	5	12.5	10	8.8	7.95	6.87	6.79	7.18	7.73	9.85	12.5
	6				7.87	6.75		6.85			12.29
	7				7.64						12.56
	pH										
	0	8.49	7.73	7.79	7.6	7.94	8.39	8.05	7.96	7.88	7.68
	1	8.49	7.73	7.76	7.59	7.93	8.35	8.02	7.94	7.87	7.69
	2	8.49	7.73	7.73	7.58	7.91	8.28	8.01	7.93	7.87	7.69
	3	8.49	7.74	7.7	7.59	7.9	8.21	7.99	7.92	7.86	7.7
	4	8.49	7.75	7.68	7.6	7.89	8.13	7.96	7.91	7.84	7.69
	5	8.49	7.75	7.68	7.58	7.88	8.13	7.94	7.92	7.83	7.7
	6				7.59	7.89		7.96			7.7
	7				7.58						7.7
	Specific Cond										
	0	170	189.9	178.7	172.5	184.4	201.3	216.9	219.8	279	120.7
	1	170	190.1	179.7	173.1	184.3	200.3	219.5	221.8	280.4	120.1
	2	170	190.4	177.5	173.8	184.4	199.3	219.3	219.7	283.8	120.9
	3	169	190.3	177.3	173.6	184.1	200.3	219.2	219.9	283.4	120.7
	4	169	189.1	177.1	173.1	184.7	200.1	219.3	219.5	293.2	120.2
	5	169	189.3	177.1	173.1	184.6	200.5	219	220.5	294	120.1
	6				173.6	185.1		219.4			120.1
	7				174.2						
	chl										
	0		11.9	15.4	21.6	12.9	8.3	6.6	8.3	6.5	22.7
	1		14.6	16.2	18.1	14	9.9	6.8	8.3	6.8	23
	2		15.5	15.7	18.4	13.4	10.6	6.3	8.7	7.7	23.1
	3		15.9	15.4	17.8	13.4	11	6.8	7.6	7.6	23
	4		16	15.5	17.5	13.3	10.7	7.2	8.1	7.7	23.8
	5		16.3	16.1	17.9	12.9	11.5	6.8	7.9	7.5	23.4
	6				17.9	13		6.5			23
	7				17.6						24.1
	Turbidity (NTU)										
	0			4.5	5.6	5.1	4	1.6	1.7	3.3	35.4
	1		3.8	4.7	5.6	5.1	4.1	1.8	2	3.1	39
	2		3.9	4.9	6.3	5.2	4.2	1.8	2.3	3.5	40.2
	3		3.9	5.2	6.6	6.1	4.4	1.8	2.4	3.8	40.2
	4		4.2	5.7	6.7	6.2	4.7	1.8	2.4	4.1	43.2
	5		4.5	5.8	7.2	6.4	4.9	1.9	2.6	3.5	40.7
	6				7.5	6.6		2.3			42.1
	7				7.4						43
	Light (ft-candles)										
	0		2400	430	350	650	3200	3000	3200	2400	800
	1		500	32	25	44	700	1000	1000	360	6
	2		23	4	3.5	10	170		200	71	0.03
	3		2.8	0.76	0.44	2.4	34		52	14	0.02
	4		0.9	0.13	0.054	0.35	8		15	3	0.01
	5		0.21	0.001	0.02	0.1	1.8		4.4	0.8	0.01
	6				0	0.05					
	7										
	Secchi										
	1	1.03	1.43	0.74	0.64	0.74	1.41	2	1.68	1.24	
	2	1	1.43	0.77	0.66	0.74	1.39	1.96	1.72	1.25	
	3	1	1.65	0.7	0.67	0.76	1.38	2	1.73	1.23	

Duluth Entry		Sample Date:									
Site 51	Temperature (C)	20-Apr-07	9-May-07	1-Jun-07	14-Jun-07	5-Jul-07	25-Jul-07	16-Aug-07	29-Aug-07	23-Sep-07	20-Oct-07
Depth (m)	0		13.6	16.3	17.6	17.2	21.5	19.6	18.2	14.7	9.95
	1		12.5	14.9	17.6	17.2	21.2	19.6	18.2	14.3	9.97
	2		10.5	14.3	17.5	17.2	20	19.6	18.2	14.2	9.98
	3		10.1	14	17.1	17.1	19.3	19.6	18.1	14	9.98
	4		9.9	13.4	16.7	16.8	18.9	19.6	18.1	14	9.99
	5		8.9	13.1	16	16.2	18.1	19.4	17.7	14	9.99
	6		8.3	12.6	15.6	16	17.7	19.1	17.6	14	9.99
	7		8.2	12.2	14.9	15.8	17.3	18.9	17.5	13.9	9.99
	8		8	11.2	14	15.6	16.8	18.9	17.4	13.9	9.99
	9				13.3	15.5	14.7	18.8		14	9.99
	DO(mg/L)										
	0		10.49	9.43	8.95	8.99	9.82	9.3	9.39	11.55	13.01
	1		10.43	9.18	8.82	8.97	9.71	9.17	9.34	11.12	12.06
	2		10.93	9.03	8.75	8.92	9.82	9.18	9.33	11.21	11.69
	3		10.82	9	8.7	8.91	9.85	9.1	9.39	11.23	11.7
	4		10.98	9.18	8.79	8.92	10.03	9.03	9.47	11	11.65
	5		11.26	9.46	9.08	9.02	10.24	9.14	9.66	10.65	11.61
	6		11.9	9.68	9.45	9.14	10.17	9.16	9.76	10.79	11.52
	7		12.04	9.87	9.94	9.24	10.19	9.04	9.79	10.72	11.56
	8		12	10.21	10.32	9.39	10.33	9.02	9.78	10.74	11.57
	9				10.64	9.35	10.75	8.8		10.35	11.5
	pH										
	0		8.18	7.69	7.57	8.26	8.26	8.21	7.72	7.71	7.7
	1		8.1	7.66	7.32	8.19	8.23	8.22	7.69	7.75	7.7
	2		8.06	7.71	7.61	8.15	8.26	8.22	7.69	7.82	7.71
	3		8.04	7.6	7.62	8.12	8.25	8.2	7.7	7.79	7.72
	4		8.05	7.44	7.46	8.12	8.27	8.15	7.7	7.75	7.72
	5		8.1	7.68	7.6	8.1	8.12	8.15	7.71	7.78	7.72
	6		8.12	7.71	7.61	8.07	8.24	8.09	7.69	7.77	7.72
	7		8.1	7.76	7.38	8.06	8.27	8.06	7.68	7.83	7.72
	8		8.09	7.83	7.69	8.04	8.27	8.08	7.68	7.64	7.73
	9				7.79	8.03	8.27	8.1		7.54	7.73
	Specific Cond										
	0		217.7	248.8	210.9	171.7	196.7	169.4	164.7	225.1	165
	1		203.6	253.2	210.7	172	194	169.7	164.7	200.1	165
	2		202.2	242.5	210.2	172	153.7	169.3	162.4	168.3	165
	3		200.6	246.9	204.4	170.7	153	169.1	151.3	168.7	164.7
	4		191.9	227.9	198.6	167.2	137.7	169.2	138.8	172	164.8
	5		171	228.1	191.9	159.4	133.4	163.7	128.3	172.4	164.7
	6		169.2	220.5	181.8	156.4	127.6	132.2	126.5	176.6	164.4
	7		165	214	170.3	151.2	125.8	137.8	124.5	170.5	164.5
	8		164.6	186.7	156.4	146.6	120.7	131.6	123.5	240.8	164.7
	9				145.2	143.5	112.8	133.6		420	164.2
	chl										
	0		8.6	5.5	13.6	7.2	8	4	1.6	8.4	19.6
	1		9.1	7.8	13.3	7.3	7.1	4.5	3.3	3.8	19.4
	2		9.5	7.8	12.1	7.3	6.3	4	3.4	2.3	20.4
	3		9.4	8.2	12	7.5	7.8	3.7	3.8	2	20.1
	4		8.8	8	11.3	6.9	5.7	4.5	3.7	1.9	20
	5		7.8	7.2	9.8	6	4.1	3.2	3.5	2.2	20.2
	6		6.8	6.7	8.6	6.1	4	3.4	2.8	2	20.4
	7		6.8	6.4	8.4	5	3.8	3.3	3	2	19.7
	8		6.5	6.5	7	5	3.8	4	2.7	1.5	19.9
	9				5.6	4.3	4.1	4		2	20
	Turbidity (NTU)										
	0		4.7	4.9	6.7	3.4	2	1.7	1.7	3.3	11.8
	1		4.8	5.3	6.6	3.4	1.7	1.8	1.9	2.7	12.1
	2		4.9	5.7	6.4	3.4	1.6	1.8	1.9	2.4	11.9
	3		4.9	6	6.5	3.5	1.4	1.7	2	2.1	11.9
	4		5	5.8	6.4	3.8	1.3	1.5	2	2.5	12
	5		4.8	5.5	5.6	4.5	1	0.9	1.8	1.9	12
	6		4.4	5.3	4.5	4.3	0.7	0.9	1.4	1.8	12.1
	7		4	5	4.1	4.5	0.7	0.8	1.4	1.8	11.8
	8		3.9	4.5	3.6	4.7	0.8	0.9	1.3	1.7	12.1
	9				3	4.4	0.8	1.8		1.9	11.7
	Light (ft-candles)										
	0		200	3100		1400	4800	2000	130	2100	90
	1		18	350		260	1300	1000	61	580	1.4
	2		4.4	55		49	64	330	46	250	0.06
	3		6.5	8.4		10	38	140	23	120	0.01
	4		1.4	1.5		0.7	24	60	12	50	
	5		3	0.35		0.22	14	32	6.6	30	
	6		0.09	0.11		0	7.5	18	4.1	16	
	7		0.04	0.05			4.5	11	2.5	10	
	8		0	0			2.8	6.6	1.6	5.5	
	9						1.8	3.8		3	
	Secchi										
	1		1.08	1.08	0.76	1.32	1.77	2.71	2.26	2.29	0.58
	2		1.12	1.07	0.8	1.3	1.79	2.79	2.22	2.26	0.67
	3		1.06	1.08	0.78	1.29	1.75	2.77	2.26	2.26	0.66

Hog Island		Sample Date:									
Site 52	Temperature (C)	20-Apr-07	9-May-07	1-Jun-07	14-Jun-07	5-Jul-07	25-Jul-07	16-Aug-07	29-Aug-07	23-Sep-07	20-Oct-07
Depth (m)	0		15.1	16.5	19.5	19.4	23.8	20.5	18.3	15.1	9.95
	1		13.6	16	19.2	19.4	23.8	20.5	18.4	14.9	9.97
	2		12.6	15.3	18.9	19.3	21.9	20.4	18.4	14.8	9.98
	3		11.3	15	18.7	19	18.8	20.4	18.4	14.7	9.99
	4		10.9	14	18	18.7	18	20.3	18.4	14.6	9.99
	5		10.9	13.5	17.3	18.3	17.4	20.3	18.4	14.6	9.99
	6		10.7	13.2	15.8	17.9	16.7	20.2	18	14.5	9.98
	7		10.4	12.7	14.5	17.6	15.5	19.6	17.7	14.5	9.98
	8						15.1				
	DO(mg/L)										
	0		9.8	10.69	8.95	8.79	9.01	8.6	9.02	10.08	12.32
	1		10.15	10.45	8.55	8.63	8.6	8.6	8.98	9.87	11.9
	2		10.23	10.2	8.28	8.55	8.82	8.45	8.91	9.77	11.79
	3		10.14	10	8.12	8.45	8.15	8.44	8.86	9.69	11.62
	4		10.17	9.5	7.9	8.53	8.33	8.4	8.82	9.58	11.56
	5		10.1	9.32	7.78	8.52	8.7	8.3	8.76	9.55	11.66
	6		10.11	9.23	8.08	8.59	8.7	8.4	8.95	9.55	11.71
	7		10.11	9.06	8.12	8.51	9.62	8.4	9.17	9.46	11.56
	8						9.06				11.48
	pH										
	0		7.76	7.81	7.62	7.97	8.39	8.19	7.72	7.74	7.74
	1		7.74	7.77	7.5	7.96	8.29	8.18	7.72	7.74	7.73
	2		7.76	7.76	7.59	7.96	8.14	8.17	7.71	7.72	7.73
	3		7.7	7.76	7.58	7.95	8.1	8.12	7.7	7.7	7.73
	4		7.68	7.72	7.58	7.95	8.01	8.1	7.69	7.69	7.73
	5		7.68	7.74	7.59	7.98	7.99	8.06	7.68	7.67	7.73
	6		7.7	7.75	7.61	7.99	8.08	8.04	7.67	7.68	7.74
	7		7.69	7.78	7.66	7.98	8.14	8.05	7.72	7.67	7.73
	8						8.14				7.73
	Specific Cond										
	0		212.8	239.4	214.2	186.3	176.4	161.4	164	240.5	160.1
	1		209.9	237.5	212.8	185.6	176.6	162.8	166.8	242.5	160.1
	2		204.2	238.5	212.6	185.2	171	162.8	166.9	245	160.2
	3		208.8	238.5	210.9	181.4	173.8	162.8	168.7	244	160
	4		209.4	239.2	213.9	179.2	163.2	161.2	167.3	241.7	160.2
	5		208.5	237.6	204.2	171.4	147	155.4	164.1	234.1	160.1
	6		209.8	237.3	200.2	165.1	140.1	155.8	152.3	218.5	160.3
	7		208.4	231.1	295.6	170.8	123.4	139.7	134.5	219.7	160.5
	8						125.5				161.1
	chl										
	0		12.5	13.7	14.1	10	5.9	3.6	3.3	2.4	17.7
	1		10.5	13.9	13.7	8.8	7.2	3.5	3.9	3.7	20.1
	2		8.6	12.9	12.8	8.9	6	3.2	4.1	3.8	19.5
	3		8.6	10.6	11.5	7.9	5.6	3.6	4.2	3.8	20.8
	4		9.2	9.5	10.3	7.7	5	3.8	4.3	3.2	21
	5		9.5	7.9	11	7.1	4.9	3.8	3.9	3.5	20.3
	6		9	6.6	10	6.5	4.1	3.8	3.3	3.4	20.1
	7		9.5	6.8	8.3	6.7	3.9	3.1	2.8	2.7	21.1
	8						3.9				20.7
	Turbidity (NTU)										
	0			7.3	6.1	5.8	1.4	2.1	2.6	4.6	10.2
	1		6.3	7	6.4	5.9	1.4	2.1	2.7	5	11.2
	2		8.4	6.4	6.4	6	1.6	2.1	2.8	5.1	11.3
	3		7.8	5.9	6.5	6	1.7	2.1	2.8	5.2	11.6
	4		6.5	6	6.8	6.1	1.6	2.2	2.9	5.4	11.5
	5		6	5.9	6.7	6.9	1.8	2.3	2.9	5.6	11.2
	6		6	5.6	6.7	9.2	2.1	2.4	3.2	5.8	11.3
	7		10.4	5.8	7.9	8.2	2.7	2.9	3.7	6.5	11.3
	8						2.7				11.8
	Light (ft-candles)										
	0		3700	3300	2800	2000	3000	2400	1400	380	140
	1		200	300	150	260	1000	1500	370	100	1.1
	2		24	38	15	38	380	450	130	50	0.5
	3		2.8	6.5	1.8	6.3	123	180	50	25	
	4		0.54	1.2	0.26	1.2	47	80	20	8	
	5		0.1	0.28	0.06	0.28	21	32	9	3	
	6		0.048	0.06	0	0.08	9	15	3.7	1	
	7		0	0		0	3.7	6.5	1.8	0.4	
	8						1.5				
	Secchi										
	1		1.4	0.83	0.89	0.98	2	2.42	1.76	1.1	0.47
	2		1.43	0.82	0.91	0.99	2	2.4	1.78	1.14	0.54
	3		1.41	0.81	0.88	0.99	2	2.43	1.76	1.15	0.59

Clough Island		Sample Date:									
Site 53	Temperature (C)	20-Apr-07	9-May-07	1-Jun-07	14-Jun-07	5-Jul-07	25-Jul-07	16-Aug-07	29-Aug-07	23-Sep-07	20-Oct-07
Depth (m)	0	8.4	17.6	19.5	22.3	24.1	27.2	23.5	21.4	16.5	10.29
	1	8.4	17.5	19.3	22	23.2	26.7	23.5	20.8	16.4	10.28
	2	8.3	16.6	18.9	21.4	22.1	26.2	23.5	20.6	16	10.28
	3	8.2	16.2	18.6	21.3	22.9	25.3	23.4	20.5	15.8	10.27
	4	8.1						23.3			10.27
	DO(mg/L)										
	0	12.2	10.24	8.45	8.02	7.94	7.18	7.05	6.77	9.98	12.87
	1	12.2	10.09	8.39	7.9	7.32	7.06	6.92	6.65	9.83	12.66
	2	12.1	9.7	8.53	7.56	6.54	6.74	6.92	6.57	9.66	12.2
	3	12	9.46	8.48	7.44	6.41	6.27	6.76	6.5	9.6	12.69
	4	11.7						6.7			12.15
	pH										
	0	8.31	8.09	7.65	7.64	8.1	8.12	7.97	7.75	7.79	7.64
	1	8.31	7.94	7.67	7.64	8.07	8.08	7.96	7.76	7.79	7.65
	2	8.3	7.85	7.66	7.65	8.07	8.06	7.97	7.76	7.79	7.66
	3	8.3	7.78	7.67	7.68	8.07	8.06	7.95	7.76	7.77	7.66
	4	8.29						7.96			7.67
	Specific Cond										
	0	165	186.6	183.6	172.3	185.8	195.8	204.9	205.2	249.7	125.3
	1	165	185.4	182	172.7	186.3	196	204.9	201.8	256	125.5
	2	165	186.4	181.5	172	186.7	196	202.6	203.3	257.3	125.5
	3	165	185.9	179.7	172.1	187.6	195.6	205.2	205.5	261.3	125.5
	4	165						205.4			125.3
	chl										
	0		16.4	11.8	16.6	10.4	8.9	7.1	7.5	6.3	21.4
	1		12.8	11.8	16.7	10.5	9.3	7	7.6	7.2	21.7
	2		12.3	12.7	15.7	11	9.1	6.8	7.1	7.1	22.6
	3		12.2	13.4	16.1	10.9	8.2	6.8	7.5	7.6	22.5
	4							7.1			22.6
	Turbidity (NTU)										
	0			5.9	4.4	10	4.3	11.9	7.1	5.2	24.9
	1		4.4	6.1	4.4	10.8	4.1	12.2	10.9	4.3	26
	2		3.9	5.1	4.6	10	3.1	12.4	13.5	5.4	27.8
	3		3.9	4.9	4.9	10.8	2.3	12.8	14.6	4.5	29.3
	4							13.2			33.1
	Light (ft-candles)										
	0		3000	500	2500	520	4500	2800	2500	3100	350
	1		250	26	32	17	180	240	520	550	1.2
	2		27	5	3.2	1.6	42	29	51	140	0.04
	3		4	0.9	0.52	0.25	16	2.6	5.1	26	0.01
	4							0.37			
	Secchi										
	1	0.83	1.57	0.8	0.67	0.72	1.21	0.9	1	1.39	0.49
	2	0.87	1.82	0.86	0.67	0.74	1.2	0.86	0.97	1.34	0.42
	3	0.82	1.82	0.83	0.69	0.75	1.23	0.9	0.96	1.36	0.49

Billings Park		Sample Date:									
Site 54	Temperature (C)	20-Apr-07	9-May-07	1-Jun-07	14-Jun-07	5-Jul-07	25-Jul-07	16-Aug-07	29-Aug-07	23-Sep-07	20-Oct-07
Depth (m)	0	8.7	18.7	18.4	21.3	22.1	26.4	23.1	20.9	15.7	10.32
	1	8.7	16.1	18.2	21.2	21.5	25.4	23.14	20.8	15.6	10.07
	2	8.7	15.4	17.8	21	21.4	24.9	23.1	20.8	15.6	10.05
	3	8.6	15.1	17.4	20.7	21.2	24.5	23	20.7	15.1	10.04
	4	8.6	14.8	17	20.6	20.9	24.1	23	20.6	15.1	10.03
	5	8.6	14.1	17	20.5	208	23.6	22.8	20.5	15.1	10.04
	6	8.6	13.7	16.9	20.4	20.4	22.5	22.8	20.5	15.1	10.03
	7	8.6		16.8	20.4	20.1	21.8	22.7	20.4		
	DO(mg/L)										
	0	11.6	10.6	8.23	7.52	7.98	6.65	7.9	7.81	9.27	12.52
	1	11.6	9.56	8.12	7.41	7.6	6.84	7.84	7.77	9.06	12.16
	2	11.4	9.56	7.95	7.31	7.54	6.82	7.78	7.67	8.99	12
	3	11.4	9.51	7.99	7.24	7.51	6.8	7.63	7.57	8.9	12.07
	4	11.3	9.52	8.12	7.22	7.44	6.71	7.41	7.48	8.88	12
	5	11.4	9.38	8.12	7.18	7.39	6.65	7.32	7.33	8.86	12.09
	6	11.6	9.3	8.09	7.14	7.15	6.57	7.27	7.28	8.77	12.03
	7	11.5		8.12	7.04	6.87	6.51	7.19	7.24		
	pH										
	0	7.86	7.62	7.59	7.5	8.03	8.08	8.32	7.82	7.79	7.55
	1	7.88	7.58	7.6	7.5	8.02	8.07	8.32	7.8	7.76	7.59
	2	7.9	7.59	0.59	7.5	8.01	8.07	8.31	7.78	7.81	7.6
	3	7.9	7.59	7.61	7.49	8.01	8.04	8.25	7.75	7.76	7.62
	4	7.9	7.58	7.6	7.49	8	8.01	8.22	7.74	7.74	7.63
	5	7.91	7.57	7.59	7.48	7.99	7.99	8.17	7.73	7.73	7.65
	6	7.91	7.55	7.57	7.48	7.98	7.95	8.19	7.73	7.72	7.65
	7	7.92		7.56	7.48	8	7.97	8.2	7.72		
	Specific Cond										
	0	165	192.9	196.6	173.4	190.6	200.9	193.9	210	243.6	132.1
	1	165	186.7	196.7	174.4	188.5	199.8	198.8	210.6	246.9	131.6
	2	165	182.7	197.7	173.5	189.8	196.5	200.7	210.8	247.7	131.4
	3	165	184	191.8	174.1	188.5	196.4	198.2	211.3	247.3	131.1
	4	165	183.2	188.8	174.4	188.7	196.5	198.5	210.5	247.3	131.2
	5	165	183.6	190.1	174.6	189	197.7	198.7	210.2	249.1	131
	6	165	184.6	191.3	174.5	191.2	204.7	198.6	210.3	248.5	131
	7	165		197	174.4	191	205.6	199.1	210.7		
	chl										
	0		11.8	9.9	15.9	13.4	8	11.8	10.4	6.7	20.1
	1		11.8	11.1	15.8	12.3	8.9	11	11.2	5.6	20.8
	2		11.9	12.5	16.1	12.1	8.9	11.8	10.7	5.7	20.5
	3		12.2	11.9	16.4	12	8.8	13	10.4	5.3	20.6
	4		11.6	12.8	16.4	11.2	8.7	12.6	10.2	5.3	20.3
	5		12.2	12.3	16.3	11.3	8.2	12.1	10.3	5.1	20.4
	6		11.1	12	15.6	11.6	7.8	12.1	9.8	5	20.9
	7			12.2	15.6	11.9	7.4	13.1	9.8		
	Turbidity (NTU)										
	0		51.6	11.7	11.6	6	3.2	8	6.2	7.6	18.7
	1		50.7	12.6	11.4	6.4	3.7	8.5	6.3	8	20.5
	2		242.5	12.2	10.5	6.6	3.8	8.1	6.7	8.3	20.7
	3		243.7	9.7	10.4	6.9	4	7.4	7.2	8.7	20.7
	4		246.4	9.4	10.7	7.5	4.2	6.9	7.3	9.5	21
	5		248.4	9.3	11.1	7.7	4.3	6.8	7.7	10.3	20.7
	6		250.2	9.1	11.2	8.6	5.5	7.4	8.2	13	21.2
	7			9.4	12.4	9.9	7.7	8.8	10.3		
	Light (ft-candles)										
	0		4500	1600	3000	4100	1800	2200	200	2700	400
	1		480	700	600	80	350	150	57	140	4
	2		5.2	40	28	10	100	31	30	32	0.07
	3		0.88	0.5	0.18	2.4	220	7.6	10	7.2	0.03
	4			0.05	0.02	0.41	1.5	1.5	2.6	1.6	0.01
	5			0	0	0.1	0.5	0.41	0.7	0.38	0.01
	6					0.05	0.15	0.1	0.19	0.13	0.01
	7					0.03	0.08	0.05	0.05		
	Secchi										
	1	0.625	1.26	0.6	0.51	0.65	1.16	1.11	0.88	0.87	0.46
	2	0.6	1.26	0.56	0.55	0.68	1.13	1.08	0.86	0.87	0.47
	3	0.62	1.26	0.59	0.54	0.66	1.13	1.08	0.88	0.89	0.44

High Bridge		Sample Date:									
Site 55	Temperature (C)	20-Apr-07	May 9,2007	1-Jun-07	14-Jun-07	5-Jul-07	25-Jul-07	16-Aug-07	29-Aug-07	23-Sep-07	20-Oct-07
Depth (m)	0	8.4	12.5	15.6	19.4	19	22.4	20.7	18.9	15.2	10.3
	1	8.4	11.6	15.4	19.1	19	21.9	20.7	18.9	15.1	10.29
	2	8.4	11.2	15	18.9	18.9	19.8	20.7	18.9	15.1	10.3
	3	8.3	10.9	14.6	18.8	18.9	19.1	20.7	18.1	15	10.3
	4	8.3	9.8	14.3	18.3	18.7	19	20.7	18.9	15	10.31
	5	7.6	9.6	14.3	17.3	18.4	18.3	20.5	18.8	15	10.31
	6	7.4	9.5	14.1	16.6	18.4	18.1	20.4	18.7	15	10.3
	7	7.2	9.3	13.6	16.1	17.5	17.9	20.1	18.7	15	10.3
	8	7.1	8.6	12.7	15.6	16.7	17.3	19.9	18.5	15	10.26
	9		8.3				17	19.8	18.4	15	10.26
	DO(mg/L)										
	0	12.5	11.16	10.01	7.96	8.98	9.51	8.41	8.99	9.84	11.4
	1	12.5	11.02	9.75	7.93	8.91	9.04	8.41	8.92	9.65	11.3
	2	12.4	11.15	9.59	7.98	8.67	9.61	8.36	8.92	9.45	11.5
	3	12.3	11.3	9.52	8.17	8.58	9.98	8.3	8.85	9.44	11.43
	4	12.3	12.06	9.3	8.33	8.64	9.86	8.34	8.55	9.43	11.39
	5	12.3	11.68	9.33	8.48	8.58	9.75	8.54	8.62	9.3	11.35
	6	12.3	11.64	9.25	8.88	8.4	9.74	8.48	8.66	9.36	11.29
	7	12.2	11.71	9.21	9.05	8.13	10.03	8.49	8.75	9.31	11.42
	8	12.2	11.89	9.34	9.17	8.05	10.04	8.45	8.92	9.31	11.42
	9		11.87				9.42	8.23	8.66	9.42	11.4
	pH										
	0	8.52	7.83	8.64	7.97	7.91	8.23	8.08	7.52	7.57	7.68
	1	8.54	7.86	8.33	7.06	7.91	8.13	8.08	7.5	7.57	7.68
	2	8.53	7.9	8.21	6.82	7.87	8.16	8.06	7.47	7.57	7.68
	3	8.54	7.95	8.07	6.48	7.8	8.19	8.06	7.47	7.55	7.69
	4	8.53	7.94	7.8	6.23	7.78	8.19	8.04	7.46	7.53	7.69
	5	8.51	7.89	7.47	6.08	7.72	8.16	8.02	7.46	7.53	7.69
	6	8.5	7.96	6.8	5.99	7.61	8.01	8.02	7.44	7.52	7.7
	7	8.48	7.93	6.63	5.9	7.8	8.23	7.99	7.44	7.51	7.7
	8	8.48	7.96	6.46	5.68	6.26	8.16	7.99	7.44	7.51	7.69
	9		7.53				6.56	7.64	7.21	6.63	7.7
	Specific Cond										
	0	190	226	207.9	186	223.8	211.7	218.9	206.9	317	144.9
	1	193	225.6	211.4	191.3	223.1	227.6	220.7	207.7	321.4	144.6
	2	191	216.4	216.4	187.4	222.1	179.3	217.3	208.8	320.3	145
	3	195	215.4	217.5	192.6	218	165.4	215.2	206.3	318.9	144.5
	4	195	195.9	218.6	196.5	209.3	164.8	206.8	204.6	317.4	144.6
	5	195	192.1	219.5	194.7	205.9	156.7	201.1	204.8	317.8	144.9
	6	194	188.7	220	198	188	149.9	198	194.1	315.4	144.8
	7	195	186.4	230.2	195.2	192.5	141.2	183.3	189.3	315.2	145.3
	8	195	175.3	219.5	189	176.7	138.8	179.6	181.6	314.8	146
	9		170.3				148.4	179.3	168.5	313.8	145.8
	chl										
	0		11.1	9.8	14.6	7.9	7.9	7.8	3.9	3.9	19.8
	1		10.4	9.5	15	8.9	12.8	7.5	4.2	4.8	16.2
	2		10.1	9.3	14.8	9.1	11	8.8	5.1	4.6	18.4
	3		9.8	8.3	14.6	9.2	8.5	9.1	4.6	4.5	20.1
	4		9	8.4	13.8	8	6.1	7.6	4.2	4.2	19.8
	5		8.8	8.3	12.8	8.9	5.1	7.6	3.4	4.9	19.8
	6		7.9	7.6	11.2	7.6	5.2	7.8	3.8	4.5	20
	7		7.8	7.3	10.3	7.3	5.2	7.9	3.5	4.5	19.6
	8		7.7	6.8	9.1	6.1	5.2	6.7	3.1	4.9	19.2
	9		7.9				5	9.3		4.7	19.2
	Turbidity (NTU)										
	0		5.3	7.4	9.3	5.7	2	15.7	2.4	5.6	36.1
	1		5.5	7.6	9.6	5.8	2.8	5.5	2.5	5.8	36.1
	2		5.6	7.6	9.5	6.2	2.8	4	2.4	5.9	36.5
	3		5.7	6.9	9.4	6.3	2.5	3.7	2.5	5.9	34.6
	4		5.4	7	9.1	6.4	2.1	3.6	2.5	5.9	34.4
	5		5.3	6.7	8	6.1	2.2	3.3	2.6	6.2	34
	6		5.1	6.7	7.3	6.2	2.3	3.2	2.8	6.2	34.8
	7		5	6.1	6.5	7	2	3.1	2.6	6.3	35.5
	8		4.6	6.1	6	7.5	1.9	3.1	2.5	6.3	34.3
	9		6.5				3.8	4.4		8.2	34
	Light (ft-candles)										
	0		200	2900	1000	1000	1200	1200	130	260	50
	1		15	200	25	90	300	200	48	35	0.8
	2		3.5	15	1.2	9	62	45	15	15	0
	3		0.5	2.5	0.12	1.3	19	14	5.6	4.8	
	4		0.14	0.26	0	0.22	7.3	3.7	2.2	1.4	
	5		0.04	0.1		0.05	3	1.4	0.9	0.4	
	6		0	0.05		0.045	1.2	0.54	0.4	0.11	
	7			0		0	0.66	0.2	0.21		
	8						0.35		0.11		
	9						0.2		0.05		
	Secchi										
	1	0.88	1.28	0.9	0.54	0.81	1.27	1.3	1.83	1.13	0.33
	2	0.92	1.26	0.92	0.54	0.84	1.28	1.38	1.79	1.15	0.41
	3	0.89	1.26	0.91	0.59	0.85	1.3	1.35	1.78	1.18	0.44

Allouez Bay		Sample Date:									
Site 56	Temperature (C)	20-Apr-07	9-May-07	1-Jun-07	14-Jun-07	5-Jul-07	25-Jul-07	16-Aug-07	29-Aug-07	23-Sep-07	20-Oct-07
Depth (m)	0		17.8	17.5	20.6	21.2	25.4	22.2	20.2	14.8	9.95
	1		16.1	14.6	20.6	21.1	24	22.1	20.2	14.6	9.94
	2		14.1		20	20.6	22.7	22	20.2	14.6	9.93
	3				18.5	19	21.6	21.9	20.1	14.5	9.93
	4				18.2	18.1	21.1	21.8		14.5	9.93
	5										
	DO(mg/L)										
	0		12.45	10.37	8.69	8.2	8.25	7.65	8.35	10.29	12.01
	1		11.14	9.13	8.56	8.1	6.84	7.55	8.26	10.05	11.73
	2		10.46		7.64	7.86	5.77	7.41	8.15	9.97	11.47
	3				6.65	6.72	5.59	7.27	8.05	9.84	11.5
	4				6.1	6.3	4.74	7.12		9.81	11.47
	5									9.48	
	pH										
	0		7.87	8.58	7.66	7.95	8.15	7.79	7.68	7.69	7.83
	1		7.83	8.39	7.64	7.92	8.02	7.76	7.66	7.66	7.84
	2		7.86		7.63	7.91	7.95	7.75	7.66	7.67	7.85
	3				7.64	7.91	7.97	7.74	7.66	7.69	7.85
	4				7.67	7.92	8	7.8		7.65	7.86
	5									7.62	
	Specific Cond										
	0		186.2	205.7	213.7	186.2	159	158.8	155.7	152.8	166.5
	1		187.4	201.9	215	185.8	163.6	163.2	155.5	153.7	166.4
	2		186		214.2	185.6	162.7	163	155.4	153.7	166.4
	3				215.1	189.2	163.5	162.9	155.5	154.3	166.4
	4				215.3	189.7	164.6	162.9		154.2	166.6
	5									154.8	
	chl										
	0		16	12.5	10.6	8.9	10.2	6.1	6.8	6	15.1
	1		11.6	12.2	10.3	9.3	7.8	6.6	6.7	5.2	15.1
	2		9.5		10.4	9.7	9.5	6.8	7.1	6.1	15.7
	3				10.7	9.1	7.1	6.3	6.6	6.5	14.3
	4				9.4	9.8	6	6		5.9	15
	5									6.6	
	Turbidity (NTU)										
	0		38.4	27.5	30.1	25.1	12.8	12.3	13.9	24	65.6
	1		37.4	28	30.5	28.2	16.2	12.4	14.3	29.8	73.1
	2		37.6		39.9	29.7	19.9	12.4	15	31.9	76.5
	3				38	33.3	22.9	12.9	17.7	31.6	78.2
	4				37.6	35.4	24.7	13.8		31.5	79.2
	5									35	
	Light (ft-candles)										
	0		3500	3500	3200	2300	2800	2800	1500	280	140
	1		200	100	75	68	250	440	230	12	1
	2		3.6		2.1	2.4	30	63	23	1	0.1
	3				0.05	0.13	2	11	2.9	0.1	
	4				0	0	0.18	1.7		0.01	
	5										
	Secchi										
	1		0.74	0.46	0.32	0.39	0.62	0.71	0.72	0.39	0.23
	2		0.72	0.45	0.38	0.37	0.63	0.74	0.7	0.36	0.23
	3		0.74	0.45	0.35	0.35	0.6	0.73	0.7	0.36	0.23

Spirit Lake		Sample Date:									
Site 57	Temperature (C)	20-Apr-07	9-May-07	1-Jun-07	14-Jun-07	5-Jul-07	25-Jul-07	16-Aug-07	29-Aug-07	23-Sep-07	20-Oct-07
Depth (m)	0	8.2	18	19.8	22.3	23.2	26.8	23.6	21.2	16	1.53
	1	8	17.4	19.7	22	23	26.7	23.6	21.1	15.9	10.5
	2	7.7	16.2	19.5	21.4	22.9	26	23.5	20.9	15.9	10.51
	3	7.4	15.7	19.4	20.9	22.5	25.6	23.5	20.7	15.7	10.5
	4	7.3	15.5	18.5	20.5	22.1	25.5	23.3	20.7	15.6	10.51
	5										10.49
	DO(mg/L)										
	0	11.9	11.05	8.88	7.75	7.39	6.77	8.12	8.01	9.75	12.76
	1	11.8	9.88	8.62	7.56	7.35	6.88	8.02	7.97	9.6	12.13
	2	11.8	9.68	8.46	7.3	7.3	6.72	7.98	7.88	9.55	12.1
	3	11.9	9.47	8.22	7.25	7.29	6.6	7.925	7.76	9.42	12.28
	4	8.6	8.16	6.9	7.29	7.24	6.46	7.82	7.59	9.24	12.28
	5										12.31
	pH										
	0	8.4	8.07	7.5	7.54	8.03	8.17	8.35	7.93	7.83	7.67
	1	8.41	7.89	7.5	7.54	8.03	8.16	8.34	7.92	7.83	7.66
	2	8.4	7.81	7.44	7.54	8.03	8.14	8.32	7.9	7.83	7.66
	3	9.41	7.76	7.42	7.55	8.03	8.12	8.3	7.89	7.8	7.66
	4	8.3	7.57	7.38	7.56	8.03	8.12	8.29	7.89	7.8	7.67
	5										7.67
	Specific Cond										
	0	174	189.2	180.6	172.7	184.3	195.5	204.3	210.1	252.3	127.8
	1	173	188.4	180.6	173	186.4	195.1	203.7	212.3	256	128.1
	2	173	195.5	180.6	172.1	188	194.2	206	212.6	255.6	128.5
	3	173	187.3	182	172.6	188.3	194.7	206.5	213.2	255.8	127.1
	4		187.1	187.1	171.6	188.7	194.7	206.3	213.2	255.3	125.9
	5										125.9
	chl										
	0		13.5	13.9	15.9	10.6	8.5	8.6	7.7	6.8	21.4
	1		12.7	14	16	11.2	8.8	8.2	7.7	6.4	21.3
	2		12.2	13.8	15.9	11.5	9.4	8.8	7.6	5.6	21
	3		12.4	13.6	15.6	11.5	8.9	9.7	7.7	5.4	21.3
	4		14.4		15.9	11.2	8	9.7	7.1	5.7	21.4
	5										22.1
	Turbidity (NTU)										
	0		120.7	4.2	4.3	4.7	1.9	2.6	2.9	3.1	20.6
	1		40	4.2	4.6	4.8	2.1	2.6	2.8	3.2	21.3
	2		39	4.2	5.2	4.8	2.9	2.9	2.9	3.4	20.7
	3		38.5	5.2	5.7	4.9	2.9	2.5	3.1	3.4	21.3
	4		39.4		5.6	6	2.9	2.9	3	3.6	21.5
	5										22.2
	Light (ft-candles)										
	0		3500	1300	2300	3500	1000	2800	2500	3200	650
	1		220	90	150	60	150	100	1000	650	2.2
	2		20	1.4	10	14	35	41	250	150	0.4
	3		2.5	0.4	0.8	3	10	18	64	0.41	0.01
	4		0.9		0.1	0.8	3	10	20	0.11	0.01
	5										
	Secchi										
	1	0.67	1.75	0.86	0.82	0.83	1.39	2.05	1.67	1.52	0.5
	2	0.69	1.75	0.83	0.79	0.81	1.37	2.04	1.69	1.5	0.58
	3	0.7	1.75	0.82	0.81	0.8	1.39	2.01	1.71	1.55	0.53

DMIR		Sample Date:									
Site 58	Temperature (C)	20-Apr-07	9-May-07	1-Jun-07	14-Jun-07	5-Jul-07	25-Jul-07	16-Aug-07	29-Aug-07	23-Sep-07	20-Oct-07
Depth (m)	0	9.7	17.5	17.1	20.9	20.8	24	21.8	20.5	16.5	10.36
	1	9.6	14	17.1	20.6	20.5	23.9	21.5	20	16.4	10.29
	2	9.2	13.2	17.1	20.3	20.3	23.7	21.4	19.9	15.7	10.26
	3	9.2	13	17	20	20	22.4	21.4	19.9	15.4	10.22
	4	9	12.6	16.9	19.8	29.5	21.2	21.4	19.8	15.2	10.23
	5	8.9	12.4	15.8	19.5	19.1	19.9	21.3	19.8	15.2	10.21
	6	8.8	12.1	15.2	19.4	19	19.6	21.3	19.8	15.1	10.2
	7	8.3	11.7	15.1	19	18.8	19.5	21.2	19.8	15.1	10.21
	8										10.21
	DO(mg/L)										
	0	12	9.89	8.88	7.72	7.99	8.2	8.49	7.75	9.37	11.33
	1	12	9.81	8.76	7.52	8	8.24	8.31	7.66	9.25	11.32
	2	11.8	9.99	8.7	7.41	7.97	8.17	8.09	7.6	9	11.3
	3	11.7	9.99	8.64	7.3	7.85	7.85	7.94	7.49	8.83	11.23
	4	11.6	9.92	8.63	7.1	7.79	7.81	7.75	7.35	8.75	11.3
	5	11.7	10	8.5	7.01	7.67	8.02	7.88	7.22	8.7	11.17
	6	11.6	9.87	8.22	6.98	7.67	8.21	7.8	7.22	8.66	11.36
	7	11.7	9.63	7.88	6.95	7.44	8.14	7.83	7.06	8.59	11.31
	8										11.19
	pH										
	0	8.44	7.65	8.6	7.55	7.98	8.26	8.37	7.66	7.72	7.68
	1	8.42	7.65	8.4	7.6	7.97	8.21	8.33	7.65	7.72	7.68
	2	8.33	7.65	8.48	7.59	7.97	8.17	8.29	7.64	7.69	7.68
	3	8.31	7.62	8.19	7.53	7.95	8.11	8.27	7.63	7.69	7.68
	4	8.35	7.55	8.04	7.47	7.94	8.13	8.26	7.62	7.67	7.6
	5	8.33	7.64	7.94	7.48	7.93	8.16	8.26	7.61	7.64	7.69
	6	8.36	7.67	7.71	7.44	7.93	8.18	8.25	7.6	7.64	7.68
	7	8.36	7.66	7.55	7.52	7.94	8.19	8.24	7.6	7.62	7.68
	8										7.68
	Specific Cond										
	0	218	190.6	177.3	185	211.9	218.9	209.9	264.1	256.4	141.6
	1	237	187.9	200.7	179.6	210.7	219.4	214.3	263.9	256.2	142
	2	263	189.6	202.7	177.2	211	218.9	218.7	264.2	255.1	143.6
	3	240	190.7	204.6	197.2	215.3	219.2	217.8	265.4	257.5	142.6
	4	256	195.3	225.1	218.5	219.2	206.4	217.4	265.2	259.5	142.2
	5	260	194.9	242.8	213.9	217.9	186.3	220.1	266.7	259.4	142.3
	6	266	196.5	257.3	230.1	217.7	181.9	219.4	267.1	261.4	142.3
	7	290	197.6	335.4	201.6	215.9	182.5	221.1	267.3	261.8	143.4
	8										144.4
	chl										
	0		8.8	10.6	15.6	9.6	8.4	6.9	18.8	4.9	8.5
	1		12.9	10.9	16.5	9.8	10.5	7.6	18.8	5.4	19.3
	2		11.9	11.2	16.2	9.6	10.5	8.8	17.7	5.8	19.8
	3		11.8	11.3	16	9.5	10.6	9	17.6	5.4	19.9
	4		11.4	10.6	15.7	8.3	8.6	10.6	17	5.2	19.7
	5		11.6	9.6	15.7	9.1	7	12.2	16.5	5	19.9
	6		11.5	8.9	15.1	8.8	7	12.2	17.4	5.1	20.4
	7		10.8		14.9	8.9	6.7	12.9	18.5	5.1	19.8
	8										
	Turbidity (NTU)										
	0		53.2	8.4	8.9	5.8	3.5	3.5	3.7	6.3	27.5
	1		9.2	8.8	9.3	5.8	3.4	3.8	3.7	7	27.4
	2		9.2	8.8	9.9	6	3.5	4.5	3.9	7.2	17.3
	3		9.4	9.1	9.7	6.3	3.6	4.7	4	7.2	26.8
	4		8.9	8.4	8.9	6.5	4.1	4.4	4.3	7.3	27.7
	5		8	8.8	8.6	6.7	5.1	4.5	4.3	7.3	27.7
	6		8.8	10	8.7	6.8	5.3	4.7	4.5	7.6	26.9
	7		9.7		9.3	7.7	5.2	5.4	4.9	7.4	26.3
	8										
	Light (ft-candles)										
	0		3500	1600	2400	3000	3700	4200	2700	3000	700
	1		48	200	100	160	550	150	110	580	4
	2		0.48	19	4.3	22	140	55	37	100	0.05
	3		0.5	1.8	0.29	4.8	30	22	17	20	0.01
	4		0.052	0.24	0.048	1	6.8	7	6.1	4	0.01
	5		0	0.05	0	0.17	1.6	2.5	2	0.9	0.01
	6			0		0.05	0.46	1.1	0.65	0.22	0.03
	7					0.03	0.15	0.3	0.2	0.05	0.01
	8										0.01
	Secchi										
	1	0.77	1.035	0.94	0.58	0.93	1.08	1.96	1.32	1	0.4
	2	0.79	1.03	0.96	0.64	0.95	1.1	1.89	1.39	1.03	0.47
	3	0.78	1.25	0.96	0.62	0.93	1.12	1.62	1.41	1.02	0.45

Midwest Energy		Sample Date:									
Site 59	Temperature (C)	20-Apr-07	9-May-07	1-Jun-07	14-Jun-07	5-Jul-07	25-Jul-07	16-Aug-07	29-Aug-07	23-Sep-07	20-Oct-07
Depth (m)	0	8.3	15.6	15.7	20.4	20.7	24.4	22.1	20	16.5	10.3
	1	8.3	14.6	15.6	19.8	20.4	24.1	21.9	19.8	16.2	10.29
	2	8.3	13	15.4	19.4	20.1	22.9	21.6	19.7	16	10.3
	3	8.2	12.7	15.4	19.1	19.9	21.1	21.5	19.6	15.8	10.3
	4	8.2	12.2	15.2	18.9	19.8	20.1	21.4	19.6	15.7	10.29
	5	8.2	11.7	14.9	18.8	19.6	19.3	21.2	19.5	15.6	10.29
	6	8.2	11.2	14.8	18.6	19.3	19	21.2	19.5	15.5	10.29
	7	8.2	10.6	14.7	18.2	19.1	18.6	21.1	19.5	15.4	10.28
	8	8.2	9.8	14.7	17.7	18.7	18.5	21.1	19.5	15.3	10.28
	9	8.2	9.8	14.7	17.4	18.5	18.3	20.8	19.4	15.3	10.28
	10	8.2		14.6		18.4			19.4	15.2	10.28
	DO(mg/L)										
	0	11.8	10.37	8.98	7.6	7.97	8.49	8.66	7.81	9.48	11.72
	1	11.6	9.52	8.94	7.42	7.89	8.44	8.6	7.58	9.26	11.5
	2	11.7	9.87	8.84	7.43	7.89	8.22	8.37	7.42	9.2	11.54
	3	11.7	9.81	8.82	7.39	7.78	8.34	8.31	7.37	9.06	11.55
	4	11.6	9.94	8.76	7.38	7.77	8.43	8.21	7.35	9	11.41
	5	11.6	9.87	8.71	7.37	7.76	8.57	8.05	7.32	8.88	11.39
	6	11.5	9.88	8.72	7.35	7.76	8.37	8.09	7.33	8.73	11.46
	7	11.5	10.29	8.75	7.28	7.67	8.65	7.95	7.17	8.74	11.31
	8	11.6	10.64	8.7	7.39	7.78	8.71	8.02	7.3	8.74	11.23
	9	11.5	9.4	8.72	7.55	7.78	8.69	7.93	7.25	8.62	11.31
	10	11.5		8.69		7.78			7.26	8.62	11.25
	pH										
	0	8.55	8.84	7.8	7.47	7.98	8.19	8.26	7.61	7.67	7.72
	1	8.55	8.45	7.76	7.53	7.94	8.13	8.24	7.6	7.68	7.71
	2	8.55	8.32	7.69	7.39	7.96	8.05	8.22	7.59	7.67	7.71
	3	8.55	8.24	7.73	7.47	7.97	8	8.23	7.59	7.76	7.7
	4	8.53	8.19	7.79	7.51	7.93	8	8.23	7.56	7.65	7.7
	5	8.52	8.17	7.79	7.42	7.92	8.01	8.19	7.58	7.62	7.71
	6	8.52	8.15	7.81	7.48	7.84	8.01	8.17	7.56	7.62	7.7
	7	8.5	8.14	7.81	7.49	7.89	8.02	8.1	7.56	7.62	7.7
	8	8.49	8.15	7.79	7.47	7.87	8.03	8.13	7.33	7.61	7.7
	9	8.47	8.03	7.81	7.49	7.91	8	8.11	7.48	7.54	7.7
	10	8.46		7.82		7.92			7.48	7.53	7.71
	Specific Cond										
	0	224	192.2	214.5	228.5	224.5	201.2	285.6	244	282	132.3
	1	224	195.7	214.9	212.8	229.4	201.6	280.3	254.7	284.2	139.1
	2	224	195.8	217.3	192.5	224.2	199.7	249.4	256.8	286.5	139.4
	3	224	199.3	218.6	190.6	222.6	191.3	237.4	254.9	285.2	139.6
	4	224	204.6	219.6	194.9	225.2	181.6	233.1	253.6	282.7	140
	5	224	203.6	219.2	201.6	230	177.7	230.1	252.7	282.8	140.3
	6	224	201.9	219.2	198.8	233.7	174.6	231.8	252	288.6	140.8
	7	224	198.2	219.9	199.9	232.2	167	234	251.7	295.9	140.3
	8	224	192.5	219.8	199.7	225.7	161.1	225.5	253.8	298.4	140.7
	9	224	187.2	220.6	197.1	215.8	157.1	220	254.2	302.3	140.7
	10	225		219.7		214			255	310.5	140.6
	chl										
	0		9.4	8.8	15.2	9	9.2	5.2	4.8	6	18.8
	1		11.5	10	15.4	9.7	10	7	5.3	5.2	20.6
	2		11.3	9.7	15.3	9.1	10	7	5.7	5.1	20.3
	3		11.3	9.8	15.1	9.2	10.9	6.9	5.1	5.3	20.3
	4		11.4	9.4	15	9.7	11.9	7.4	4.3	5.3	19.6
	5		10.8	9.6	15.7	9.1	9	8.6	4.3	4.9	20
	6		10.6	9.9	15	8.6	7.1	8	4.5	4.4	19.2
	7		11.1	9.2	13.9	8.5	7.1	8.5	4	4.7	19.3
	8		9.3	9.9	12.3	8.2	5.9	8.3	3.3	4.5	19.3
	9			10.3	11.2	7.8	6.3	9.1	4	4.5	20
	10			9.7		7.7			3.3	4.6	
	Turbidity (NTU)										
	0		32	8.9	7	5.4	3.1	3.2	3.1	5.5	33.9
	1		7.4	8.9	7.9	5.6	3.2	3.9	3.3	5.6	33.8
	2		7.5	8.8	8.6	5.8	3.4	4	3.5	5.7	34.4
	3		7.4	10.2	8.9	5.8	3.5	4.2	3.4	5.9	35
	4		7.5	12.2	9	5.8	3.6	4.1	3.3	6.2	34.8
	5		7.4	12.7	8.9	6.2	3.7	4.6	3.3	6.2	35.5
	6		7.1	13	8.9	6.5	4.2	4.7	3.2	6.3	35.1
	7		6.8	13.3	8.6	6.6	4.2	4.6	3.3	6.2	34
	8		6.6	13.3	8	6.5	4.2	4.4	3.5	6.1	33.6
	9			12.7	7.1	6.1	4.7	5.1	3.4	6.1	33.6
	10			12.3		6.1			3.3	7.5	
	Light (ft-candles)										
	0		4200	3100	3500	3800	4500	3500	200	3000	550
	1		80	200	90	200	700	110	60	620	1.2
	2		7.5	25	6	37	150	54	38	120	0.11
	3		1	3.3	0.45	4	35	26	25	25	
	4		0.16	0.3	0.046	1	10	11	10	5	
	5		0.048	0.05	0.02	0.18	2	4.5	3.2	1.5	
	6		0.01	0	0	0.05	0.8	1.4	1.1	0.4	
	7		0			0	0.28	0.37	0.49	0.12	
	8						0.12	0.15	0.15		
	9						0.05		0.05		
	10										
	Secchi										
	1	0.78	1.16	0.88	0.75	0.97	1.24	1.63	1.47	1.21	0.35
	2	0.52	1.17	0.84	0.69	0.96	1.23	1.61	1.46	1.19	0.36
	3	0.56	1.16	0.89	0.73	0.96	1.24	1.58	1.48	1.18	0.37

Barker's Island		Sample Date:									
Site 60	Temperature (C)	20-Apr-07	May 9,2007	1-Jun-07	14-Jun-07	5-Jul-07	25-Jul-07	16-Aug-07	29-Aug-07	23-Sep-07	20-Oct-07
Depth (m)	0		15.1	16	18.8	19.2	23.6	20.4	18.7	15.1	9.98
	1		13.2	15.4	18.7	19	23.4	20.4	18.7	15.1	10.01
	2		12	15	18.5	19	20.5	20.4	18.7	14.9	10.01
	3		11.4	14.6	18.5	18.9	19.1	20.3	18.7	14.9	10
	4		11.1	14.2	17.1	18.7	18.6	20.3	18.7	14.8	10
	5		9.84	13.8	16.3	18.2	17.9	20.2	18.6	14.8	9.97
	6		10.8	13.5	15.9	17.4	17.5	20	18.2	14.7	9.98
	7		10.7	12.7	15	17	16.4	19.1	17.7	14.7	9.97
	8		10.7	12.1	14.2	16.8	15.3	18.9	17.7	14.6	9.96
	DO(mg/L)										
	0		11	9.82	8.01	8.29	9.33	8.65	8.65	9.66	13.87
	1		10.31	9.67	7.9	8.31	9.23	8.57	8.51	9.55	12.25
	2		9.76	9.46	7.71	8.23	8.7	8.5	8.48	9.31	11.71
	3		9.49	9.39	7.66	8.15	8.97	8.35	8.46	9.22	11.71
	4		9.78	9.2	7.61	8.19	8.9	8.3	8.42	9.01	11.62
	5		10.9	9.13	7.84	8.18	8.9	8.3	8.39	9.01	11.4
	6		9.86	9.06	7.95	8.33	8.88	8.24	8.28	8.93	11.51
	7		9.78	8.95	7.99	8.45	8.71	8.22	8.03	8.92	11.43
	8		9.72	8.79	7.84	8.47	8.19	8.25	8.02	8.86	11.39
	pH										
	0		7.65	8.04	7.93	7.89	8.33	8.22	7.63	7.67	7.68
	1		7.7	7.96	7.84	7.88	8.2	8.19	7.63	7.65	7.69
	2		7.71	7.93	7.77	7.87	8.05	8.16	7.61	7.63	7.69
	3		7.71	7.89	7.95	7.86	8.09	8.12	7.59	7.65	7.69
	4		7.71	7.86	7.67	7.84	7.93	8.05	7.58	7.63	7.7
	5		7.71	7.81	7.67	7.88	8	8.02	7.56	7.62	7.7
	6		7.73	7.78	7.66	7.89	8.05	7.95	7.55	7.58	7.7
	7		7.76	7.76	7.65	7.9	8.05	7.96	7.57	7.58	7.7
	8		7.76	7.73	7.64	7.93	8.07	7.97	7.57	7.58	7.71
	Specific Cond										
	0		215.2	235.3	210.5	202.6	186.6	172.4	181.9	347.6	156.8
	1		215.7	234	210.6	202.7	186.4	173.1	182	349.6	156.9
	2		207	236	209.8	201.5	185.6	173.4	182.1	352.6	15.5
	3		207.8	236.4	214.6	201.5	167.4	172.5	181.9	354.2	156
	4		208.5	235.9	208.4	198.8	167.9	172	179.8	354.5	155.9
	5		210.2	239	301	178.1	164.7	171.2	177.1	354.4	155.2
	6		209.4	236.3	197.3	166.9	158.9	167.4	172	352.2	155.6
	7		208.8	234.5	193.3	159.7	159	145	152	349.3	155.4
	8		210.6	227.7	187.9	149.3	151.5	136.3	152.2	342.1	155.5
	chl										
	0		9.2	9	12.5	8.9	6.4	4.3	4.6	4	19.4
	1		9.5	10.2	11.9	8.7	7.1	4.6	4.5	4.3	20
	2		8.9	8.5	11.7	9.2	6.5	5.6	4.4	4.6	20.2
	3		10.3	8.2	10.9	8.5	6.4	4.6	4.2	4.3	20
	4		10.1	7.7	11.6	8.1	6.3	4.9	4.3	3.8	20
	5		10	7.5	10.9	7.8	5.3	4.9	3.5	4	19.1
	6		10.8	7.6	10.5	6.5	5.1	5.2	2.9	4.2	19.6
	7		10.6	7.6	9.3	6.5	5.1	5.6	3	3.6	19.6
	8		11.4	7.6	7.2	5.4	5.8	5.6	2.3	3.9	20
	Turbidity (NTU)										
	0			5.9	6.7	6.1	1.6	2.5	1.8	4.7	238.7
	1			6.1	6.7	6.3	1.6	2.7	2.2	4.8	241.2
	2			6.1	6.4	6.4	1.7	2.8	2.3	5.1	246.3
	3		7.3	6.3	6.4	6.5	2.2	2.9	2.3	5.2	251.2
	4		7.4	6.7	6.8	6.6	1.8	2.7	2.4	5.5	255.2
	5		7.3	6.9	6.6	6.6	1.8	2.8	2.5	5.4	259.4
	6		7.2	6.8	6.2	6.5	1.7	3	3.3	5.7	261.8
	7		7.4	6.9	6.4	6.2	1.7	3.2	3.9	6.8	263.6
	8		17	7.2	7.7	6.2	6.4	3.9	4.6	6.2	266.3
	Light (ft-candles)										
	0		2400	2400	2500	1500	2700	2300	1000	2200	150
	1		160	250	110	160	680	1000	280	430	1.4
	2		22	45	8	19	210	300	100	100	0.3
	3		2.8	7	1	3.4	73	100	35	24	
	4		0.49	1.2	0.13	0.62	25	36	14	6.5	
	5		0.05	0.21	0.02	0.15	10	15	6	1.7	
	6		0.002	0.067	0	0.05	4.3	5.3	2.5	0.5	
	7		0	0			1.7	2.4	1	0.1	
	8						0.68	1	0.49	0.1	
	Secchi										
	1		1.41	0.84	0.86	0.97	1.87	1.96	2.17	1.2	0.51
	2		1.36	0.98	0.88	0.98	1.89	2	2.14	1.2	0.51
	3		1.39	0.97	0.89	0.97	1.91	2.06	2.16	1.21	0.51

Multibeam Bathymetry Survey of the Duluth-Superior Harbor

Final Report

Richard D. Ricketts — Large Lakes Observatory
University of Minnesota Duluth
2205 E. 5th St. Duluth, MN 55812
ricketts@d.umn.edu

Nigel J. Wattrus — Large Lakes Observatory
University of Minnesota Duluth
2205 E. 5th St. Duluth, MN 55812
nwattrus@d.umn.edu

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Multibeam Bathymetry Survey of the Duluth-Superior Harbor

Richard D. Ricketts and Nigel J. Wattrus
Large Lakes Observatory (LLO)
University of Minnesota Duluth
2205 E. 5th St.
Duluth, MN 55812

Executive Summary

This project is a continuation of the Great Lakes Maritime Research Institute (GLMRI) 2006 project, 'Feasibility study: Usefulness of modern acoustic methods to the maritime industry in relation to changes in water depth in the Great Lakes' by Colman and Ricketts. We used state-of-the-art acoustic imaging techniques to address a fundamental issue for Great Lakes mariners: water depth in the Duluth-Superior Harbor. The project addresses the GLMRI focus area 'Marine transportation and port environmental issues.'

We collected high resolution multibeam bathymetry data and used the data to make detailed maps of water depth in the survey area. The data can be used to create 'fly-through' animations, although this has not yet been done with the data from the project. The results of the survey show a variety of features that may be of interest to the maritime industry, such as the configuration of the main basins in the harbor. Maximum water depths in the harbor are found in areas with the heaviest ship traffic, especially where freighters are expected to turn, for example just inside the Duluth and Superior entries, and in the northern section of the East Gate Basin. Anchor drag marks are found throughout the harbor and scour marks associated with water flowing in and out the harbor are found at both the Duluth and Superior entries.

This type of survey can be used in other areas where water depth is critical, such as the St. Mary's River near Sault St. Marie. Also the data collected here will be used as baseline data for comparison to data collected during any future surveys collected by the Large Lakes Observatory.

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Introduction

This project addresses the GLMRI focus area ‘Marine transportation and port environmental issues’ and is a follow-up project to Colman and Ricketts’ 2006 project ‘Feasibility study: Usefulness of modern acoustic methods to the maritime industry in relation to changes in water depth in the Great Lakes’.

Changes in water depth due to changes in lake-level or sediment erosion and deposition are a major issue for the maritime industry in the Great Lakes. These concerns are monitored to address shipping and port-maintenance interests using modern lake-floor imaging technologies, such as multibeam bathymetric measurements.

Water depth in the Great Lakes is a critical issue for the maritime industry because of the direct correlation between water depth and cargo size. In shallow passages, ship loads must be lightened in order that the vessel does not run aground. Reducing the load causes a loss of freight revenue, negatively impacting the economics of the operation. Water depth is determined by the elevation of the lake floor and the elevation of the water surface. The elevation of the water surface is affected on a weekly to yearly basis by the amount of precipitation and evaporation in the lake basin. On longer time scales it is affected by the ongoing tilting of the lake basin in response to unloading of the earth’s crust following the melting of the last great ice sheets [1,2]. Changes in the elevation of the lake floor either increase water depth (indicative of sediment erosion) or decrease water depth (indicative of sediment deposition).

Our objective for this study is to determine the configuration of the Duluth-Superior Harbor using state-of-the-art acoustic imaging techniques addressing almost all of the concerns discussed above. We conducted a survey of the Duluth-Superior Harbor using the Research Vessel Blue Heron’s multibeam sonar system. The multibeam data gives us a detailed view of the Duluth-Superior Harbor that can serve as a baseline for comparison to any future natural or man-made changes in the harbor. The survey also gives us experience using the equipment in harbor settings, which is unlike our typical survey area, allowing us to work out any problems before any similar work in the future.

Methods

The LLO has a survey-grade multibeam bathymetry system mounted on the hull of the RV Blue Heron as well as extensive computer facilities, with which we processed these data and create maps and images of the lake floor.

The Reson Seabat 8101[1] used in this survey is a 240 kHz multibeam that uses 101 1.5-degree beams to measure the bathymetry of the lake floor. The width of the swath illuminated on the lake floor is approximately 7.5 times water depth in water less than 70 m deep. The system has a range resolution of 1.25 cm. Its lateral resolution (in the absence of vessel motion and positioning error) is dependant upon water depth and the number of beams retained in the processed data. The system is capable of producing data that meets the IHO standards for hydrographic surveying [3]. In order to do this, a TSS POS MV/320 motion sensing and positioning system[1] is used to measure the survey vessel's motion (roll, pitch and heading) to an accuracy of less than +/- 0.05 degrees and its position to less than 1 m horizontally and 25 cm vertically. Post-acquisition processing of the data was preformed using CARIS HIPS/SIPS computer programs[1].

[1] The authors and the Great Lakes Maritime Institute do not endorse products or manufacturer's Trade names or manufactures names appear herein solely because they are considered essential to this report.

Results and Discussion

We successfully collected multibeam bathymetry data of the lake floor in the Duluth-Superior Harbor. Our survey tracklines are shown in Figure 1. The composite multibeam image (Figure 2) shows a variety of features on the harbor floor. The most prominent features are the areas with especially deep water (>11 meters) found just inside both the Duluth and Superior entries and at the northern edge of the East Gate Basin. These areas are where the large freighters that enter the Harbor must brake and turn, and are probably an expression of bottom sediment being eroded by currents created by the ships' propellers as they increase speed after making the turn.

Additional man-made features include anchor drag marks, best seen in the images that are enlargements of the different sections of the harbor (Figures 3, 4, 5 and 6), as well as the deeper water found in a channel to the east of the main channel of the Duluth Harbor Basin (Figure 3), probably an indication of sediment being moved by currents created by the propellers of freighters that are 'cutting the corner' and taking a shorter route to the East Gate Basin. More 'natural' features include scour marks found near the Duluth and Superior entries (Figures 3 and 6) presumably caused by inflowing and outflowing water generated by the Nemadji and St. Louis Rivers and by seiches. These features are approximately 20 cm in depth, 4 meters wide and 100 meters long and are best seen near the Superior entry (Figure 6).

The multibeam data provides a detailed bathymetric chart of the harbor. Although not shown here these charts can be viewed as a three-dimensional model, from any designated perspective, and the three dimensional perspectives can be combined to create a virtual 'fly through' of the survey area. Obviously, detailed bathymetric data are of great interest to the maritime community. Using multibeam swath systems is much more efficient and produces much more complete data than traditional single-track soundings. During this project we collected 6.1 gigabytes of data within approximately 130km of ship track lines over a period of six 12 hour days. This gave us high resolution data of approximately 7 km^2 of the harbor bottom, a task that would take much longer using traditional single-track soundings. Although the shallow nature of harbors makes the area of coverage of a multibeam swath narrower than that found in deeper waters, as can be seen by the 'holes' of missing bathymetric data on the various multibeam figures shown here, this is a problem that can be corrected using closer survey lines.

In summary, we have shown that collecting high-quality data from the floor of Lake Superior is feasible, and that such data may be of interest to the maritime community. We plan to process the data further, creating three-dimensional views of the data and virtual 'fly throughs' of the survey areas, and we plan to make all of the images available to the public through the Large Lakes Observatory web site.

Potential Economic Impacts

Water depth in the Great Lakes is a critical issue for the maritime industry since it directly affects the size of cargos that can shipped. This project illustrates the use of high resolution acoustic imaging equipment in mapping the bathymetry of the Duluth-Superior Harbor. In combination with the results of the Colman and Ricketts 2006 GLMRI project, we have shown that the Large Lakes Observatory and the Research Vessel Blue Heron are extremely capable in mapping shallow water areas of interest to the maritime industry. Using multibeam sonar equipment and side-scan sonar equipment (the 2006 project), we can image the lake floor, describe submerged features and document sediment erosion and deposition. Since erosion and deposition affect water depth, a better understanding of erosional and depositional processes is useful to the maritime community. Changing practices in how ships are operated may influence sediment deposition and erosion, as can be seen by the presence of deep water near the Duluth and Superior entries and in the East Gate Basin, presumably caused by ship traffic. Future surveys of the area using multibeam and side-scan sonar will be able to reference this work to delineate any changes in the morphology of the lake bottom. This information would be useful to harbor planners when considering future dredging, keeping costs down and limiting disruptions to harbor operations.

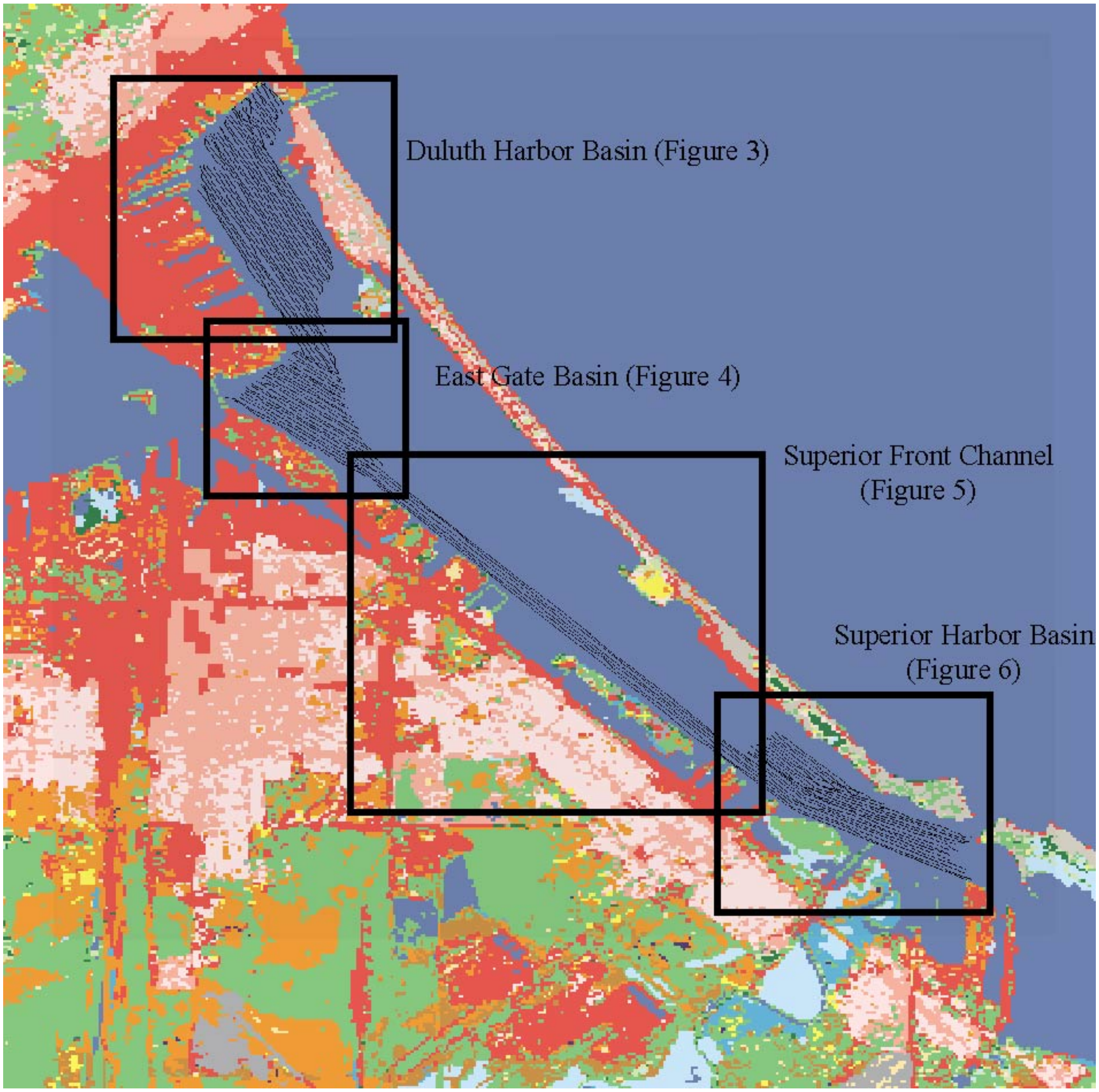

Figure 1: Ship tracklines for the multibeam bathymetry data.

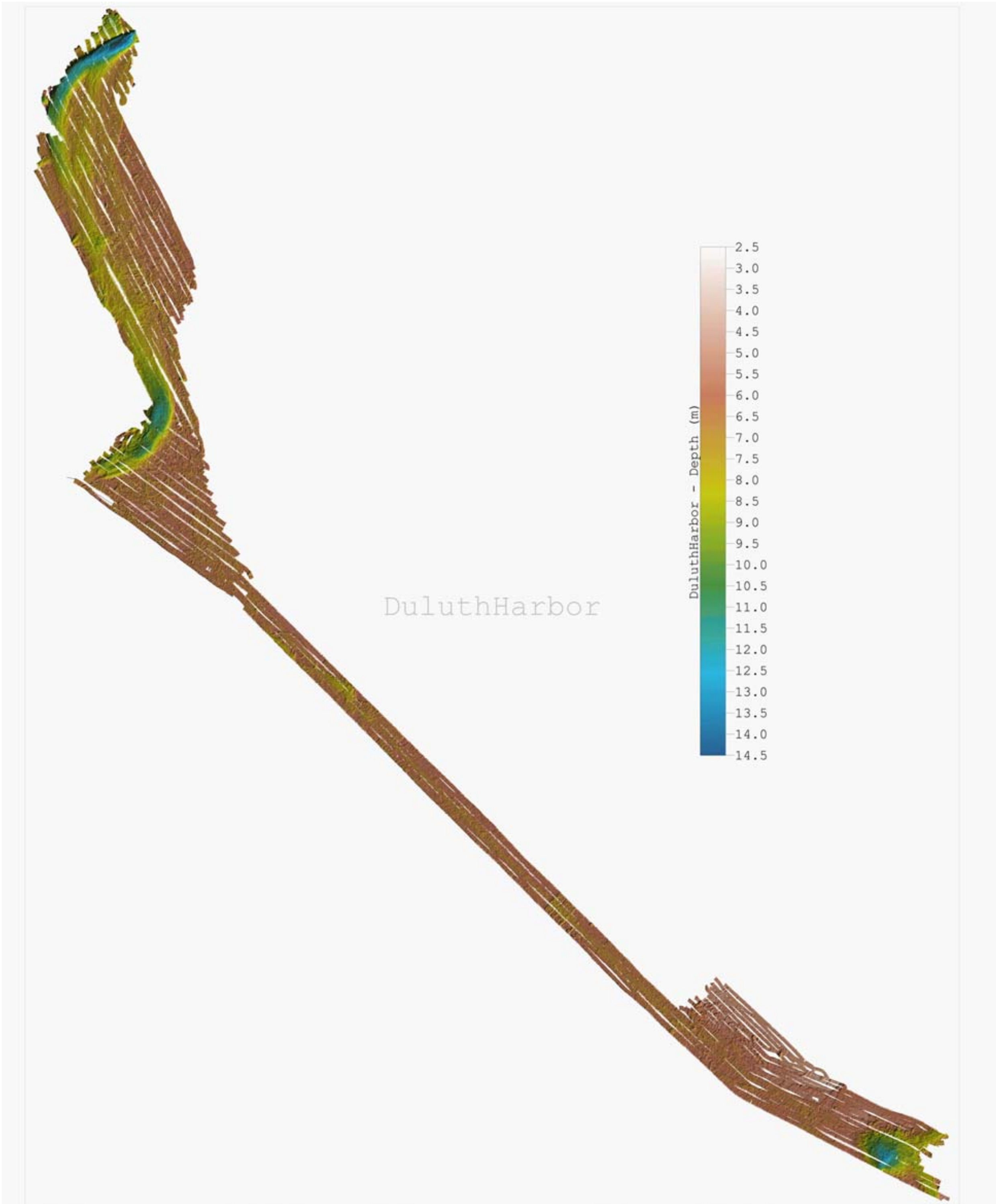

Figure 2: Multibeam bathymetry data for the Duluth-Superior Harbor.

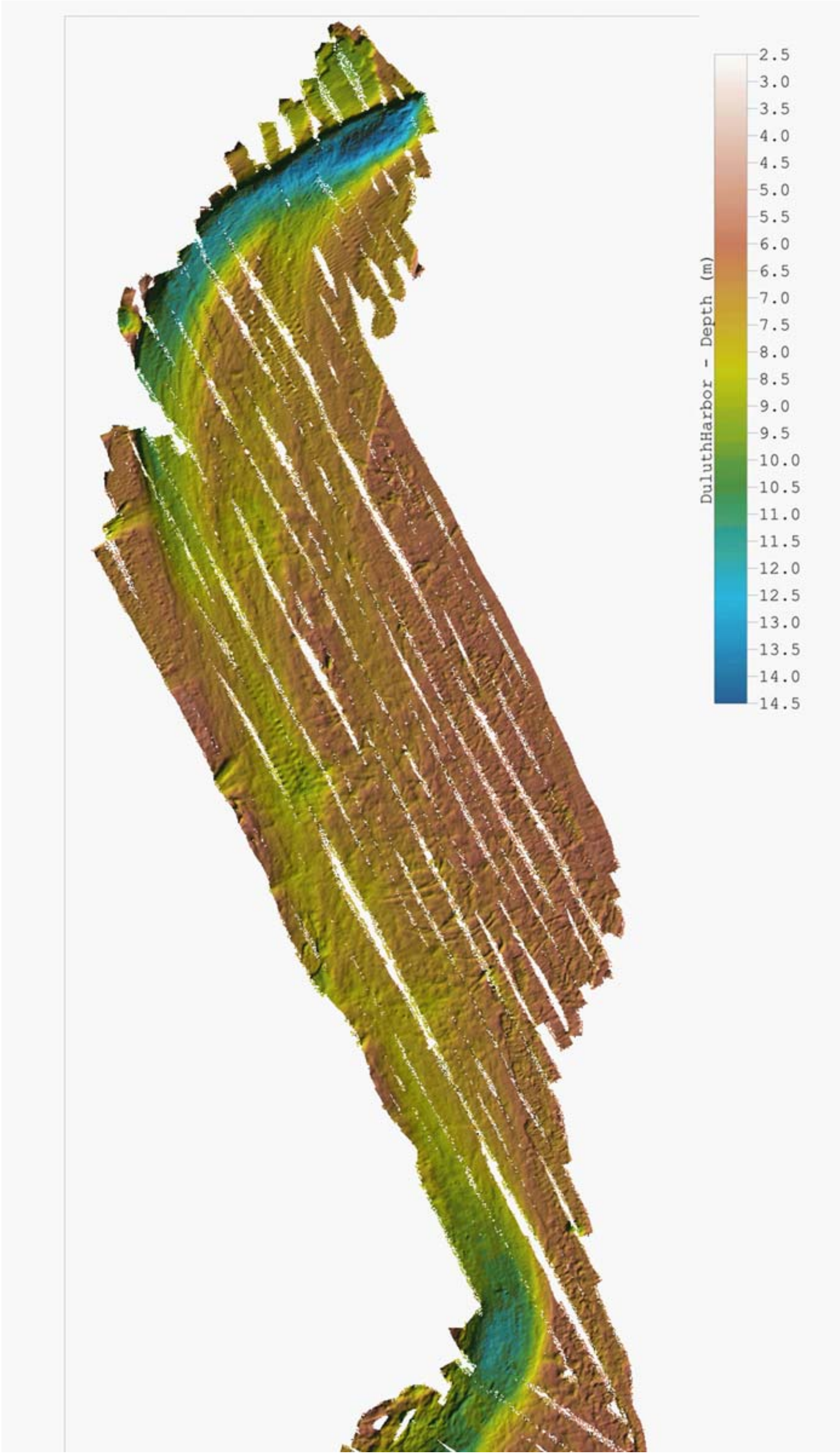

Figure 3: Multibeam bathymetry data for the Duluth Harbor Basin.

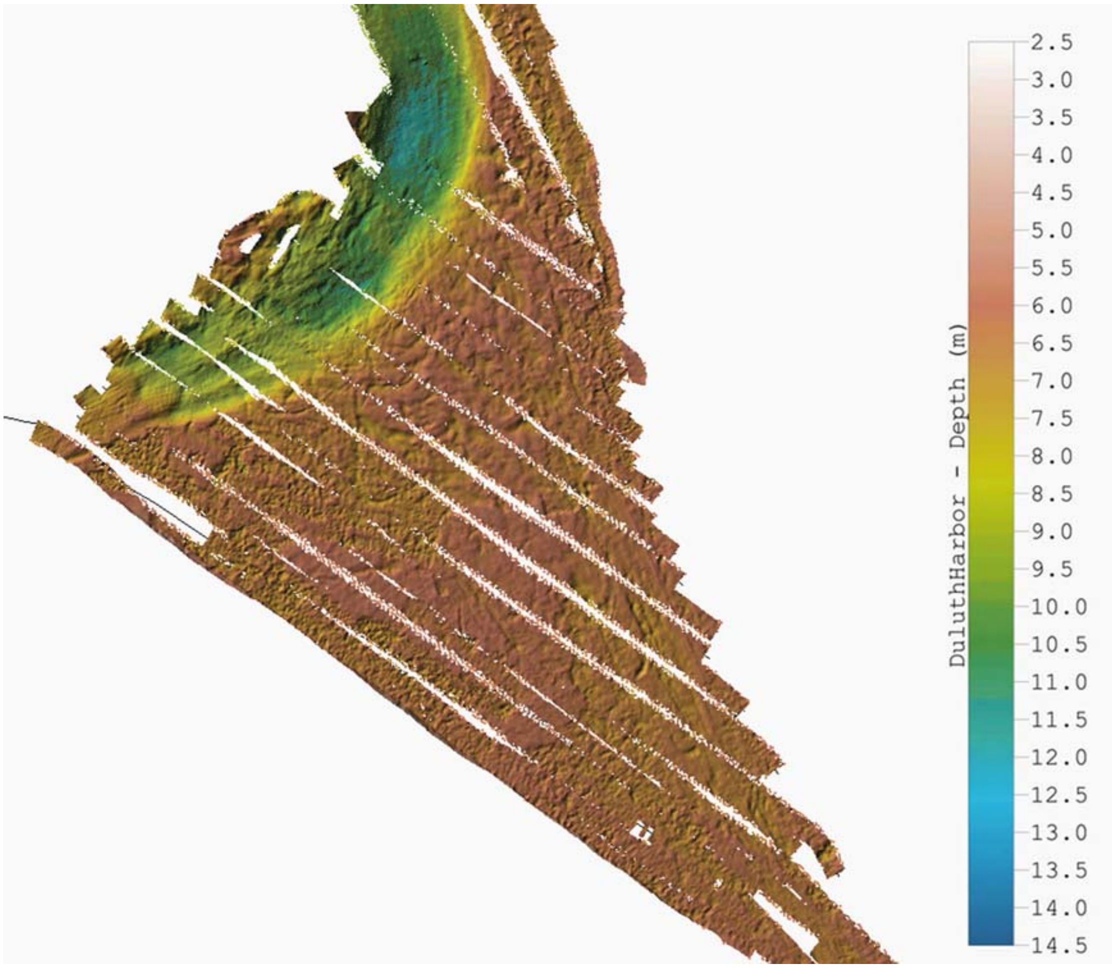

Figure 4: Multibeam bathymetry data for the East Gate Basin.

Figure 5: Multibeam bathymetry data for the Superior Front Channel.

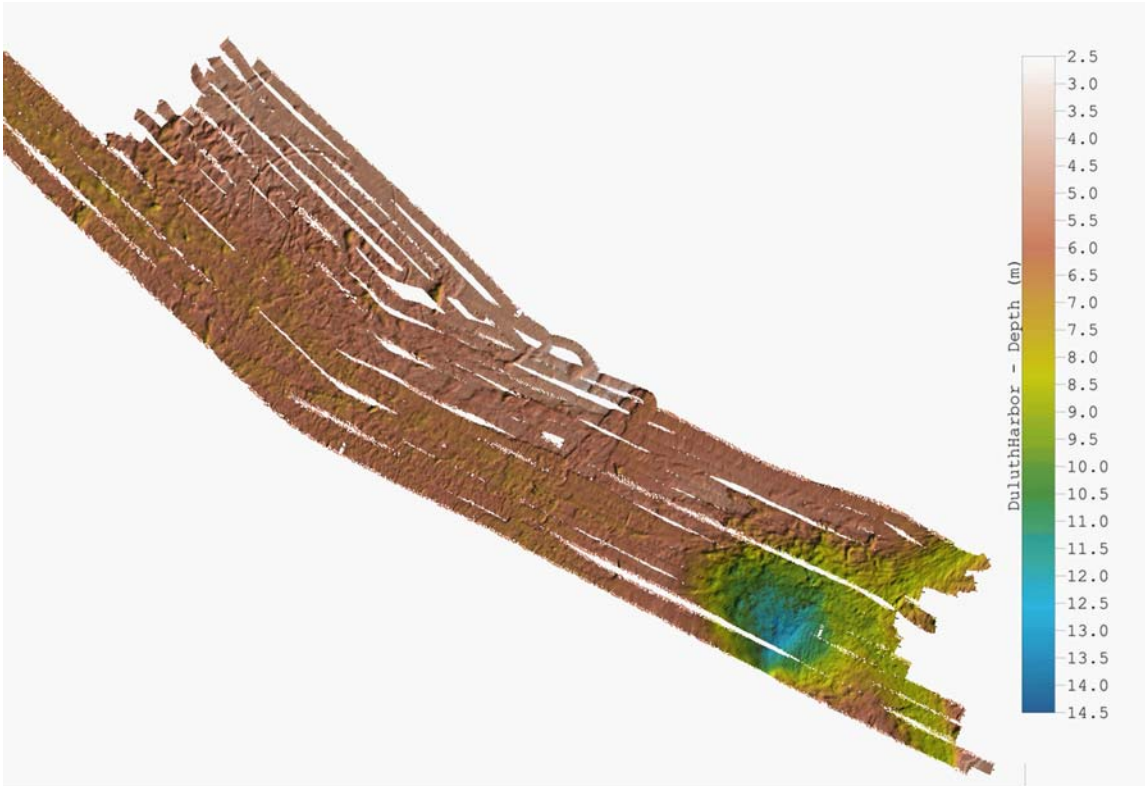

Figure 6: Multibeam bathymetry data for the Superior Harbor Basin.

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Great Lakes Maritime Research Institute

A University of Wisconsin - Superior and University of Minnesota Duluth Consortium

Great Lakes Maritime Transportation K-12 Education Program for Teachers, Students, & Communities

Year 2: December 15, 2006 – November 15, 2007

Final Report

Joan Chadde, Education Program Coordinator
105 Dillman Hall - Michigan Technological University
1400 Townsend Dr., Houghton, MI 49931-1295
Tel: 906-487-3341 Email: jchadde@mtu.edu

November 15, 2007

Department of Civil & Environmental Engineering
Michigan Technological University
1400 Townsend Dr., Houghton, MI 49931-1295

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Annual Report
on
Great Lakes Maritime Transportation K-12 Education Program for Teachers, Students & Communities

Implementation of Year 2 Project Objectives is described below each of the objectives.

1) Conducted one 6-day Summer Teacher Institute in Duluth, MN from July 29-August 3, 2007.

- 17 participants attended from the states of OH (2), MI (8), WI (6), MD (1)
- Tim Downey from the St. Lawrence Seaway Corporation attended and encouraged the offering of a similar experience/program for those in government agencies who work with the shipping industry.
- Participants visited a variety of sites (many typically inaccessible to the general public) and had the opportunity to interact directly with ship captains, industry personnel, and port managers.
- Teachers earned two graduate credits from Michigan Technological University.
- Teachers were required to develop one classroom lesson or outreach program. Teachers' lessons are posted on the *K-12 Great Lakes Maritime Transportation Education* website (http://wupcenter.mtu.edu/education/great_lakes_maritime/index.htm) and will become part of the *Great Lakes Maritime Transportation Educators Guide*.
- Institute participants paid $450 this year, up from $250 in 2006. The higher cost included lodging (at a hotel in Canal Park rather than at UM Duluth residence halls), plus most meals, field trip transportation, two MTU graduate credits, and classroom materials.

See 2007 summer institute agenda. (Attachment 1)
See 2007 Evaluation Summary. (Attachment 2).
Mark your calendars: July 20-25, 2008 for next summer's Teacher Institute.

2) **Maintain and enhance *K-12 Maritime Transportation Education website***
http://wupcenter.mtu.edu/education/great_lakes_maritime/index.htm

This website lists Programs for Educators, Educational Resources, teachers' newly developed lessons, *Great Lakes Shipping: Across the Country & Around the World* interactive web module, upcoming maritime events, and links. New materials, photos, events, links, etc. added throughout the year.

3. Developing *Great Lakes Shipping Curriculum & Activity Guide for K-12 Educators* for publication that will include lessons developed by 2006 and 2007 teacher institute participants.

See list of lessons developed by 2007 participants. (Attachment 3)

4. Provided financial incentives for Institute participants to engage in educational outreach.

a. Lisa Bircher (2006 participant) presented her lessons at the annual conference of the Science Education Council of Ohio (SECO) annual conference.
b. Lisa Bircher (2006 participant) submitted an article on her lessons to the National Science Teachers Association *Science Teacher* journal.
c. Article "Teaching Teachers" by Joan Chadde published in Great Lakes Seaway Review
d. Article submitted by Joan Chadde to Maggie Blum, US Maritime Administration, for U.S. Dept of Transportation newsletter
e. Six-part monthly presentation series on Great Lakes Shipping at the Portage Lake District Library in Houghton, MI by Joan Chadde. This included several presentations by ship captains (Capt. Bill Hanrahan and Capt. Dave Laban) on Great Lakes shipping from November 2006 to May 2007.
f. Two presentations by Joan Chadde on Great Lakes shipping for the Keweenaw County Historical Society. Capt. Bill Hanrahan participated in one of these.

5. Developed and disseminated 12 Great Lakes Shipping education "chests" for schools and museums.

2007 Great Lakes Shipping Education "Chests" have been distributed to:

MI Berrien County Intermediate School District Marquette Maritime Museum Thunder Bay Marine Sanctuary Saginaw Valley Math & Science Center Western UP Center for Science, Math & Environ. Education **OH** Lake County Soil & Water Conservation District	**IN** Indiana Dunes National Lakeshore **WI** Wisconsin Maritime Museum (Manitowoc, WI) Whitefish Dunes State Park (Sturgeon Bay, WI) **MN** Lake Superior Maritime Museum & Visitor Center

(NOTE: Recipients have agreed to conduct a training workshop in their local area after receiving the chest.)

Great Lakes Shipping Education "Chest" contains:

HANDS-ON TEACHING SUPPLIES 9'x12' Great Lakes Canvas Floor Map Shipping & Receiving Port labels Country, State, River labels Purple and red yarn Bagged samples of: iron ore/taconite pellets (5), coal (3), limestone (3), grain (5), salt (3), general cargo (LEGOs) (3) Great Lakes Ships playing cards Ship captain's hat & foam freighter Model of Great Lakes ore carrier (TBA) **CHILDREN'S LITERATURE** A True Book: St. Lawrence Seaway The Day the Great Lakes Drained Mail by the Pail The Great St. Lawrence Seaway The Edmund Fitzgerald: Lost With All Hands Paddle to the Sea The Edmund Fitzgerald: The Song of the Bell **REFERENCES** U.S. Flag Shipping on the Great Lakes brochure Great Lakes Facts Map Set (Michigan Sea Grant) Great Lakes Environmental Atlas Lake Superior Circle Tour Map U.S. Army Corps Soo Locks brochure	**VIDEOS / CDs / DVDs** Steel Starts Here DVD A Vital Waterway: Grt Lakes St. Lawrence Seaway System video (10 min) Perspective of a Vital Waterway video (21 min) Living on the Edge: Grt Lakes-St. Lawrence River Shoreline DVD (25 min) Top Ten Threats to the Great Lakes CD Tragedies in the Mist DVD Shipwreck: The Mystery of the Edmund Fitzgerald DVD Great Lakes Shipwreck Museum at Whitefish Point DVD Great Lakes Shipping Overview PowerPoint Presentation CD (in notebook) **CURRICULUM MATERIALS** Notebook of Great Lakes Maritime Transportation Lessons Exploring the Great Lakes: A Logbook of Adventures Lake Effects: The Lake Superior Curriculum Guide for Grades K-8 (See activities: *More Than Just A Lake, Geography Concentration,* and *Cooperative Clean Up*) Lake Rhymes – Folk Songs of the Great Lakes Region CD & Book Paddle to the Sea Curriculum Activity Guide **Posters** NOAA Map of Great Lakes (#14500) USDA Water Cycle Diagram of Parts of a Ship

6. **Attend state and national conferences to recruit institute participants and disseminate Great Lakes Maritime Transportation teaching tools:**

- Presentation at Wisconsin Association for Environmental Education, Manitowoc, WI
- Presentation at Michigan Science Teachers Association, Grand Rapids, MI
- Presentation at Michigan Council of Social Studies, Lansing, MI
- Poster session at International Association for Great Lakes Research (w/ Dr. Richard Stewart) at Penn State, PA
- Two presentations at Northern Michigan University (NMU) Seaborg Center annual conference in Marquette, MI
- Poster session at Making A Great Lake Superior conference in Duluth, MN

7. Developing “*F is for Freighter*” children’s book on Great Lakes shipping.
Dale Bergeron and Marie Zuikov from Minnesota Sea Grant have provided comments on the first draft. More work will take place in Year 3.

(Attachment 1)

Sponsored by Great Lakes Maritime Research Institute and Michigan Technological University

Great Lakes Maritime Transportation Summer Institute Agenda

~ Sunday, July 29 to Friday, August 3, 2007 ~

Sunday, July 29

Noon EST	Vans depart Michigan Tech in Houghton for Duluth. Stop at Northern Great Lakes Visitor Center.
6 pm CST	Check into Canal Park Lodge
8 pm CST	Course overview & introductions in Hospitality Room. - Great Lakes Maritime Transportation Education Resources, activities, and discussion.

Monday, July 30

7:00 am	Group breakfast & discussion in Hospitality Room
8:00 am	Depart for Duluth Seaway Port Authority.
8:30 am	*Overview of Shipping* by Duluth Seaway Port Authority (Adolph Ojard, Lisa Marciniak, Ron Johnson)
10 am	*Exotics & Ballast Water* by Dale Bergeron and Doug Jensen, Minnesota Sea Grant
11:30 am	Lunch & Harbor Tour aboard *Vista Queen* at Barker's Island w/ Ron Johnson
3 pm	*Harbor Dredging & Impacts of Changing Lake Levels on Great Lakes Shipping* by Gene Clark, P.E., Coastal Engineering Specialist, UW Sea Grant Institute
4-6 pm	*Lake Superior Maritime Visitor Center Programs* by Thom Holden, Army Corps of Engineers

Tuesday, July 31

7:00 am	Group breakfast & discussion in Hospitality Room
7:30 am	Depart Duluth for Hibbing
9-Noon	Tour Cleveland Cliffs iron ore mine & taconite processing plant in Hibbing, MN
Noon -2 pm	Lunch & drive back to Duluth
2:00-4:45 pm	*Coast Guard responsibilities for security, aids to navigation, control of invasive species*
5-6 pm	Tour S.S. William A. Irvin

Wednesday, August 1

7:00 am	Group breakfast & discussion in Hospitality Room
8:00 am	Depart for Two Harbors.
8:30 am	*Shipping Logistics* by Katie Ferguson (Great Lakes Fleet) at Canadian National Ore Dock in Two Harbors
10:00 am	*Edna G. Tugboat* tour
Noon	Picnic lunch at Split Rock Lighthouse
1-3 pm	Tour Split Rock Lighthouse
4:00-6:00 pm	Great Lakes Aquarium (optional)

Thursday, August 2

7:00 am	Group breakfast & discussion in Hospitality Room
8:00 am	Depart for Midwest Energy.
9 am	Tour Midwest Energy Coal transition point (Superior, WI)
11:30 am	Lunch at The Anchor in Superior
1:00 pm	Burlington Northern Taconite Facility & Ore Docks
4-6 pm	*Balancing Social, Economical & Environmental Aspects of Great Lakes Shipping* - by Dr. Richard Stewart, GLMRI co-director, UW-Superior

Friday, August 3

7 am	Group breakfast & discussion in Hospitality Room
8:30 am	Depart for Lake Superior Warehousing
9 am	Tour of Lake Superior Warehousing by Jonathan Lamb
10:30 am	Tour of Murphy Oil by Joe Cuseo
Noon	Lunch
1-3 pm	Wrap-up discussion & course evaluations

(Attachment 2)

Great Lakes Maritime Transportation Teacher Institute
~ July 29 - Aug 3, 2007 ~

EVALUATION SUMMARY (17 responses)

Your opinions and suggestions are important to us. Please respond thoughtfully to the following questions so that we can make necessary improvements to next year's teacher institute.

	Poor	Fair	Average	Good	Excellent	NA
Logistics:						
1. How well did the registration process keep you informed? -Liked the updating emails	**0**	**0**	**4-24%**	**5-29%**	**8-47%**	**0**
2. How did you find the accommodations at Canal Park Lodge? -Hotel was wonderful! -Wow!	**0**	**0**	**0**	**0**	**17-100%**	**0**
3. How was the food throughout the week?	**0**	**0**	**1-6%**	**3-18%**	**13-76%**	**0**
Educational Usefulness:						
4. How useful are the educational materials that you received?	**0**	**0**	**1-6%**	**8-47%**	**8-47%**	**0**
5. Overall, how well did the variety of activities meet your curriculum needs?	**0**	**0**	**3-18%**	**7-41%**	**6-35%**	**1-6%**
6. How well did the course meet your personal learning objectives? -Very satisfied	**0**	**0**	**1-6%**	**5-29%**	**11-65%**	**0**
7. Would you recommend attending this same institute to your peers? Please explain: <u>Yes Explanations:</u> -Well worth it to HS science teachers -It's a good way to do a summer class -Hands on, interesting experience -I learned more in 1 week than I've learned living in the area for 20 years. -So interesting <u>Maybe Explanations</u>: slow down pace!	**YES –** **14-82%**	**NO – 0**	**MAYBE – 3-18%**			
8. How did you hear about the Institute? E-Mail Source: school Websites: COSEE, MTU, Google, Joan, Conference	Flyer at school **0**	Newspaper **0**	Friend **3-18%**	Email List Source: **4-23%**	Website List: **8-47%**	Other (be specific): **2-12%**

9. Suggest ways to recruit more teachers in your state for next summer's institute. Providing names of specific people or organizations would be greatly appreciated.

- Science Education Council of Ohio ~ Feb. 2008 (Akron, OH).
- National Science Teachers Association regional and national conferences
- Possibly sending flyers, etc to those who took course to place at their schools.
- Wisconsin Teachers Association
- CESA – Cooperative Education Service Agency in Wisconsin
- WAEE – Wisconsin Association for Environmental Educators
- National Assoc for Interpretation

- Michigan math/science center network.
- Send email to past attendees and ask them to encourage a coworker to attend the institute.
- I can't believe every teacher wouldn't want to participate! It's been an amazing week! Joan does a fantastic job coordinating it all!
- Email me with info and I can distribute to my district.
- Have the institute in Wisconsin.
- Advertise in large school districts.
- The class should be in July so teachers aren't going here right after schools let out and before school resumes.
- Advertise more online and set up areas at teacher conferences/workshops.
- Offer more incentives to attend.
- Boatnerd.com
- Great Lakes Information Network –GLIN list-serve
- Contact teacher organizations to disseminate materials, especially in Port Cities.
- Send special mailings to WI, MN, IN, IL, OH, NY, Canada, PA (these states under-represented at institute).
- This course can also benefit business teachers and school career counselors.

10. How useful were the pre-course readings and websites to enhance your content knowledge and prepare you for the course?

- Good. (3)
- "Great Lakes, Great Ships" was pretty technical but good
- Maybe add GLIN website to next year's pre-course readings?
- Useful, informative but not covered much in class.
- Readings were OK. Most info could have just been covered in the websites however.
- Very good. Especially liked the 10-minute video online.
- Gave me an introduction to topics covered in the institute. Not sure the handbook was worth it. Maybe more info or outline of the programs we'll be seeing or hearing.
- Website was useful. Pre-course readings were too complicated and technical to hold interest.
- Excellent background information.
- Some I used. Others I didn't have time to find – but will follow up and check them out.
- Can't sit and read from a PC – need readings in hard copy well ahead of time. Couldn't get through reading Great Ships for the Great Lakes. I think that was too many pages to print in order to read. Other readings and outline ideas were good. Interesting.
- I had trouble getting the video up. "Great Ships for the Great Lakes" was most informative for me.
- Very good overview of broad topic.
- Readings were OK. A lot of paper to print out.
- Didn't have time to read them.
- The readings and websites were very helpful for prior knowledge. I like having background info so I understand info better.

11. Which parts of the Great Lakes Maritime Transportation Teacher Institute will you be able to use in your curriculum or work?

- The Iron Mining DVD (a great visual for students)
- The Coast Guard Safety info.
- Personal experiences of seeing the coal, pellet, dock and other processes that GL shipping involves.
- Connections made within the group and presenters.
- Materials gathered from presenters.
- Buoyancy

- Invasive species.
- The information from the lectures and outings.
- Tours to mine, docks were very helpful.
- Talks opened up my attention to very interesting way of looking at our interdependence.
- My age group (K): Importance of equalized weight within a boat, importance of shipping and types of transportation
- All- Most especially with business or career classes.
- Most of it.
- Impact on the economy.
- Different aspects of water transportation.
- The tours and hands-on materials will enhance my curriculum.
- Interested in “green ships” and invasive species.
- Will provide useful background info for my point papers for Seaway Management.
- Everything will get put to use one way or another.
- I have such a new appreciation of the importance of the Great Lakes on the U.S. economy.
- Mapping skills of routes and economics of different modes.
- Career information for guidance of students.
- Connecting products like coal through their chemistry (i.e. high/low sulfur & different BTU’s, etc.)
- Ballast water issues.
- I will be able to use all of the info I received this week at the institute.
- Info on invasive species, ballast water issues.
- Personal anecdotes for general discussion in class about tours we took, etc. – This is invaluable!

12. What did you like *BEST* about the Great Lakes Maritime Transportation Teacher Institute?

- Port Authority Introduction & their involvement throughout the Institute
- Coast Guard boat ride, presentation, and harbor tour. These guys were able to give us a little different of a spin on how they see the Great Lakes shipping industry. (5)
- Lunch cruise through harbor
- Midwest Energy tour and Great Lakes Fleet visit
- The field trips to places most people never see was awesome and very much appreciated. Very thorough (6)
- The location was fabulous
- Nice size group
- Good choice of topics to give us an overview
- Great materials provided
- Included all aspects! Can use for all content areas.
- I think it was awesome that all of the companies and the Coast Guard and visitor center and Corps. of Engineers (everywhere we went) took their time to spend with our group. I know how valuable their time is and feel I can’t thank them enough. The same goes to Joan, Dale, Lisa & all.
- The ability to network with other excellent teachers from the Great Lakes region! Connections made that would never happen ordinarily. Several class participants whose background varied widely (engineers, chemists, biologists) made the experience especially interesting (4)
- All the tours and presenters that are so very knowledgeable about their sites and procedures (2)
- Dr. Stewart’s lecture—it was key in bringing awareness and connection to the subject (3)
- The opportunity to be exposed to several key industries dependent upon water-borne transportation in a week-long course was extremely helpful to me.

- Schedule worked pretty well considering all the events
- I really liked all the hands-on activities and how all forms of Great Lakes shipping was covered---from the methods of shipping to the major products
- Variety of speakers and presentations
- Midwest Energy tour
- Duluth Port Authority

13. What did you like *LEAST* about the Great Lakes Maritime Transportation Teacher Institute?

- Personally, it was the Hibbing Taconite tour, but content-wise, I wouldn't want this eliminated because seeing iron ore in raw state and the bulk quantity and the process that takes it to next stages is critical to understanding the transportation issues. Tour could have been better. (2)
- Needed to provide more reflection time.
- Rearrange the sequence of programs.
- Too rushed—days start too early and end too late.
- I know some teachers might say the pace was too much. However, doing a class such as this, I'd rather be doing and seeing as many things as I can pertaining to the subject in the time allotted.
- Some of the places we went may have been considered optional or give more choices like we did when given the choice between Irvin or GL Aquarium. Choices are good for people
- Nothing I disliked. I would have liked more depth on the ballast water issues and other environmental concerns, but I realize my subject mater is more involved the K-12
- PowerPoint presentations

14. Suggest ways to improve the content or schedule of the Great Lakes Maritime Transportation Teacher Institute for next year.

- Have maps to where we are going included in welcome packet with routes there highlighted (I like to put places in relationship with each other
- Rearrange speakers so they build on each other. Like a general overview→history→etc. Best part was when we went to the mine and the next day to the ore docks. Better connection.
- Possibly have 2-way communication between vans along with written directions to sites (x 2)
- Allow time for reflection in the afternoon. We need time to process what we have seen, work on journals. More organized sharing.
- Possibly add a day to spread things out (x 5)
- More biology content (for me)… Could a biologist be invited to actually discuss invasive species because most people don't know about these. Ex. When I was talking to other participants about the ruffe, they didn't know what it was so what do they don't really know zebra mussels, gobies, etc.
- Do a tour of the GL Maritime Museum
- Ask someone to create a digital picture exchange after the event
- Have people arrive earlier on Sunday. It's so awesome here people definitely will appreciate more time.
- Present some information on the evolution of Great Lakes shipping
- The Irwin tour should be a must! (2)
- It would be great to see a freighter up close, and a tour of an active boat would be amazing. (2)
- Having more free time to explore some of the places that we visited would have been nice.
- Some presenters repeated almost verbatim what others had covered. Limit duplication.
- Talk to an actual Great Lakes sailor… (2)

(Attachment 3)

Great Lakes Maritime Transportation Lessons for Grades 3-12

by 2006 Great Lakes Maritime Transportation Summer Teacher Institute participants

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http://wupcenter.mtu.edu:80/education/great_lakes_maritime/index.htm

Great Lakes Maritime Research Institute

A University of Wisconsin - Superior and University of Minnesota Duluth Consortium

Environmental Effects of Marine Transportation: Develop an Environmental Management System Model University No: 144 051038 4

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PI Name
Lynn A. Corson, Ph.D., Director

Clean Manufacturing Technology Institute
Purdue University
2655 Yeager Road, Suite 103
West Lafayette, IN 47906
Ph: 765-463-4749
Fax: 765-463-3795
E-mail: corson@purdue.edu

Co-PI Name
Steven A. Fisher, Executive Director

American Great Lakes Ports Association
700 12th Street NW, Suite 700
Washington, DC 20005
Ph: 202-625-2101
Fax: 202-625-2104
E-mail: fisher@greatlakesports.org

Date of Report
October 31, 2007

PI's Host University, Department, and address
Purdue University
Center for the Environment
503 Northwestern Avenue
West Lafayette, IN 47907

PURDUE
UNIVERSITY

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Executive Summary

The American Great Lakes Ports Association has partnered with the Clean Manufacturing Technology Institute at Purdue University in West Lafayette, Indiana to examine the environmental management aspects of port operations, including the oversight of tenant operations that could negatively impact the environment.

The research has been and will continue to be conducted via two-day site visits to 12 American and Canadian ports and interviews with port and tenant personnel, tours of port facilities and internet and other document research.

The research will produce an environmental management system “model” for adoption by small, public ports and a compendium of best environmental management practices to prevent or reduce negative impacts on the environment from port and tenant operations.

The research, through Phase 1, and the analysis of operations at four of the 12 ports revealed:

- Environmental compliance of the port and its tenants appears to be influenced by a combination of management resources and community interest, as well as regulatory agency and corporate oversight;
- The provisions of port lease agreements with tenants pertaining to environmental protection could be strengthened;
- The issuance of environmental permits to ports and their tenants are not uniform among the states/provinces;
- Few ports have initiated a “master” plan for controlling stormwater run-off and responding to spills/releases of hazardous materials, both of which are regulated activities;
- Ports have engaged in environmental projects of various types, individually and with partners, affecting their property and neighboring property;
- Community outreach programs to engage, involve and respond to the public vary considerably among the ports.

Phase 2 of the research will include visits to eight American and Canadian ports to pursue the project purpose and objectives and refine the analysis of Phase 1 findings.

Introduction

The overall objective of the research project is to develop an environmental management system "model" that can be used by small, public ports on the Great Lakes to examine port and tenant operations and the actual and potential impact of those operations on the surrounding environment.

The objective of the first phase of the project is to develop an environmental evaluation tool using information gathered from a series of two-day site visits at four Great Lakes ports. After receiving approval of representatives of the American Great Lakes Ports Association, project staff will proceed to use the tool for subsequent evaluations, in the second phase of the project, at eight other American and Canadian Great Lakes Ports.

The aspects of the evaluation tool that comprise the focus of the site visits include:

- The legal (e.g., lease) and other forms of agreement between the port authority and its tenants governing tenant operations and the potential environmental impacts of such operations;
- The compliance and permit status of the port authority and its tenants, pursuant to local, state or provincial, and federal environmental regulations;
- The adequacy of the infrastructure and protective measures provided by the port authority for its tenants or by its tenants (especially those with "bare ground" leases) to prevent spills/releases of hazardous or potentially hazardous materials (e.g., salt, fertilizer, cement, petroleum products) that could contaminate port authority property and/or waterways;
- The relationship between the port authority and its tenants for clean-up and/or remediation of property contaminated by spills/releases of hazardous materials;
- The relationship between the port authority and rail lines and trucking companies serving the port authority and its tenants, as it pertains to environmental protection;
- The relationship between the port authority and neighboring private property owners/operators using common port facilities and waterways, as it pertains to environmental protection;
- Review of past and recent environmental accomplishments (e.g., wetlands restoration, brownfield redevelopment) and community outreach programs pertaining to environmental matters.

Each of these will be examined in the remainder of this report.

Background

As a component of the Great Lakes-St. Lawrence maritime industry's "Green Marine" initiative, the American Great Lakes Ports Association (AGLPA) approached Purdue University (CMTI) in 2006 to assist them in developing a project to: 1) survey environmental practices at Great Lakes ports, 2) compile a catalogue of best management practices for port operations, and 3) develop a simplified Environmental Management System tool that would help small port entities improve environmental performance.

Developed jointly by Purdue-CMTI in partnership with AGLPA, the project will evaluate 12 U.S. and Canadian ports with regard to a host of environmental issues. The goal is to not only establish an environmental compliance baseline, but also to identify areas of opportunity at Great Lakes ports for environmental enhancement. Perhaps of greatest use, the project will develop a manual of best practices that will assist small ports in finding ways to manage environmental issues within limited budget and staff resources.

As the owners and stewards of considerable tracts of land in many Great Lakes cities, the ports are eager to address any environmental liabilities and, also, to identify opportunities for possible new restoration projects.

Research Approach

The first phase of the research project involved a series of two-day site visits to four Great Lakes ports. The visits included interviews with port directors and other administrative staff, staff or consultants responsible for environmental matters, management staff at tenant operations, local planning officials, economic development officials and other government representatives and a driving and walking tour of port and neighboring property, including tenant operations.

Documents, including those provided by port personnel as well as annual reports and marketing brochures collected during the visit were reviewed. The environmental regulatory compliance and permit status of each port and its tenants was accessed via federal and state or provincial websites providing such information prior to the visits.

The Port Environmental Evaluation Form (Appendix A) was used to guide the interviews and the tours and record the information for the subsequent preparation of the port report.

Findings and Analysis

<u>Governance</u>

The four ports visited differ markedly in governance and environmental management and the form of governance (e.g., independent public authority, unit of local government, state or provincial chartered entity) appears to influence, but not totally determine, a port's authority and predisposition to exercise oversight of, for example, the operations of tenants that could have a negative impact on the environment. The resources available to the port - - staff, consultants and budget - - also influence the priority given to environmental management of port and tenant operations.

Tenant Lease Agreements

One obvious way of attempting to influence tenant operations, vis-à-vis environmental protection, is through the lease agreement offered by the port.

A review of lease agreements for the four ports visited reveals a variety of provisions pertaining to tenant environmental responsibilities:

- Tenant must comply with all federal, state and municipal environmental laws, regulations, ordinances; agree to use the site consistent with its intended use; responsible for obtaining environmental permits;
- Tenant must comply with all environmental laws and regulations; indemnify port with respect to claims, orders, actions regarding pollutants or toxic substances; responsible for clean-up and solely responsible for damages;
- Tenant must comply with all local, state and federal laws and regulations; indemnify port; provide notices of non-compliance; pay all costs associated with spills, clean-up and remediation of leased property (even if not required by a government agency); annually provide copy of emergency preparedness and response plan; annually provide list of hazardous materials; seek approval of the port to install USTs (Underground Storage Tanks); allow port to inspect the property and conduct environmental audits and site assessments, including at the termination of the lease; extend lease provisions to sub-lessee.

The range of provisions, from basic "boilerplate" to comprehensive oversight of tenant operations that could impact the environment, could reflect the port's form of governance and the environmental knowledge of the attorney who drafted the lease more than the management prerogative of the port authority or its administration. It is also apparent that the "landlord-tenant relationship" is crucial to achievement of the economic development goals of the port. Port management made it clear that they were not regulators and that other agencies of state, municipal and federal government had that role.

Tenant and Port Regulatory Compliance and Permit Status

Compliance inspections by state/provincial and federal agencies are and should be made and most of those interviewed thought regulatory oversight to be reasonable and useful.

With regard to permitting, some of the findings include:

- Air permits are most prevalent among tenants, followed by hazardous waste (RCRA) and water discharge (NPDES); Confined Disposal Facility permits for dredged material is most common among ports;
- Compliance enforcement by government authorities is not uniform and some tenant facilities that are not permitted should be;
- Larger tenants with regional or nationwide operations appear to be in full compliance;
- Control of fugitive dust from access roads and bulk product storage and handling is a challenge to ports and tenants, alike;
- Diesel emissions from ships, cranes, other heavy equipment, trains and trucks is not perceived as a problem, but is not uniformly monitored by government agencies.

Environmental compliance of the port agency, its tenants and adjacent non-tenant marine operators appear to be influenced by a combination of: management resources, community interest, local, state and federal regulatory oversight and corporate oversight.

<u>Preventing/Controlling Stormwater Run-off and Hazardous Materials Spills</u>

The water-side location of ports and most tenants poses a more significant environmental concern than for facilities located inland, especially with regard to stormwater run-off and hazardous materials spills.

Below are some of the findings from the first four port visits:

- Stormwater run-off from bulk storage piles, tank farm secondary containment structures, piers and dredge areas is being addressed at some locations by the installation of infrastructure modifications (e.g., detention ponds, stormwater drains, catch basins, low-profile berms at the edge of piers, sloping the edge of piers away from the water); however, protections appear to be inconsistent depending on the age of the facility and the type of cargo-handling activity taking place;
- At U.S. ports, liquid bulk tank farms and fueling facilities should have federally-required Spill Prevention Control and Countermeasure (SPCC) Plans;
- Ports, generally, have not prepared a “master” environmental response plan addressing releases from the transfer, movement and storage of materials at or by tenant facilities, ship owners, rail lines, truck lines and adjacent property owners;
- Not all port authorities are on the “call list” or have “first call” status when a spill occurs on its property occupied by a tenant;
- Individual tenants or transporters may have a plan or procedures that exist independent of others;
- Emergency response organizations are either the local fire department or a contract spill response organization - - some of the latter are tenants of the port;
- The Coast Guard is not considered a “first responder” organization by the majority of ports or tenants;

- In general, spill response procedures seemed to differ by location, depending upon municipal and state/provincial requirements. Spill response notification procedures were not always commonly understood.

In the U.S., stormwater regulations applicable to municipal and other public facilities were promulgated in 1999 and some Great Lakes states are only, now, issuing permits, so regulatory compliance and enforcement is generally lacking. Also, stormwater run-off doesn't have the same visibility or receive the same public scrutiny as air emissions and hazardous waste generation because of the general perception that it's a natural consequence of precipitation - - in other words, "it's always been there."

The Spill Prevention, Control and Countermeasure (SPCC) Plan required by the U.S. Environmental Protection Agency incorporates requirements that were included in the original 1972 Clean Water Act, before regulations existed to control air emissions and the generation of hazardous waste. Yet, SPCC plans were essentially ignored by most facilities because of the misconception that the regulations applied only to petroleum production and petroleum storage operations. Only in the 1990's when the requirements were amended and the promulgation of proposed rules in the Federal Register included clarification and definition of the rules did facilities begin to understand the breadth of coverage of the SPCC plan requirements.

Some U.S. port operations and many tenant operations are subject to these rules and some of both groups have plans and conduct drills to "practice the plan," but more of both groups need to. The remaining eight port visits, in the second phase of this research project, will allow further examination of this aspect of environmental protection by Great Lakes ports.

<u>Past and Recent Environmental Program Accomplishments</u>

It is apparent that ports are aware of the environment in which they are located. Their introduction to environmental concerns has usually been a result of community input or large projects such as contaminated sediment remediation, brownfield redevelopment, management of dredge material disposal, etc.

Ports have engaged in cooperative environmental projects with neighbors to restore wetlands; other ports have initiated marine recreation improvements (e.g., marinas), improved fish habitat and restored shorelines, some with walking trails for the recreating public.

The community outreach programs vary among the ports visited. Some ports have adopted a policy of inclusivity and may regularly meet with citizen groups, organize advisory committees, include representation on their governing board, establish a "hotline" for the public to report perceived environmental problems and other such measures.

The second phase of the research will attempt to ascertain whether and to what extent, a port's involvement in environmental projects and its conduct of community outreach programs is a critical aspect of an environmental management program.

Potential Economic Impacts of the Research Results

For large port businesses incorporating transportation, processing, storage, manufacturing and similar operations, many of which involve hazardous and polluting materials, the environmental impacts of incidents due to improper or inadequate management can be considerable, especially because of their location on the Great Lakes.

There are no environmental impacts - - negative or positive - - in the port or any other business sector that are not directly or indirectly linked to economic impacts. One port manager stated clearly that "what is good for the environment is good for business."

The outcomes of this research, included below, need to be viewed from both the environmental and economics perspective:

- An increased awareness by port directors and staff as to the potential impact of their and their tenants' operations on the environment;
- An increased understanding of the role/responsibility of a port authority for the operations of its tenants that could impact the environment;
- Possible changes in the policies, procedures and practices employed by port authorities for improved management of port property and oversight of tenant operations.

Continuing Research: Phase 2

Phase 2 of the project will apply the "model" developed from the environmental evaluation of four Great Lake ports during Phase 1 to port and tenant operations at eight other Great Lake ports.

The evaluations will include all aspects of port and tenant operations that have or could potentially have an impact on the environment (air, land, water) in which a port is located. The evaluation will also include a description and assessment of policies, procedures and practices employed by ports to prevent port and tenant operations from negatively impacting the environment. These "best practices" will be compiled as a guide for distribution to port managers.

Appendix A

Port Environmental Evaluation Form

Port Site Visit Environmental Evaluation Form

____

(Name and Location of Port)

Date of Site Visit: ________________ Evaluation Team Member: ____________________

____

1. General Information

   a. Description of port governance structure, staff, resources, budget:

   b. Physical configuration of each port:

   c. Types and tonnage of cargo handled at the port:

   d. Number of facilities and acres within the port authority's jurisdiction:

   e. Number of facilities and acres adjacent to the port authority's jurisdiction:

2. Names of Lessees	Activity/Product	Building/or Outside Area (*If bare ground)

3. Port Land Use (General Observations)

   a. Drums, tanks (including AST or UST) or other containers used for chemical or petroleum storage:

   b. Pits, ponds or lagoons for storage or treatment of wastewater or stormwater:

   c. Standing pools of water or wet areas not caused by weather conditions:

   d. Stained soil or pavement or dead or stressed vegetation:

   e. Random accumulation/storage of solid waste material (including recyclables):

   f. Transformers, capacitors or hydraulic equipment which may contain PCBs:

g. Stormwater runoff (with materials migration) from outside dry bulk storage areas:

h. Secondary containment of liquid bulk storage tanks:

i. Wastewater discharged to a treatment plant within or outside port property:

j. Sensitive natural resources (e.g., wetland) on or proximate to port-owned land:

k. Dredge material disposal/use:

l. Operations/activities that are obvious sources of air emissions:
   - tenants

   - trucks, trains, ships entering port property

   - truck, fork lifts, cranes and other port or tenant-owned machines

   - dry bulk storage piles and access roads as source of dust (particulate) emissions

4. Port Spill Response Operations

a. Material handling operations, such as dry and liquid bulk on-loading/off-loading and storage, are performed by the port and its tenants according to procedures that prevent migration of material or spills/releases to waterway:

b. The port authority and the rail lines and trucking companies serving the port have an agreement regarding response to and responsibility for spills and releases:

c. The port authority and neighboring private property owners have an agreement regarding response to and responsibility for spills and releases:

d. The port authority and its tenants have an agreement regarding response to and responsibility for spills and releases:

e. The port authority and ship owners serviced by the port have an agreement regarding response to and responsibility for spills and releases:

5. Port Environmental Management

a. Provisions of existing environmental policy:

b. Designation of staff with responsibility for environmental matters and description of tasks in pertinent job description(s):

c. Existence of a reporting system for environmental incidents: type of incidents recorded; fines paid; legal issues pending:

d. Estimated annual expenditures for environmental protection: personnel and non-personal categories:

e. Estimated annual research and development expenditures for environmental protection improvements:

f. Description of environmental training programs for employees:

g. Description of community outreach programs pertaining to environmental matters:

h. Description of how landlord ports work with tenants on environmental issues:

i. Provisions of lease agreements or other instruments with tenants governing environmental matters:

j. Description of the major environmental liabilities at each port area:
    - on port authority land

    - on land adjacent to the port authority

k. Description of the major environmental successes at each port:
    - as a result of port authority action

    - as a result of the action of others

l. Description of "brownfields" or other reclamation on port authority land:

m. Description of any port authority interaction with local government planning officials:

6. Compliance and Permit Status of the Port Authority and its Tenants (federal, state, provincial, local):