The Benefits of Navigation on the Great Lakes and Ohio River System: Carbon Emissions Reduced

US Army Corps of Engineers®
Buffalo District

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TABLES

1. Introduction

Corps navigation projects are typically justified based on the cost savings associated with moving commodities by water rather than land. However, maintaining waterways for shipping provides additional benefits not typically considered in Corps analyses. These additional benefits can be attributed to externality costs that are avoided due to the on-going maintenance of the navigation projects.

An externality exists when an individual's actions affect the well-being of another individual in ways that do not involve compensation. A “negative externality" results when part of the cost of producing a good or service is born by a firm or household other than the producer or purchaser. A "positive externality" results when part of the benefit of producing or consuming a good or service accrues to a firm or household other than that which produces or purchases it.

One of the externalities that has drawn interest in recent years is the carbon footprint associated with Corps of Engineers projects and activities. A carbon footprint is "the total set of greenhouse gases (GHG) emissions caused by an organization, event, product or person"[1]. For simplicity of reporting, it is often expressed in terms of the amount of carbon dioxide (CO_2) emitted. CO_2 is of particular concern as a greenhouse gas due to its contributions to the phenomenon of global warming. In the U.S., total carbon emissions have increased 7.3 percent from 1990 to 2009, an average of 0.4 percent annually[2]. Executive Order (EO) 13514 was signed by President Obama on October 5, 2009 and outlined a number of targets for Federal Agencies regarding the reduction of their carbon footprint. In its 2011 Report to Congress, the U.S. Department of Transportation Maritime Administration indicated that greater use of water transportation could generally reduce carbon dioxide emissions relative to other transportation modes[3]. This study will in part support these goals.

The purpose of this analysis will be to determine if and how carbon emissions would change if goods currently moved by water through the Great Lakes and the Ohio River System (ORS) were moved via land routings such as truck or rail. It will examine the changes in emissions based on a scenario where the Great Lakes and ORS area completely closed to shipping and all goods are forced to a full overland routing. In doing so, it will attempt to provide a justification for maintaining the water ways for navigation that is not typically considered in a traditional Corps analysis.

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[1] Wiedmann, T. and Minx, J. A Definition of 'Carbon Footprint'. In: C. C. Pertsova, Ecological Economics Research Trends: Chapter 1, pp. 1-11, Nova Science Publishers. Hauppauge NY, USA. https://www.novapublishers.com/catalog/product_info.php?products_id=5999. June 2007.
[2] U.S. Environmental Protection Agency. “Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009”. April 2011.
[3] U.S. Department of Maritime Administration. “America’s Marine Highway Report to Congress”. April 2011

2. Modal Alternatives

The closure of shipping on the Great Lakes and ORS would cause tonnage normally moved by water to be diverted to all overland routings consisting of rail and truck. These overland routings would require significant increases in vehicle trips and vehicle miles traveled. While this shift in transportation mode would result in significant increases in transportation costs, it would also result in increases in externalized environmental costs. Externalized costs - including noise, vibrations and air pollution emissions from engines - can lead to a variety of environmental impacts, including smog, crop damage and global warming. Therefore, the continued maintenance of the Great Lakes and Ohio River System for shipping allows for the avoidance of these costs, including carbon emissions, to be claimed as a benefit.

In order to accurately assess the changes in carbon emissions associated with the closing of shipping on the Great Lakes and ORS, it is first important to correctly identify the transportation alternatives likely to be implemented under such a closure. In general, these modal alternatives will be all-land routings consisting of either rail or truck. For the purpose of this analysis, it is assumed that both the commodities and the associated quantities would remain the same regardless of whether shipping were to continue. In other words, it is assumed that if the Great Lakes and Ohio River System were to be closed to shipping, manufacturers would simply find the cheapest alternative available to transport the same quantity of goods that they would have transported via shipping (i.e. no product substitution). Since a significant portion of Ohio River and Great Lakes tonnage consists of coal and iron ore, commodities that are not generally duplicated by commodities from other regions, it is reasonable to assume that geographic substitution will not occur.

Several reports have been produced by the Inland Navigation Planning Center of Expertise that analyzed the actions taken by shippers and major carriers when lock closures have actually occurred. The Ohio River locks that were assessed consisted of McAlpine Lock and Dam (2004 closure)[4], Hannibal Locks and Dam (2005 closure)[5], and Greenup Lock and Dam (2003 closure)[6]. Closures were of relatively short duration, lasting 10 days, 26 days, and 52 days respectively. In each case, shippers were warned in advance and were able to take advanced action. In many cases, these actions consisted of stockpiling product, shifting production to another facility, obtaining resources from another source, or simply altering production. However, in each study a number of shippers did report switching to an alternative mode of transportation. In particular, it should be noted that Greenup had the highest percentage of shippers switch to an alternative mode. This suggests that as closure duration increases, so will the likelihood of a modal shift. While these studies did address the economic costs associated with the

[4] U.S. Army Corps of Engineers. "McAlpine Lock Closure in 2004: Shipper and Carrier Response Results of Surveys". IWR Report 05-NETS-R-08. September 2005.
[5] U.S. Army Corps of Engineers. "Hannibal Locks and Dam: Causes and Consequences of Lock Closures 21 October to 16 November." IWR Report 06-NETS-R-08. May 2006.
[6] U.S. Army Corps of Engineers. "Shipper and Carrier Response to the September – October 2003 Greenup Main Lock Closure". IWR Report 05-NETS-R-02. February 2005.

modal change, they did not investigate costs associated with increased traffic on roadways or increases in emissions.

2.1 ORS Modal Changes

Depending on the specific circumstances, a closure of the Ohio River could be expected to divert traffic in a number of ways. In this analysis, it is assumed that such a closure would necessitate an all-land routing; either rail, truck or a combination of the two. The alternative routings, associated mileages, and tonnages of commodities were provided by the Tennessee Valley Authority (TVA) for 1,552 origin/destination routes and utilized 2006 data. This data was provided for both the current (including water) and alternative (land only) conditions. For example, a movement currently exists under which 1,099,001 tons of coal are barged 158 miles from Pittsburgh down the Monongahela River to the Ohio River to Wheeling, West Virginia. If the waterway were to be closed to navigation, the coal would have to be transported via a combination of rail (98 miles) and truck (68 miles). Such a transfer could result in significant transportation cost increases, as well as an increase in emissions. In all cases, the alternative route selected was that which would be most likely in the event of a closure (due to cost and/or feasibility), although a number of other options may have existed. The 1,552 origin/destination routes represent a total of 231,421,740 tons of commodities and roughly 80% of the total tonnage that moves through the Ohio River System.

Table 1 shows a sample of ten movements by tonnage for the ORS including the miles traveled under the current (water) scenario as well as the alternate mode. It should be noted that in many cases, the total miles traveled per trip under the all-land routing are actually less than under the current waterway routing scenario. However, the number of trips are likely to be significantly greater, resulting in a higher total mileage.

Table 1. Ohio River System Ton-Miles by Mode for 10 Sample Movements

ORIGIN	DESTINATION	COMMODITY	TONS	WATER MILES CURRENT	RAIL MILES CURRENT	TRUCK MILES CURRENT	RAIL MILES ALL LAND	RAIL MILES ALL LAND
Ohio River Mile 843	Cumberland River Mile 103	Coal	2,659,128	181	-	-	-	152
Ohio River Mile 345	Pittsburgh, Pa	Coal	2,088,442	365	190	-	563	-
Ohio River Mile 314	Pittsburgh, PA	Coal	2,330,592	334	136	-	564	-
Ohio River Mile 577	Louisville, KY	Crushed Stone	1,772,989	25	-	-	-	31
Ohio River Mile 111	Pittsburgh, PA	Coal	3,555,09	77	-	-	-	69
Ohio River Mile 879	Ohio River Mile 954	Limestone	1,611,447	75	-	-	-	56
Kanawha River Mile 73	Ohio River Mile	Coal	1,230,857	342	-	45	45	365
Big Sandy River Mile 8	Ohio River Mile 405	Coal	2,542,241	96	-	80	-	170
Ohio River Mile 111	Ohio River Mile 259	Coal	3,869,158	148	8	-	-	120
Ohio River Mile 314	Ohio River Mile 77	Coal	1,641,570	237	90	-	390	-

The transportation cost evaluation conducted by TVA broke the actual commodity movements into a number of movement legs, starting at the source of the bulk commodity and ending at the location of the final user. For existing routings that used water, the legs consisted of loading at the origin of the bulk commodity, a line haul charge to the shipping port, a commodity transfer charge at the shipping port, the line haul charge to the destination port (water cost), a commodity transfer charge at the destination port, a line haul charge to the end user and a commodity unloading cost at the final users location. For the all land route, the legs of the movement included: loading charges at the origin of the bulk commodity, a line haul charge to either a commodity transfer point or an end user, a commodity transfer charge at the commodity transfer point if a transfer point was involved, a line haul cost to the final end users location, and a commodity unloading cost at the users destination.

The TVA rate data provided the number of tons for each movement, as well as the mileages by mode per movement. As a result, it was possible to determine the ton-miles traveled for each movement by mode by simply multiplying the tonnages by the corresponding mileages. Special care was taken to insure any rail or truck mileage existing under current shipping scenarios was subtracted from the truck/land mileages currently used in conjunction with the water movements. This insured that all additional land mileages were the net increases that would occur with closing of the Ohio River System. These net increases in mileages were then summed for all affected origin/destination routes to arrive at total number of additional rail/truck ton-miles traveled in the absence of Ohio River shipping, as well as the reduction in vessel ton-miles associated with such a closing. The total ton miles by mode for both routing scenarios are shown in Table 2 below. Additional ton miles totaled 12,664,861,321 and 62,209,923,439 for rail and truck respectively while vessel ton miles were reduced by 98,325,035,879.

Table 2. Ohio River System Total Ton-Miles by Mode

MODE	TON MILES CURRENT	TON MILES ALL LAND	CHANGE WITH SWITCH TO ALL LAND
Truck	2,772,311,146	15,437,172,467	12,664,861,321
Rail	31,236,005,415	93,445,928,854	62,209,923,439
Vessel	98,325,035,879	0	(98,325,035,879)

2.2 Great Lakes Modal Changes

Like the ORS, a closure of the Great Lakes to navigation would result in a modal change to all-land routings. The alternative routings, mileages, and tonnages for 857 Great Lakes movements were once again provided by the TVA[7]. These 857 movements represented a total of 179,407,770 tons of commodities and included all of the Great Lakes

[7] Tennessee Valley Authority Navigation and Hydraulic Engineering. "Transportation Rate Analysis: Great Lakes and St. Lawrence Seaway". Prepared for the U.S. Army Corps of Engineers Huntington District 2005.

movements in excess of 20,000 tons. These 857 movements represented approximately 75% of the total tonnage that moves through the Great Lakes. The methodology for determining the number of ton miles was the same as that described for the ORS in Section 2.1. Once again, special care was taken to insure any rail or truck mileage existing under current shipping scenarios was subtracted from the truck/land mileages currently used in conjunction with the water movements. This insured that all additional mileages were the net changes that would occur with closing of the Great Lakes. These net changes were then summed for all affected origin/destination routes to arrive at total number of additional rail/truck/vessel ton-miles traveled in the absence of Great Lakes shipping. Additional ton-miles totaled 133.1 billion and 1.47 trillion for rail and truck respectively while vessel ton-miles were reduced by 1.56 trillion. The ton-miles by mode for both routing scenarios are shown in Table 3.

Table 3. Great Lakes Ton-Miles by Mode

MODE	TON MILES ALL WATER	TON MILES ALL LAND	CHANGE WITH SWITCH TO ALL LAND
Truck	9,827,832,792	142,946,394,903	133,118,562,111
Rail	571,151,365,895	2,042,553,478,267	1,471,402,112,371
Vessel	1,571,973,295,762	8,285,990,567	(1,563,687,305,195)

3. Emissions

A determination of the pollution abatement benefits associated with continued shipping on the Ohio River System and the Great Lakes consists of three steps: (1) determining the most likely traffic diversions based on economic alternatives; (2) determining the change in ton-miles associated with these diversions; (3) converting ton-miles into gallons of fuel consumed and; (4) the conversion of fuel consumption figures into pollutant emissions. Steps one and two were outlined in Section 2 of this report. Steps three and four are discussed in the following sections.

3.1 Fuel Consumption

After determining the mileages for the various Great Lakes and ORS movements, the next step was to estimate the diesel fuel consumption under the two routing scenarios. Fuel consumption rates vary largely depending on transportation mode and are shown in Table 4 below. Fuel consumption rates for rail, truck and inland barge were based on information provided by the Texas Transportation Institutes Center for Ports and Waterway's "A Modal Comparison of Domestic Freighter Transportation Effects on the General Public" (2009)[8]. Fuel consumption rates for Great Lakes vessels were based on

[8]Texas Transportation Institute. "A Modal Comparison of Domestic Freighter Transportation Effects on the General Public". Prepared for the U.S. Department of Transportation Maritime Administration. March 2009.

TVA estimates found in the "Soo Locks Reevaluation Report" which utilized the TVA's Vessel Costing Model (VCM)[9].

Table 4. Mode Specific Fuel Consumption

Mode	Ton-Miles per Gallon
Great Lakes Freighter	690
Inland Barge	576
Rail	413
Truck	155

The calculation of fuel consumption for each origin/destination pair was achieved by multiplying the fuel consumption rates for each mode of transportation times the ton-miles traveled by that mode. This was done for both the current (water) routings as well as the all land routings. This produced the total gallons of fuel consumed for each origin/destination pair for both the all land scenario as well as the current (water) scenario. The gallons for each movement were summed to give the total gallons consumed over all movements. The gallons of fuel consumed under both routing scenarios are shown for both the Great Lakes and Ohio River System in Tables 5 and 6 below.

Table 5. Ohio River System Fuel Consumption by Mode for the Various Routing Scenarios (gallons)

	Including Water	All Land	Difference
Truck	17,885,878	99,594,661	81,708,783
Rail	75,631,974	226,261,328	150,629,354
Vessel	170,703,187	0	-170,703,187
Total	264,221,040	325,855,990	61,634,950

Table 6. Great Lakes Fuel Consumption by Mode for the Various Routing Scenarios (gallons)

	Including Water	All Land	Difference
Truck	3,432,197	47,276,113	43,843,916
Rail	107,586,837	319,176,086	211,589,249
Vessel	143,777,795	774,861	(143,002,934)
Total	254,796,830	367,227,061	112,430,231

[9] U.S. Army Corps of Engineers. "Soo Locks Limited Reevaluation Report: Appendix B – Emission (PM-10) Costs Avoided". Detroit/Huntington Districts, January 2004.

3.2 Total Carbon Emissions

Next, it was necessary to convert fuel consumption into carbon emissions. Carbon dioxide emissions per gallon of fuel consumed were estimated to total 22.2 pounds per gallon based on information provided by the U.S EPA[10]. These estimates are shown in Table 7. Multiplying these emission rates times the total gallons of fuel consumed in the various movements produced annual carbon dioxide emission estimates for both the current and all-land routing alternatives. The changes in carbon emissions are shown in Table 6. A modal switch to an all land routing resulted in an increase of 1,368,295,890 (18.9 percent) pounds of carbon dioxide on the ORS and an increase of 2,495,951,130 (30.6 percent) on the Great Lakes. Overall, shipping saves an average of 5.91 pounds (.002955 tons) of carbon dioxide emissions per ton of commodity on the ORS and 13.91 pounds (.006955 tons) per ton of commodity on the Great Lakes when compared to all-land routings. When evaluated on a per ton-mile basis, Great Lakes navigation provided savings of 0.01913 lbs. per ton mile while the ORS provided savings of 0.02211 per ton mile.

Table 7. Total Carbon Emissions (lbs)

	Including Water	All Land	Difference	% Change	Per Ton
Great Lakes	5,656,489,636	8,152,440,766	2,495,951,130	30.6	13.91
Ohio River	5,865,707,088	7,234,002,978	1,368,295,890	18.9	5.91

4. Emission Reductions by Commodity

The carbon savings by commodity associated with maintaining the Ohio River and Great Lakes open for shipping are shown in Tables 8 and 9. These commodity specific savings were determined by sorting the rate data by commodity and employing the methodology described in Sections 2 and 3 above. Carbon savings per ton of commodity ranged between 0.51 (iron and steel) and 13.08 (other) for the Ohio River and 7.32 (coal) and 23.61 (aggs) for the Great Lakes. It should be noted that these savings are due primarily to the alternative modes and routes that would be traveled due to a closing rather than any specific characteristic of the commodity. It would not be appropriate to apply the commodity specific savings as presented below to a particular movement of a commodity and assume that the carbon savings would be the same. Instead, Tables 8 and 9 are meant only to show how carbon emissions have changed for the sum of the various movements by each commodity. If someone wanted estimate of potential carbon savings for a particular movement/closure, the average saving per ton of 5.91 (Ohio River) or 13.91 (Great Lakes) should be used regardless of commodity.

[10] U.S. EPA. "Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel" http://www.epa.gov/oms/climate/420f05001.htm

Table 8. Ohio River Carbon Savings by Commodity

COMMODITIES	TONS	TOTAL CARBON SAVINGS	LBS CARBON SAVINGS/TON COMMODITY
Coal	140,238,442	747,038,217.34	5.33
Petrol	11,883,127	93,090,209	7.83
Aggs	42,025,987	323,052,346	7.69
Grain	8,524,689	53,336,709	6.26
Chem	5,909,635	43,821,682	7.42
Ores and Minerals	5,476,531	9,001,030	1.64
Iron and Steel	10,194,089	5,210,424	0.51
Other	7,169,240	93,745,268	13.08
Total	231,421,740	1,368,295,890	5.91

Table 9. Great Lakes Carbon Savings by Commodity

COMMODITIES	TONS	TOTAL CARBON SAVINGS	LBS CARBON SAVINGS/TON COMMODITY
Coal	40,236,011	29,4418,186	7.32
Petrol	4,479,299	67,870,399	15.15
Aggs	37,981,142	896,640,337	23.61
Grain	12,212,065	189,861,574	15.55
Chem	1,523,905	14,419,772	9.46
Ores and Minerals	8,348,981	150,532,337	18.03
Iron and Steel	64,569,811	649,110,780	10.05
Other	10,056,263	233,097,742	23.18
Total	179,407,477	2,495,951,130	13.91

5. Emission Reductions by Harbor, Lock and River

The carbon savings by associated with maintaining the Great Lakes projects open for shipping are shown in Tables 10 through 13. These savings were determined based on 2008 tonnages as provided in The Great Lakes and Ohio River Navigation Systems

Statistical Supplement 2010[11]. In each case the average carbon saving per mile of 13.91 lbs/ton (.006955 tons/ton) was used as determined in Section 3.2. Tables 10 and 11 show the carbon savings associated with each of the major Great Lakes harbors and locks. Tables 12 and 13 apply the average carbon savings per ton and apply them to the tonnages moving through the various harbors and locks by each commodity. This analysis assumes that closure of a harbor or lock would result in a full overland routing rather than a routing to a different port. Since a goal of this analysis is to show the impacts of closing the Great Lakes to shipping, this approach is appropriate. However, if maintenance were to continue on some harbors, it is likely that shippers would re-route to another port and then switching to an alternative mode at the new harbor in order to move the commodity to its final destination.

Table 10. Great Lakes Carbon Savings by Port

PORT	TONS OF COMMODITIES	TONS OF CARBON SAVINGS PER TON OF COMMODITY	TOTAL CARBON SAVINGS (TONS)
Duluth-Superior, MN-WI	45,341,808	.006955	315,352
Indiana Harbor, IN	15,380,630	.006955	106,972
Cleveland, OH	10,637,330	.006955	73,982
Lorain, OH	2,186,022	.006955	15,203
Toledo, OH	10,954,686	.006955	76,189
Two Harbors, MN	13,432,959	.006955	93,426
Ashtabula, OH	6,905,941	.006955	48,030
Presque Isle, MI	8,807,609	.006955	61,256
Gary, IN	9,030,152	.006955	62,804
Burns Harbor, IN	6,283,154	.006955	43,699
Taconite Harbor, MN	772,687	.006955	5,374
Calcite, MI	5,833,596	.006955	40,572
Stoneport, MI	6,625,427	.006955	46,079

[11] US Army Corps of Engineers Great Lakes and Ohio River Division. "Great Lakes and Ohio River Navigation Systems Statistical Supplement 2010". 2010.

Table 11. Great Lakes Carbon Savings by Lock

LOCK	TONS	CARBON SAVINGS PER TON	TOTAL CARBON SAVINGS (TONS)
Soo Locks			
Poe	62,574,000	.006955	435,202
MacArthur	18,060,000	.006955	125,607
Davis	11,000	.006955	76.5
Soo Total	80,645,000	.006955	560,886
Chicago Lock	107,000	.006955	744
Black Rock Lock	136,000	.006955	945

Table 12. Carbon Savings for Great Lakes Ports by Commodity

	Duluth Superior	Indiana	Cleveland	Toledo	Two Harbors	Ashtabula	Presque Isle	Gary	Burns Harbor	Calcite	Stoneport
Tons Coal	21,740,637	361,680	49,853	3,303,616	-	2,580,256	2,240,725	10,277	28,652	-	-
Lbs Carbon Savings/Ton Coal	13.91	13.91	13.91	13.91	13.91	13.91	1391	13.91	13.91	13.91	13.91
Total Tons Carbon Savings Coal	151,206	2,515	347	22,977	-	17,946	1,558,424	71	199	-	-
Tons Petrol	-	995,105	26,627	448,050	-	-	-	31,191	35,349	16,439	-
Lbs Carbon Savings/Ton Petrol	13.91	13.91	13.91	13.91	13.91	13.91	1391	13.91	13.91	13.91	13.91
Total Tons Carbon Savings Petrol	-	6,921	185	3,116	-	-	-	217	246	114	-
Tons Aggs	2,917,699	1,283,595	3,372,008	928,055	59,803	526,370	167,805	209,603	805,012	5,754,414	6,625,427
Lbs Carbon Savings/Ton Aggs	13.91	13.91	13.91	13.91	13.91	13.91	1391	13.91	13.91	13.91	13.91
Total Tons Carbon Savings Aggs	20,293	8,927	23,452	6,455	416	3,661	116,708	1,458	5,599	40,022	46,080
Tons Grains	1,059,966	-	-	724,287	-	-	-	-	35,349	-	-
LBs Carbon Savings/Ton Grains	13.91	13.91	13.91	13.91	13.91	13.91	1391	13.91	13.91	13.91	13.91
Total Tons Carbon Savings Grains	7,372	-	-	5,037	-	-	-	-	246	-	-
Tons Chem	34,769	-	7,800	5,006	137,493	-	10,682	-	-	-	-
Lbs Carbon Savings/Ton Chem	13.91	13.91	13.91	13.91	13.91	13.91	1391	13.91	13.91	13.91	13.91
Total Tons Carbon Savings Chem	242	-	54	35	956	-	7,429	-	-	-	-
Tons Ores/Minerals	327,656	111,369	711,220	368,531	-	174,972	-	84,709	163,911		
Lbs Carbon Savings/Ton Ores	13.91	13.91	13.91	13.91	13.91	13.91	1391	13.91	13.91	13.91	13.91
Total Tons Carbon Savings Ores	2,279	775	4,947	2,563	-	1,217	-	589	1,140	0	0
Tons Iron-Steel	18,770,787	12,026,209	5,472,676	4,685,817	13,373,156	3,395,394	6,399,079	8,625,430	4,932,345	61,873	-
Lbs Carbon Savings/Ton Iron-Steel	13.91	13.91	13.91	13.91	13.91	13.91	1391	13.91	13.91	13.91	13.91
Total Tons Carbon Savings Iron-Steel	130,551	83,642	38,062	32,590	93,010	23,615	4,450,559	59,990	34,304	430	-
Tons Other	490,294	602,672	756,146	358,837	-	218,267	-	68,942	157,775	870	-
Lbs Carbon Savings/Ton Other	13.91	13.91	13.91	13.91	13.91	13.91	1391	13.91	13.91	13.91	13.91
Total Tons Carbon Savings Other	3,410	4,192	5,259	2,496	-	1,518	-	479	1,097	6	-

Table 13. Carbon Savings for Great Lakes Locks by Commodity

	Poe	MacArthur	Davis	Soo Total	Chicago Lock	Black Rock Lock
Kilo Tons Coal	18,540	3,688	-	22,228	-	-
Lbs Carbon Savings/Ton Coal	13.91	13.91	13.91	13.91	13.91	13.91
Total Tons Carbon Savings Coal	128,946	25,650	-	154,596	-	-
Kilo Tons Petrol	197	100	-	297	15	136
Lbs Carbon Savings/Ton Petrol	13.91	13.91	13.91	13.91	13.91	13.91
Total Tons Carbon Savings Petrol	1,370	696	-	2,066	104	946
Kilo Tons Chem	156	180	-	336	-	-
Lbs Carbon Savings/Ton Chem	13.91	13.91	13.91	13.91	13.91	13.91
Total Tons Carbon Savings Chem	1,085	1,252	-	2,337	-	-
Kilo Tons Crude Materials	40,272	8,954	-	49,226	20	-
Lbs Carbon Savings/Ton Crude Materials	13.91	13.91	13.91	13.91	13.91	13.91
Total Tons Carbon Savings Crude Materials	280,092	62,275	-	342,367	139	-
Kilo Tons Manufactured Goods	438	595	-	1,033	-	-
Lbs Carbon Savings/Ton Manufactured Goods	13.91	13.91	13.91	13.91	13.91	13.91
Total Tons Carbon Savings Manufactured Goods	3,046	4,138	-	7,185	-	-
Kilo Tons Food Farm Products	2,959	4,489	11	7,459	-	-
Lbs Carbon Savings/Ton Food Farm Products	13.91	13.91	13.91	13.91	13.91	13.91
Total Tons Carbon Savings Food Farm Products	20,580	31,221	77	51,877	-!	-
Kilo Tons Equipment and Machinery	12	53	-	65	72	-
Lbs Total Carbon Savings/Ton Equipment	13.91	13.91	13.91	13.91	13.91	13.91
Total Tons Carbon Savings Equipment	83	369	-	452	501	-

A similar methodology was employed for determining the carbon savings for Ohio River locks and rivers. Tables 14 and 15 applied the average carbon savings of 5.91 lbs/ton (.002955 tons/ton) to the tonnages reported for each river and lock in the Statistical Supplement. Note that this analysis focused on those locks that received the greatest level of tonnages in 2008. Table 16 was developed by applying average carbon savings to the tons of each commodity passing through a specific lock. Again, this analysis assumes that closure of a lock would result in a full overland routing. Since a goal of this analysis is to show the impacts of closing the Ohio River to shipping, this approach is once again appropriate.

Table 14. Ohio River Carbon Savings by River

RIVER	TONS	CARBON SAVINGS PER TON	TOTAL CARBON SAVINGS (TONS)
Ohio	230,800,000	.002955	682,014
Kanawha	20,200,000	.002955	59,691
Monongahela	28,000,000	.002955	82,740
Allegheny	2,500,000	.002955	7,387
Green/Barren	9,100,000	.002955	26,890
Cumberland	23,300,000	.002955	68,851
Tennessee	49,700,000	.002955	146,863
Barkley Canal	15,400,000	.002955	45,507
Big Sandy River	17,400,000	.002955	51,417
Little Kanawha	100,000	.002955	295
Hiwassee	300,000	.002955	886

Table 15. Ohio River Carbon Savings by Project

RIVER	TONS	CARBON SAVINGS PER TON	TOTAL CARBON SAVINGS (TONS)
Emsworth	21,273,000	.002955	62,861
Dashields	21,788,000	.002955	64,383
Montgomery	20,813,000	.002955	61,502
New Cumberland	29,159,000	.002955	86,164
Pike Island	34,590,000	.002955	102,213
Hannibal	45,586,000	.002955	134,706
Willow Island	43,834,000	.002955	129,529
Belleville	46,903,000	.002955	138,598
Racine	48,616,000	.002955	143,660
Robert C. Byrd	52,320,000	.002955	154,605
Greenup	59,849,000	.002955	176,853
Meldahl	54,067,000	.002955	159,768
Markland	53,214,000	.002955	157,247
McAlpine	57,341,000	.002955	169,442
Cannelton	58,061,000	.002955	171,570
Newburgh	71,228,000	.002955	210,478
J.T. Meyers	69,514,000	.002955	205,413
Smithland	77,098,000	.002955	227,824
L/D 52	89,704,000	.002955	265,075
L/D 53	77,824,000	.002955	229,969

Table 16. Carbon Savings for Ohio River Projects by Commodity

	Robert C. Byrd	Greenup	Meldahl	Markland	McAlpine	Cannelton	Newburgh	J.T. Meyers	Smithland	L/D 52	L/D 53
Kilo Tons Coal	34,352	35,244	30,210	27,192	28,307	30,023	39,263	36,331	40,798	34,446	22,937
Lbs Carbon Savings/Ton Coal	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91
Total Tons Carbon Savings Coal	101,510	104,146	89,271	80,352	83,647	88,718	116,022	107,358	120,558	101,788	67,779
Kilo Tons Petrol	2,842	8,335	8,117	5,711	5,848	3,358	3,782	4,094	4,097	4,799	5,234
Lbs Carbon Savings/Ton Petrol	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91
Total Tons Carbon Savings Petrol	8,398	24,630	23,986	16,876	17,281	9,923	11,176	12,098	12,107	14,181	15,466
Kilo Tons Aggs	4,240	4,072	3,675	3,599	3,461	4,429	4,278	1,016	3,380	13,354	10,929
Lbs Carbon Savings/Ton Aggs	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91
Total Tons Carbon Savings Aggs	12,529	12,033	10,860	10,635	10,227	13,088	12,641	3,002	9,988	39,461	32,295
Kilo Tons Grains	199	239	264	1,755	2,396	2,439	3,735	6,379	7,103	9,797	10,131
LBs Carbon Savings/Ton Grains	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91
Total Tons Carbon Savings Grains	588	706	780	5,186	7,080	7,207	11,037	18,850	20,989	28,950	29,937
Kilo Tons Chem	2,770	3,596	3,614	4,965	5,417	5,747	6,119	7,012	7,089	8,659	8,803
Lbs Carbon Savings/Ton Chem	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91
Total Tons Carbon Savings Chem	8,185	10,626	10,679	14,672	16,007	16,982	18,082	20,720	20,948	25,587	26,013
Kilo Tons Ores/Minerals	2,238	2,358	2,464	3,422	3,979	4,395	5,601	6,015	5,966	7,066	7,295
Lbs Carbon Savings/Ton Ores	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91
Total Tons Carbon Savings Ores	6,613	6,968	7,281	10,112	11,758	12,987	16,551	17,774	17,630	20,880	21,557
Kilo Tons Iron-Steel	3,205	3,398	3,527	4,560	5,790	5,806	5,972	6,220	6,190	8,325	8,811
Lbs Carbon Savings/Ton Iron-Steel	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91
Total Tons Carbon Savings Iron-Steel	9,471	10,041	10,422	13,475	17,109	17,157	17,647	18,380	18,291	24,600	26,037
Kilo Tons Other	2,474	2,608	2,196	2,012	2,144	1,865	2,479	2,447	2,475	3,257	3,684
Lbs Total Carbon Savings/Ton Other	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91	5.91
Total Tons Carbon Savings Other	7,311	7,707	6,489	5,945	6,336	5,511	7,325	7,231	7,314	9,624	10,886

6. Impacts to Global Carbon Dioxide Levels

The CO2 content of the atmosphere is typically expressed in the parts per million (ppm) while the use of fossil fuels is expressed in tons. As shown in Section 3.2, conversion to all-land routings will result in increases of 1,368,295,890 pounds of carbon dioxide on the ORS and an increase of 2,495,951,130 pounds on the Great Lakes. These correspond to total tonnages of 684,148 and 1,247,976 respectively. While much of the earth's atmospheric carbon comes from natural sources, a significant portion does come from anthropogenic sources. It is estimated that approximately 6,576 million tons of carbon dioxide are released annually from anthropogenic sources[12] in the United States alone. As a result, the increases associated modal changes on the ORS and Great Lakes represent increases of .0104% and .0190% in U.S. anthropogenic carbon contributions respectively (.0294% when combined).

The next step is to determine how the increases due to a modal change would impact atmospheric concentrations. The average mass of the earth's atmosphere is estimated to total 5 quadrillion tons (5x10^15). Dividing the ORS and Great Lakes emissions by the total mass of the atmosphere gives the fractions .000137/1million and .0002496/1million respectively. This indicates that the increases in carbon emissions associated with a modal change to an all land routing will equate to changes of .000137 ppm and .0002496 ppm respectively.

7. Economic Cost of Carbon Emissions

In recent years, a number of studies have been conducted in order to attempt to place a dollar value on carbon emissions. These efforts have largely focused on costs associated with climate change due to increased carbon levels in the earth's atmosphere. In a review of 28 published studies that examined the marginal damage costs of carbon dioxide emissions, Tol[13] conducted an analysis of existing studies and determined the average costs damage costs associated with carbon emissions. In general, it was determined that there is a high level of variability among studies, as well as a high level of uncertainty in each of the individual estimates. This variability is largely due to differences in assumptions regarding climate scenarios, adaptation, regional disaggregation, and impacts (some studies assumed catastrophic impacts). In particular, studies that suggested values of over $50/tC typically required unlikely scenarios of climate change. Overall, the analysis of these 28 studies showed a mode of $2/tC (ton of carbon), a median of $14/tC, a mean of $93/tC, and a 95th percentile of $350/tC. Due to the high level of variability among estimates, this analysis will utilize the median ($14/tC) as determined by Tol's study.

[12] U.S. Energy Information Administration. "Emissions of Greenhouse Gases in the United States 2009". 2011.

[13] Tol, Richard S.J., "The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties". Energy Policy 33 (2005) 2064-2074.

Based on the assumption that each ton of carbon emitted has a cost of $14/tC, the total costs associated with a switch to an all-land routing are estimated to total $9,578,072 for the ORS and $17,471,664 for the Great Lakes.

8. Summary and Conclusions

As shown in the previous sections, closing the Ohio River System and the Great Lakes to shipping and re-routing to all-land movements would result in significant increases in pollutant emissions, particularly carbon. This was determined by determining the mode specific mileages traveled under two specific scenarios – the current route including the mileage traveled through the ORS and an alternative routing consisting solely of land transportation. These mileages were then converted to fuel consumption and total emissions. Overall, this initial analysis shows transportation of the existing tonnages through the Ohio River System and the Great Lakes yields measurable benefits in terms of reductions in carbon emissions. When compared with the all-land routings, Great Lakes and Ohio River navigation allows for a reduction of 1,932,124 tons of carbon annually. Overall, this represented 25.11% reduction over the two systems, an amount that can be considered very significant. Since the movements considered in this analysis represented approximately 80% of the total movements on the ORS and 75% on the Great Lakes, it is likely that the total reductions are actually greater than what is presented in this effort.

In addition to determining the total carbon savings by maintaining the two systems for navigation, we were also able to determine the breakdown in savings by commodity, river, lock, and port. This information is important as it shows the value of the various navigation projects in terms of reducing carbon emissions.

Lastly, we attempted to assess how modal changes on the Great Lakes and ORS might impact global carbon levels and also attempted to put a dollar value on these changes. Overall, it was determined that modal changes to all-land routings would result in a .0294% increase in anthropogenic carbon dioxide. This increase would correspond to an increase of .0003866 ppm in global carbon concentrations. Due to the high level of uncertainty in the science, no attempt was made to relate changes in carbon emissions on these two systems to global climate change. In other words, it was beyond the scope of this effort to say that the increases in carbon emissions on the Great Lakes and ORS would result in global temperature changes of a particular amount.

While it was not possible to assess the potential global climate change impacts associated with a modal change, a number of studies have been completed that have attempted to put a dollar value on carbon emissions. Since both the approaches and results of these studies have varied significantly, we used a study conducted by Tol which analyzed 28 studies which focused on the costs associated with carbon emissions. When using the median value of $14/tC (which was significantly lower than the mean), it was determined that the carbon emissions associated with a closing would result in total costs of $27,049,736 annually.

Overall, closing the Ohio River System and Great Lakes to shipping would result in significant increases carbon emissions. With increased emphasis on carbon footprint and global climate change, it is apparent that maintaining these two systems for navigation provides important benefits in terms of reducing carbon emissions. While these savings may appear relatively minor on a global scale, it is important to note that the results presented represent annual values. If a closing occurred over a longer period of time, the impacts in terms of emissions would continue to accumulate and likely result in increased global impacts. As a result, this analysis provides further justification for maintaining these systems for navigation well beyond the traditional transportation cost savings typically used for justifying navigation projects.

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