Grain Transportation Study

Final Report

Analyzing the movement of grain before and after the four lower Snake River dams are removed

Water Foundation

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Table of Contents

Table of Tables

Table of Figures

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1 Introduction

For many years (Ball and Casavant, 2003; Pacific Northwest Waterways Association and FCS Group, 2020; USACE et al., 2020), there have been discussions about the removal of the four lower Snake River (SNR) dams (Lower Granite, Little Goose, Lower Monumental, and Ice Harbor) and locks, and the potential environmental and economic effects of this action. One key area of discussion is the role that these dams and locks play in the transport of wheat in the Pacific Northwest (PNW), as they allow for the transport of grain by barges. Today, almost half of the wheat produced in the region is exported from the PNW ocean ports (Kalama, WA; Portland, OR; Vancouver, WA; and Longview, WA). This wheat originates in growing states, including North Dakota, Montana, Kansas, Idaho, Washington, and Oregon. In 2021, the PNW exports represented approximately 50% of the wheat (and flour) exported from the US (USDA, 2022b), compared to 36% in 2013 (USDA, 2014).

Nationally, most of the wheat to be exported reaches ocean ports by train (about 60%), followed by barge (28%), and the remaining by truck (USDA, 2021b). In the PNW, the mode share of wheat is highly dependent on where it is grown; for example, the wheat produced in northern Idaho is mostly destined for export through the PNW ocean ports, and through the Lewiston-Clarkston elevators using truck and barges for almost 99% of the volume. The share of truck-barge drops to 66% in the Southwest region, and to zero in the Southcentral and Southeast wheat growing regions of the State (Idaho Wheat Commission et al., 2007). Similar trends are observed in Washington State, with mode choice dependent on accessibility and proximity to the different modes of transport. From all the wheat that is exported through the PNW (about 16 million metric tons) (USDA, 2021a), about 2-2.6 million metric tons (13-16%) travel through the Snake River (SNR) (USACE, 2022). Farms in Washington and Idaho are responsible for most of the tonnage transported through the SNR.

Overall, all wheat transported is multi-modal, requiring truck movements from farms to diverse types of facilities including grain elevators, river ports, rail shuttle facilities, ocean ports, or to end customers. This is important when trying to understand the emissions associated with grain movements, and is critical when analyzing the effects on emissions of the removal of barge traffic between Clarkson-Lewiston and Pasco, as the loss of the barge option will affect the other mode options for grain (and other commodity movements). Individually, modes have different efficiencies in terms of fuel and energy consumption and the associated emissions, with rail and barge requiring much less fuel to transport cargo than trucks require. As mentioned above, any movement, whether by train or barge, still requires a truck movement (at the origin, destination, or at an intermediary facility). Consequently, any comparison across multimodal transport options must account for the entire transport, and not just focus on one specific leg or movement. If the goods require long trucking distances to reach a specific, more efficient mode, total emissions could be higher than for an alternate transport route.

This study seeks to estimate the potential changes in emissions of wheat transport originating in Idaho, Washington, and northern Oregon destined for PNW ocean ports when the possibility to transport on the lower SNR dams and locks is removed. The study concentrates on the estimated direct emissions from the vehicle types used (i.e., truck, rail, and barge), and develops an approximate sketch multimodal transport planning model based on secondary data (e.g., transport networks, location of elevators, river ports). Although there may be other effects resulting from the dam removal related to river and water conditions, the environment, ecology, local economy and jobs, and safety, among others, this study is limited to the direct changes in transport emissions.

This report is organized as follows. Section 2 discusses the methodology and data used to develop the model. Section 3 discusses high-level results of the estimated baseline and alternative scenario. And the report ends with conclusions derived from the findings.

2 Methodology and Data

Throughout the years, several studies have focused on the transport of wheat in the PNW region, and while important research reports and other publications are available, the models used or developed by those studies, or the input data are not publicly available. Therefore, to accomplish the objectives of this study required the development of a transport model from scratch using secondary data, assumptions, and approximate approaches. The key main components of the developed model are related to the:

- Volumes of grain (wheat) produced, their origins and destinations.
- Locations of wheat processing facilities (e.g., elevators), and modal facilities (e.g., ocean port elevators, river ports, rail shuttle facilities).
- Transport modes available, and their characteristics (i.e., efficiencies, costs), as well as the transportation networks (e.g., rail, roads), and multimodal transportation routes (e.g., truck to barge, truck to rail).

2.1 Wheat Production

As discussed, this study concentrates on wheat produced in Washington, Idaho, and Oregon. According to the United States Department of Agriculture's National Agricultural Statistics Service (2022a), in 2019, these states produced approximately 267 million bushels (~7.3 million metric tons) of wheat (see Table 1), with roughly half of that destined for export (the remainder was for domestic consumption, and some percentage for feed or seed). Wheat production has remained relatively constant during the last few years.

Table 1. Wheat Production & Percent of Crops within a Distance Threshold from the SNR

State	Bushels	Metric tons	100 miles	150 miles	200 miles	250 miles
Idaho	84,949,849	2,311,717	28%	38%	44%	58%
Oregon	45,246,701	1,231,286	28%	56%	66%	68%
Washington	137,570,970	3,743,680	90%	97%	98%	100%
Grand Total	**267,767,520**	**7,286,683**	**61%**	**74%**	**79%**	**84%**

The analyses use county-level production data disaggregated at the Zip-level (1,308 Zip codes) proportionally to the ZIP code area. The centroid of the Zip code was used as the aggregator for wheat produced; thus, the analyses use the Zip code geographic boundaries as the basis for the transportation analysis zones (TAZs). Considering the lack of a disaggregated origin-destination matrix to identify the locations that ship their crops through the SNR, the analyses estimated the proportion of the crops located within a straight-line distance threshold (e.g., 100, 150, 200 and 250 miles) of the SNR as a proxy for the driving distances to the river ports. Table 1 shows the approximated share of the total crops within those distance thresholds, identifying major differences for Oregon and Idaho. For example, in Washington, the estimates show that about 90% of the crops locate within one hundred miles and almost all crops locate within 250 miles; whereas in Idaho and Oregon, just 58% and 68% of the crops locate within the 250-mile distance, respectively. Figure 1 below shows the relative concentration of wheat production in the southeast region of Washington State relative to the Columbia and lower SNR.

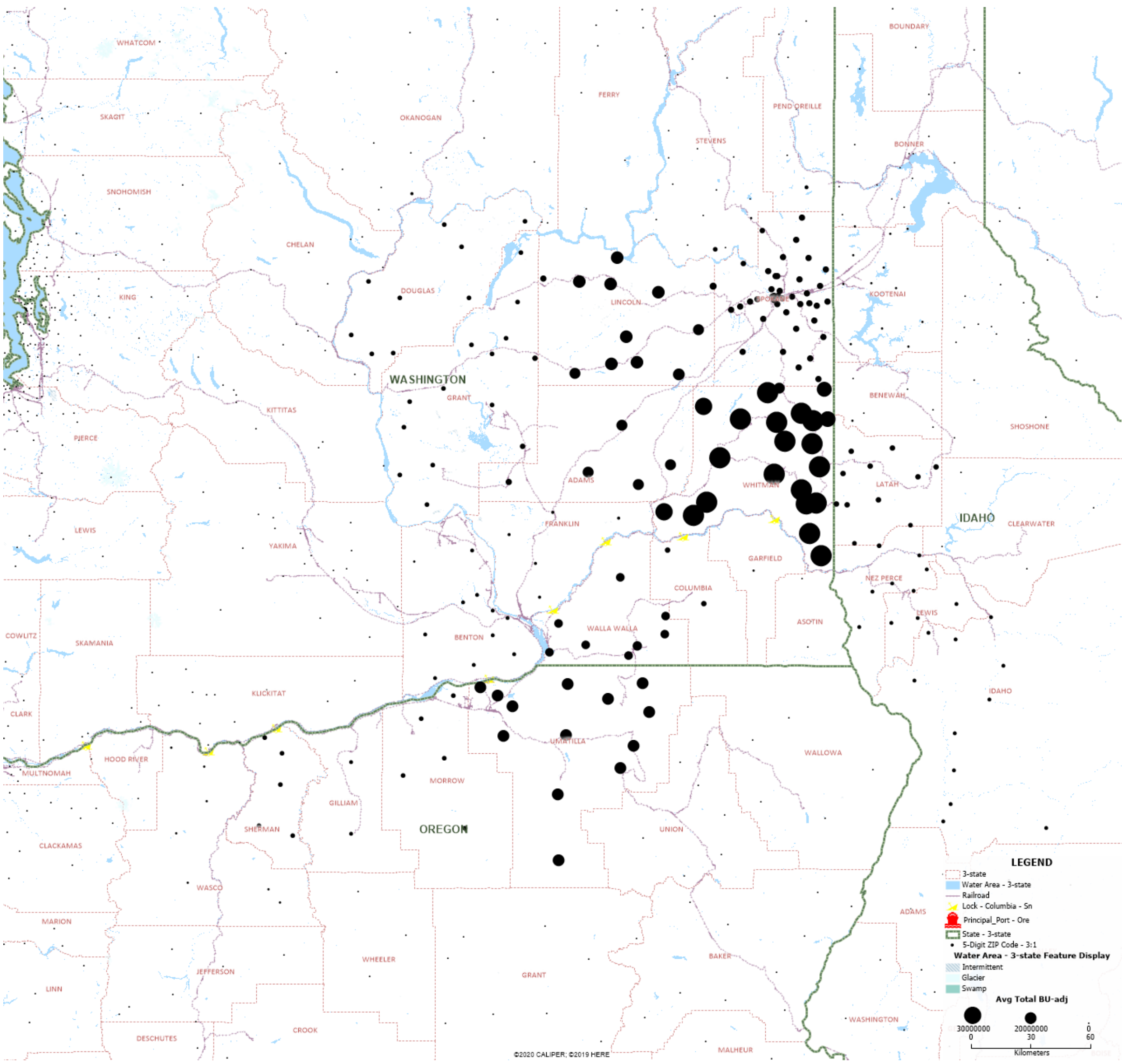

Figure 1. Relative Wheat Production per TAZ Centroid

2.2 Wheat Transport Facilities

The analyses concentrated on identifying key facilities that are part of the wheat multimodal transport network in the PNW region, including grain elevators, rail shuttle facilities, river ports, dams and locks, and ocean ports (elevators). Shuttle facilities, river ports, dams (and locks), and ocean ports are easy to identify, and there are publicly accessible geographic information system (GIS) layers for these. Shuttle facilities include Ritzville, McCoy, Highline, Grain Handling LLC, and Endicott facilities; ocean ports are in Kalama WA, Portland OR, Vancouver WA, and Longview WA; and lower SNR dams include Lower Granite, Little Goose, Lower Monumental, and Ice Harbor, while dams in the Columbia River include McNary, John Day, The Dalles, and Bonneville. The study identified a total of twenty-five river grain docks along the lower SNR and Columbia River. Using Google, a visual inspection was conducted of each of these locations to identify whether they had rail access or not. Figure 2 shows the location of elevators (blue), elevators with rail access (red), rail shuttles (orange), and the rail network.

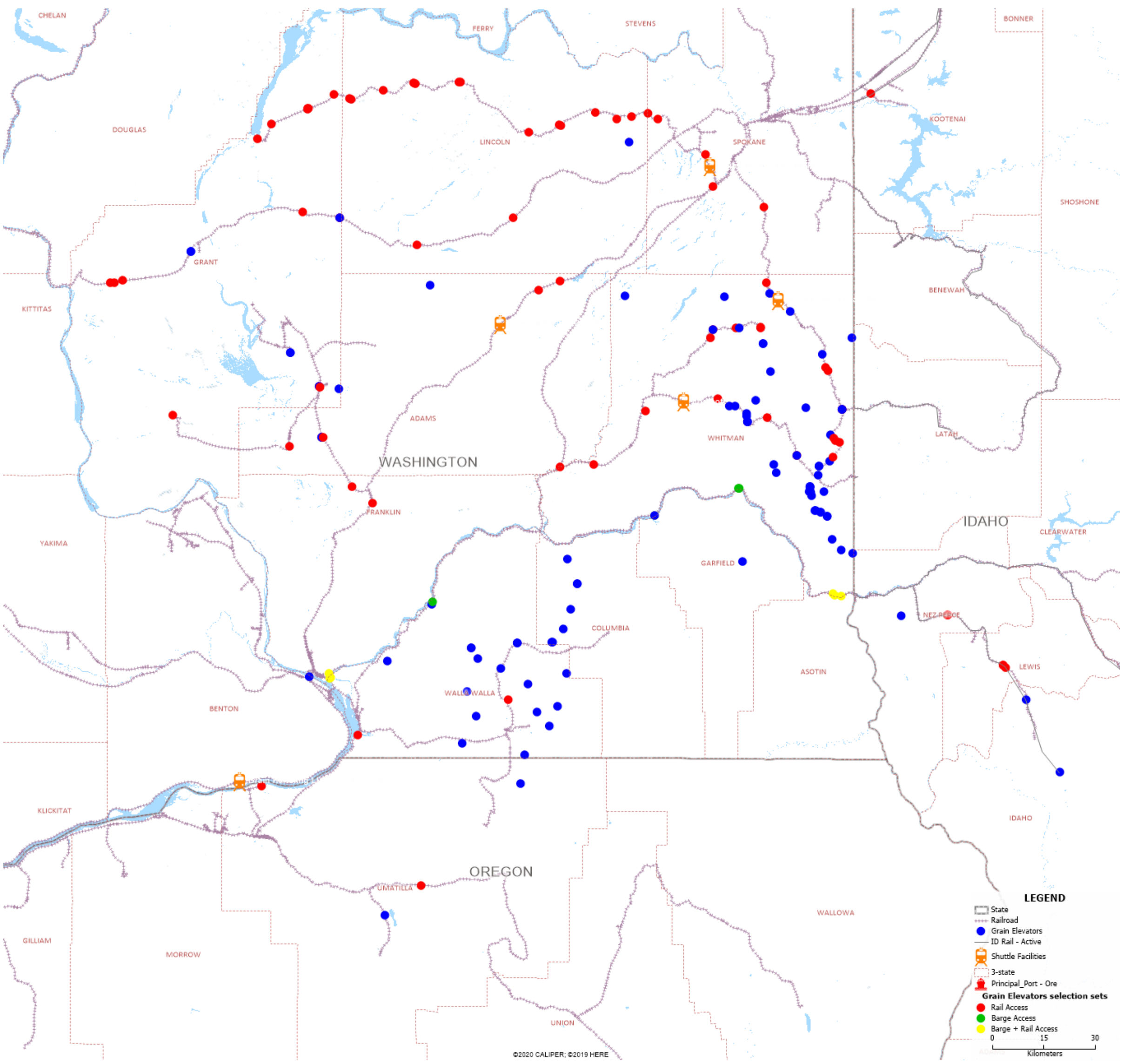

Figure 2. Location of Key Wheat Transport Facilities

However, identifying grain elevators was not an easy task. The study used several sources, in addition to visual inspection, to identify grain elevators. Sources included elevator registrations, online searches, the Pacific Northwest Farmers' Cooperative, the Highline Grain Growers Inc. list of elevators, research reports, and grain elevator regional directories, among others. Despite major efforts, no official list or information was obtained. A total of 242 elevators were identified, and in a process like the one followed with the river ports, visual inspections of each location were conducted to identify whether they had direct access to rail, the river, or both. 109 of the elevators appear to have direct access to rail, though it was not possible to verify that such accessibility was currently enabled. A number of these elevators with rail access concentrate on the Burlington Northern and Santa Fe Railway (BNSF) lines leading to Spokane.

Another limitation of the data relates to the capacity, or other operational characteristics of the elevators. The study assumes no capacity constraint at these facilities, and that any farm (or TAZ centroid) could ship wheat to (and through) these facilities.

2.3 Wheat Transport

2.3.1 Networks & routes

The study considers the multimodal transport of wheat for export through truck, rail, and inland waterways (barges). The first step of the process to create the transportation system was to identify the transportation networks. Through the Washington Department of Transportation (DOT), Idaho DOT, and Oregon DOT, the study collected individual data on the road, rail, and waterway networks. Other sources, such as open GIS platforms, United States Army Corps of Engineers, United States Department of Agriculture, University portals, and the websites of the Union Pacific and BNSF railways, provided additional information or served to complement the data.

Based on current practices for wheat transport (USACE et al., 2020), the study considers the following wheat transport route options:

1. Farm – Truck – River port – Barge – Ocean port
2. Farm – Truck – Elevator – Truck – River port – Barge – Ocean port
3. Farm – Truck – Elevator with rail – Rail – Ocean port
4. Farm – Truck – Elevator – Truck – Elevator with rail – Rail – Ocean port
5. Farm – Truck – Rail Shuttle – Rail – Ocean port
6. Farm – Truck – Elevator with rail – Rail – Shuttle – Rail – Ocean port
7. Farm – Truck – Elevator – Truck – Elevator with rail – Rail – Shuttle – Rail – Ocean port
8. Farm – Truck – Shuttle – Rail – River port with rail – Barge – Ocean port
9. Farm – Truck – Elevator with rail – Rail – Shuttle – Rail – River port with rail – Barge – Ocean port
10. Farm – Truck – Elevator – Truck – Ocean port

In options 2, 3, and 7, the first 'Elevator' includes those with and without rail access. The analyses use the centroid of the TAZ as the aggregator of wheat for the farms within a Zip code. Options 8 and 9 were not finally considered, as these options are not currently used in practice.

2.3.2 Transport Distances

The study used Maptitude and ARCGIS for data processing and analyses. Specifically, the shortest distance was estimated for every pair of locations (e.g., TAZ centroid, elevators, river ports, shuttle facilities, and ocean ports) for the existing transport modes (see Table 2 for description).

Table 2. Description of Transport Distances Estimated between Locations

Location	Number	Truck leg	Rail leg	Barge leg
TAZs	1,306	TAZ – Elevator; TAZ – Shuttle; TAZ – River port		
Elevators	242	Elevator – Elevator with Rail; Elevator – Shuttle; Elevator – River port; Elevator – Ocean port		
Elevators with rail	109	Elevator with rail – Shuttle	Elevator with rail – Shuttle; Elevator with rail – Ocean port	
Rail shuttle	5		Rail shuttle – Ocean port	
River ports	25			River port – Ocean port
Ocean ports	4			

Because no data were available about the actual routes selected for every shipment, and because of the simplified assumption on the use of TAZs, the analyses considered, where possible, the ten shortest distances from each leg specific origin to the respective destinations (e.g., the distances from a Zip centroid to the ten closest elevators). This was necessary because all combinations were estimated and including distances from a TAZ in northern Washington to an elevator below the SNR might not make sense. Additionally, the minimum, 25th percentile, median, 75th percentile, and maximum distances were identified and recorded for future use in scenario analyses. There were combinations for which only 4 or 5 distances could be estimated, e.g., those including rail shuttles or ocean ports as destinations; thus, further assumptions were made, or the statistics were manually selected.

For every TAZ, the study then constructed the shortest overall route (1-10 defined before), assuming the selected leg (based on the distance statistic) for the corresponding mode. Filters were introduced to omit origins that rendered inconsistent routes, e.g., origins in southeast Idaho that do not use barging along the SNR, or those with trucking distances over a specific distance threshold. Moreover, based on anecdotal data, a flag was created to identify those origins that are located below State Route 26, as it was identified through personal communications that most of these farms use the SNR due to proximity.

2.3.3 Transport costs

Cost, time, accessibility, reliability, and other factors affect the mode choice and export path of wheat. This study did not conduct a mode choice analysis or analyze the elasticities of choices due to changes in such factors. Rather, the analyses are based on assumptions about travel distances for capacity unconstrained modes, considering transport rates per transported bushel over specific distances for truck, rail, and barge from USACE et al. (2020). The study assumes an all-or-nothing assignment of the shipments from a TAZ to the ocean ports using the cheapest route option. Figure 3 shows a comparison of the rates for different distances. As shown, it is interesting to see how barges outperform rail for distances longer than 250 miles. It is important to note that for rail and barge, as discussed, an initial truck movement is required, Figure 3 also shows the average rate for rail and barge assuming an initial truck leg of 25 and 50 miles. In addition to potential impacts on travel time and reliability, multimodal transport has additional costs such as transshipment costs associated with the unloading and loading of the cargo plus any other handling and inventory costs. The EIS discusses that the rates per bushel assume a handling cost of $5 cent per bushel for any shipment delivered to grain elevators, shuttle facilities, or river ports.

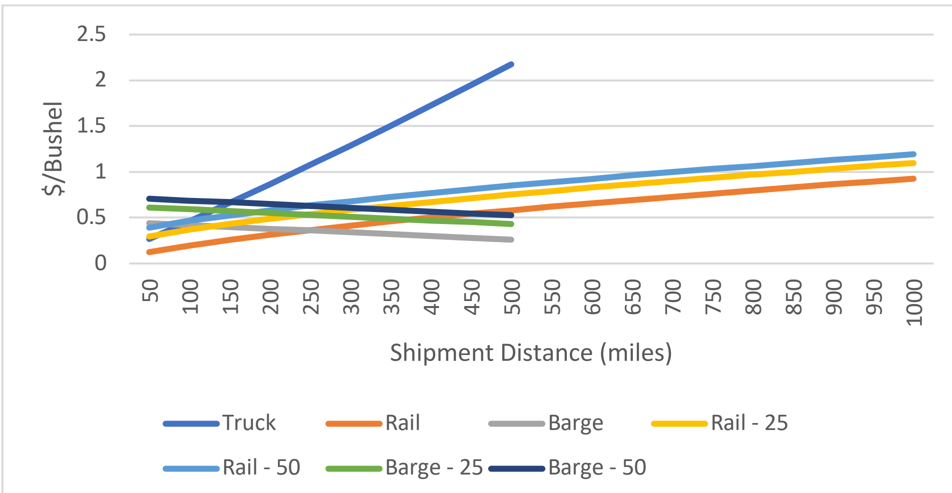

Figure 3. Estimated Transport Cost for Wheat Shipments

To be able to conduct sensitivity analyses, additional parameters were introduced to affect the rates per bushel for specific modes, e.g., an increase or decrease in the overall rate by x%, specifically the change in rate of shuttle rail, or additional transshipment costs.

Using the transport distances selected for every mode, leg, and route, and the cost functions, the study estimates the total cost of each route option and selects the cheapest to represent the most likely route for each origin. In an all-or-nothing assignment, the bushels aggregated at the TAZ centroid are then assumed to use that transport option resulting in the estimated modeling of the approximated flows through the network. Considering that there is no detailed information to validate the assumptions and the results, the study analyzed additional available information.

2.4 Available Wheat Transport Data

2.4.1 Rail Shipments (Waybill Sample)

The Carload Waybill Sample provided by the Surface Transportation Board (2022), is a stratified sample of carload waybills for all U.S. rail traffic carriers (that move 4,500 or more revenue carloads per year). Although there is a detailed Waybill Sample, there is also a public version of the waybill data, but it is highly aggregated at the Bureau of Economic Analysis (BEA) classification system. Table 3 shows the BEA areas in the study region (those that include any area in OR, WA, or ID). The study gathered and expanded the sample for these regions and estimated the productions and attractions for wheat products. Unfortunately, the data only showed information of rail tonnage from areas 167 – Portland-Salem, and 169 Richland-Kennewick-Pasco, to area 170 of Seattle-Tacoma-Bremerton (see Figure 4), and due to the size of these areas this data was not useful for the analyses. Other data available only include general statistics about the share of wheat from Washington and Idaho transported by rail, and in some cases mode share information is available by region.

Table 3. BEA Areas in the Study Region and Origin and Destination or Rail Tonnage

BEA	Description	167	170
143	Casper, WY-ID-UT		
147	Spokane, WA-ID		
148	Idaho Falls, ID-WY		
149	Twin Falls, ID		
150	Boise City, ID-OR		
152	Salt Lake City-Ogden, UT-ID		
165	Redding, CA-OR		
166	Eugene-Springfield, OR-CA		
167	Portland-Salem, OR-WA	32,676	8,960
168	Pendleton, OR-WA		
169	Richland-Kennewick-Pasco, WA	52,380	5,352
170	Seattle-Tacoma-Bremerton, WA		

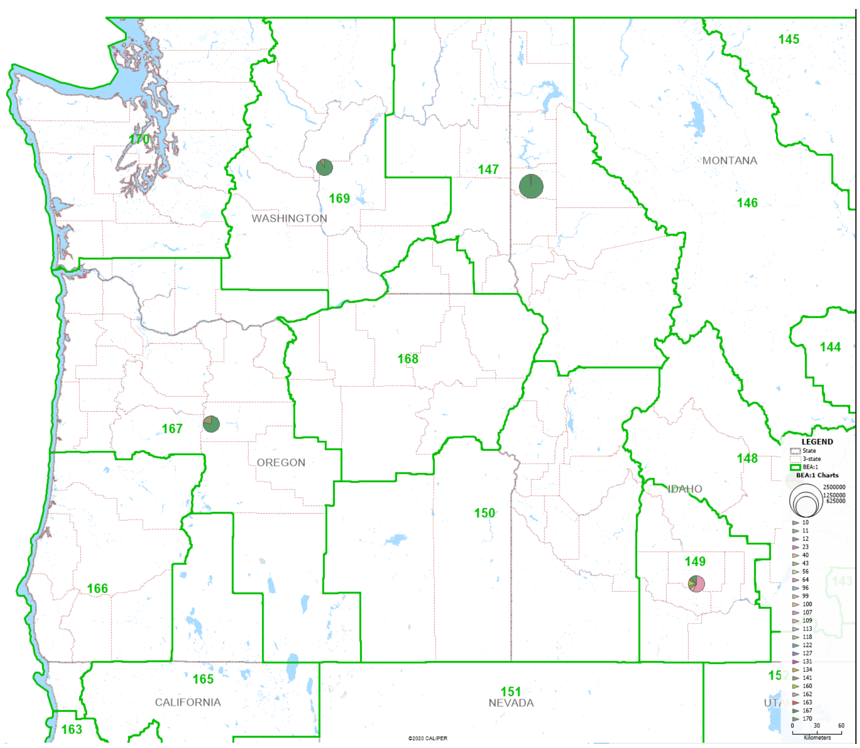

Figure 4. BEA Areas in the Study Region

2.4.2 Barge Shipments

There is detailed barge data provided by the US Army Corps of Engineers through its Lock Performance Monitoring System (USACE, 2022). Table 4 shows the total tonnage (short tons) of food and farm products downbound in 2021 at each of the locks in the lower SNR and at the Bonneville location in the Columbia River. The data shows that in 2021, 2.4 million tons were transported along the lower SNR (between Lower Granite and Ice Harbor, with the majority (more than two thirds) loaded into barges at river docks between Clarkson-Lewiston and Lower Goose dams. Last year, at Bonneville the tonnage reached a yearly total of 4.95 million tons of food and farm products, from which the majority is wheat. It is important to mention that post Ice Harbor, other wheat flows arrive to the Columbia River from origins outside of the study region. These additional origins were not considered in this study and there was no data available to quantify those flows.

Table 4. Monthly Kilotons Reported for Food and Farm Products Downbound in 2021.

	Lower Granite	**Little Goose + LG**	**Little Goose Only**	**Lo Mo + LG + LG**	**Lo Mo Only**	**Ice Harbor - all dams combined**	**Ice Harbor Only**	**Between Ice Harbor & Bonneville**	**Total at Bonneville**
January	172	256.1	84.1	296.6	40.5	357.8	61.2	252.4	**610.2**
February	154.32	260.25	105.93	300.95	40.7	409.75	108.8	156.65	**566.4**
March	38.6	45.3	6.7	63.7	18.4	75.9	12.2	177.9	**253.8**
April	192.5	263.04	70.54	343.29	80.25	425.04	81.75	285.55	**710.59**
May	35.6	127.99	92.39	154.95	26.96	215.18	60.23	254.88	**470.06**
June	53.5	123.41	69.91	133.92	10.51	147.02	13.1	134.77	**281.79**
July	30.4	107.8	77.4	133.8	26	196.85	63.05	203.55	**400.4**
August	101	255.7	154.7	290.2	34.5	328	37.8	225.85	**553.85**
September	38.7	99	60.3	113.2	14.2	150.45	37.25	266.18	**416.63**
October	25.2	58.8	33.6	66	7.2	69.95	3.95	139.25	**209.2**
November	26.5	68.8	42.3	66	-2.8	97.3	31.3	115.5	**212.8**
December	26.2	128.45	102.25	12.6	115.85	138.15	125.55	123.25	**261.4**
	894.52		**900.12**		**180.57**	**2611.39**	**636.18**	2335.73	**4947.12**
	34.25%		34.47%		6.91%		24.36%		

2.5 Emission Factors

The heart of this study is an estimation of emissions, and efforts were made to identify the most accurate emissions data for the modes transporting wheat. Throughout the process, the study identified different references for the fuel efficiency of the different modes and found large variability in the available estimates (Jessup and Casavant, 1998; Shaw et al., 1998; Casavant and Ball, 2001; Muleski, 2001; Muleski et al., 2001; O'Donnell, 2009; Eastern Research Group Inc., 2010; State of Oregon Department of Environmental Quality, 2011; TRC, 2014; Pillot et al., 2016; STC-NESTRA B.V., 2018; Kruse et al., 2021; Illinois Environmental Protection Agency, 2022), with barge and rail having the largest differences across the different sources. For example, references show that rail can transport a ton of cargo between 202 and 594 miles, and barges can transport that ton of cargo from between 203 and 573 miles, using a gallon of fuel. Therefore, a comparison of impacts will be affected by the rates of emissions chosen. There has been a continuous lack of accurate emissions data, especially for the movements along the SNR and Columbia rivers, and understandable criticism has been raised over the use of national averages and estimates (even from sources such as the U.S. Environmental Protection Agency). This study does not fully escape this limitation, as there are no current or accurate emission rates for the fleets of vehicles transporting wheat in the PNW. After pondering several potential sources of data, this study selected two main sources. The first is a study commissioned by the California Department of Transportation (Caltrans) under agreement No. 74A113, titled "M-580 Corridor Multimodal Freight Network Optimization Study" (California Department of Transportation and CPCS, 2022). This study was developed to assist decision-making to identify and prioritize investment opportunities in the I-580 and I-80 corridor between San Francisco Bay Area and Northern San Joaquin Valley. The M-580 study gathered emission rates for trucks and rail from the California Air Resource Board (2022) "Draft Truck vs. Train Emissions Analysis" and barge emission rates from the US Environmental Protection Agency, Emission Standards for Nonroad Engines and Vehicles, 2016 (EPA, 2016). The second selected reference is a recent study commissioned by the National Waterways Foundation titled "A Modal Comparison of Domestic Freight Transportation Effects on the General Public 2001-2019," based on work supported by the U.S. Department of Transportation under Grant Award Number 69A3551747130 (Kruse et al., 2021). This study used EPA's Motor Vehicle Emissions Simulator (MOVES3) to estimate emission rates for trucks (EPA, 2020), and EPA's fleet-average emission factors considering the mix of locomotive tiers and retrofitted ones (EPA, 2009). Similarly, the study uses emissions based on the assumptions and methodology behind the EPA's 2020 SmartWay Shipper Company Partner Tool (EPA, 2019). Table 5 summarizes the emission factors used in this study. Additionally, for comparison purposes, the table shows the emission rates used by one of the first studies analyzing the impact of removing the dams and locks in the lower SNR by Casavant and Ball (2001), 20 years ago. As shown, there are significant differences in the various sets of emission rates.

Table 5. Emission Factors (grams/ton-mile) Considered in the Study

Study	Mode	Ton-Mile/Gallon	CO2	Hydrocarbons	CO	NOx	PM
TTI 2019	Truck	151	140.7000	0.0200	0.0394	0.4500	0.0200
	Rail	472	21.5700	0.0083	0.0564	0.2182	0.0053
	Barge	675	15.0800	0.0058	0.0394	0.1526	0.0037
M580	Truck	121	84.3390	0.0060	0.0348	0.2114	0.0049
	Rail	929	10.9200	0.0029	0.0286	0.1108	0.0018
	Barge	647	16.5564	0.0094	0.2730	0.2218	0.0128
Casavant and Ball (2001)	Truck	NA	NA	0.3771	0.0409	0.1654	0.0278
	Rail	594	NA	0.5080	0.0198	0.0531	0.0135
	Barge	379	NA	0.4969	0.0225	0.0676	0.0107

This study selected the two referenced studies' emission rates because they are the result of recent research; the M-580 will be used by Caltrans in their decision-making regarding the marine highway project, and the second one was based on Federally funded work. Additionally, the two reports provide a detailed description of the sources and methodologies used to estimate the emission rates. Nevertheless, given the variability and the fact that no primary data was collected from vehicles used in the PNW, these estimates are just approximations and should be considered as such for comparison purposes. The actual emissions from the transport of wheat in the region are still unknown.

3 Empirical Results

Two key sets of results are generated by this study: 1) baseline estimates, and 2) an alternative scenario in which the lower SNR dams and docks are removed. Thus, there is no barge traffic along the SNR in the second alternative scenario. A summary of the set of assumptions used are as follows:

- Wheat shipments from every origin to the ocean ports select the route that minimizes their total cost, including the cost of each individual leg (by mode and distance).
- No probabilistic choice model is used in this study.
- Costs are deterministic and fixed, and the rates per bushel/ton are dependent on the shipment distance.
- Farm shipments are aggregated at the Zip code level and concentrate at the ZIP code centroid.
- No capacity constraints for handling, processing, and transporting wheat are considered.
- The median transport distance between pairs of origins and intermediary destinations are used, estimated based on the selection of the top ten shortest distances (or fewer if fewer than ten shortest distances are available).
- Trucks and barges are assumed to return empty, and their efficiency changes by an assumed factor in the return trip.
- The removal of the dams does not affect the rates for the different modes (though there are parameters to evaluate the effect of changes in rates).
- The removal of dams is implemented in the model by removing the river ports in the SNR.
- The model only estimates direct emissions from the vehicles, and no other emissions are considered. Moreover, emissions associated with vehicles idling, and the loading and unloading of grain are not included.

Table 6 shows the estimated tonnage and ton-miles for both the baseline and the no-dam scenario. In terms of ton-miles, although every single shipment uses trucking as part of its route, truck ton-miles only represent 17% of the total mileage. For rail, tonnage represents 25% and ton-miles 32%, and for barge the shares are 64% and 52%, respectively. As expected under the no-dam case, the amount of wheat transported by barge reduces by 39% and ton-miles reduce by 57%. In this scenario, truck ton-miles slightly increase by 8% and rail movements significantly increase, almost doubling in tonnage and ton-miles. In the baseline, average truck mileage is about 61.41 miles per ton, increasing to 76.06 miles (an 8% increase) in the no-dam scenario; rail shipment average mileage reduces from 466 to 447 miles (a 4% reduction); and the average barge distances per shipment reduce about 30% from 293 to 204 miles per ton.

Table 6. Estimated Tonnage and Ton-miles for Baseline and No Dams Scenario

	Baseline				Scenario (No Dams)			
	Metric tons		Ton-miles		Metric Tons		Ton-Miles	
Truck	5,841,799	100%	358,745,466	17%	5,841,799	100%	385,919,655	18%
Rail	1,454,936	25%	679,032,564	32%	2,918,050	50%	1,304,906,915	60%
Barge	3,763,661	64%	1,103,806,297	52%	2,300,547	39%	470,459,063	22%

Although there are no other data sources to directly compare the results obtained by the model, some statistics are used as reference. For example, according to the Washington Grain Comission (2022), and the Oregon Aglink Organization (2022), between 85 to 90% of the wheat grown in these states is exported. A study by Idaho Wheat Commission et al. (2007) estimates that almost 52% of the wheat produced is exported. Recalling the data from Table 1 and these statistics, the estimated total wheat exported by the model has a difference of less than 4%. Additionally, other sources indicate that the mode share for wheat in Idaho is 29% truck, 35% barge and 36% rail, and for Washington, these numbers are 3%, 60% and 37%. Omitting Oregon because of lack of mode share data, and standardizing by export shares, the estimated reference mode share is 37% rail and 53% barge in the PNW. The estimated results produced by the model seem to be consistent with general statistics, although there are some differences.

Using emissions from the M-580 and the TTI2019 reports, the study estimated the associated emissions for the baseline and the alternative scenario. Table 7 shows the large variability between the two sets of emissions. Interestingly, while the M-580 rates show a benefit reduction in CO2 of about 9%, using the TTI results in an increase of CO2 emissions of 1.37%.

Table 7. Estimated Emissions (metric tons) and Fuel Consumed (millions of gallons)

	Mode	Diesel	CO2	Hydrocarbons	CO	NOx	PM
Baseline Emissions – TTI 2019	Truck	4.75	100,951	14.35	28.27	322.87	14.35
	Rail	1.44	14,647	5.64	38.30	148.16	3.60
	Barge	3.27	33,291	12.80	86.98	336.88	8.17
	Total	9.46	148,889	32.79	153.55	807.92	26.12
Alternative Scenario Emissions – TTI 2019	Truck	5.11	108,598	15.44	30.41	347.33	15.44
	Rail	2.76	28,147	10.83	73.60	284.73	6.92
	Barge	1.39	14,189	5.46	37.07	143.58	3.48
	Total	9.27	150,934	31.72	141.08	775.64	25.83
	Difference	**-2.02%**	**1.37%**	**-3.25%**	**-8.12%**	**3.99%**	**-1.08%**
Baseline Emissions – M-580	Truck	5.95	60,512	4.34	25.00	151.66	3.49
	Rail	0.73	7,415	1.97	19.42	75.24	1.22
	Barge	3.41	36,550	20.75	602.68	489.65	28.26
	Total	10.09	104,477	27.06	647.09	716.55	32.97
Alternative Scenario Emissions – M-580	Truck	6.40	65,096	4.67	26.89	163.15	3.76
	Rail	1.40	14,249	3.78	37.32	144.58	2.34
	Barge	1.45	15,578	8.84	256.87	208.70	12.04
	Total	9.26	94,923	17.29	321.08	516.43	18.14
	Difference	**-8.26%**	**-9.14%**	**-36.08%**	**-50.38%**	**-27.93%**	**-44.98%**

Similarly, the estimated NOx varies between an increase of 4% and a reduction of almost 28%, and although there are significant differences in the estimates for the other pollutants, the reduction direction is consistent across emissions rates. Figure 5 illustrates these differences.

Figure 5. Comparison of Estimated Emissions across Scenario and Emissions Rates Source

As shown, the resulting estimated emissions significantly differ based on the emission factors used. This change is not only in terms of magnitude, but also in terms of the behavior of the different pollutants, with the M-580 rates compared to the TTI2019 exhibiting a different trend between CO2 and the other pollutants. Overall, these results seem to indicate that the removal of the dams could have a minimal negative impact (in CO2 and NOx), or a significant benefit in terms of direct emissions.

4 Conclusions

More than 20 years ago, Casavant and Ball (2001) evaluated the energy and emission impacts of removing the lower SNR dams and found that *"…looking narrowly at environmental concerns, a drawdown of the Snake River for salmon restoration does not have a negative impact."* Their study also concluded that differences in the emission factors used could affect the results, as they found the overall change in emissions to be positive (1.29%) using one set of factors, and negative (2.08%) using another set. The results of this current study are consistent with the findings and the limitations of that original study, albeit the differences found here are much larger.

Besides the findings related to whether removing the dams will have a negative or positive impact under the assumptions adopted in this study and the data limitations, it is worth mentioning that:

- This study only concentrates on the direct change in emissions, and there may be other important (positive and negative) externalities that require further study, including, but not limited to, the additional transport capacity required, especially for rail; power generation requirements; water quality; regional economic effects; road infrastructure investments; safety and traffic; and the transport of other commodities; among others.
- Even though several major agencies and organizations at the Federal, State and Local levels, and other trade organizations are directly involved with the transport of wheat, there is no single repository of relevant data. Some statistics provided in different sites may be conflicting, and finding the data is exceedingly difficult. It would be a great benefit for multiple stakeholders if different data sources were consolidated, and a repository of such data was created. As mentioned, this study had to conduct individual visual inspections and browse and search multiple sources to create a database of elevators.
- There is a lack of consistent emission data and efficiency factors for the modes and vehicles used in the PNW. In fact, there are only a handful of studies in the US and abroad related to barges and inland waterways in general. This represents a significant challenge for the adequacy of estimates for studies like this one, or for any type of emissions inventory in general. Although it could be prohibitively expensive to measure emissions at every location, a type of "barge use and inventory survey" could be an efficient way to collect relevant operational information, especially since the number of barges in operation may not be large (compared to trucking).
- There is a lack of consistency across different studies and their assumptions with respect to the definition of the study region, and the parameters used.

Finally, the Columbia River System Operations Environmental Impact Statement published in 2020 touched on some of the previous points and concentrated on the assessment of the potential impacts of the removal of the dams. In doing so, the study used a Transportation

Optimization Model (TOM) which provides additional resolution to the analyses, although the main components are similar to the approximate model developed here. What is interesting from the System Operations reports is that no emissions were estimated for the modeled mode flows. To compare their results with the ones obtained here, the emission rates from the M-580 and TTI 2019 were implemented on their results. Additionally, to be consistent with the assumptions adopted here, TOM's results were expanded to account for the return trips for the truck and barge movements. Additionally, the analyses are limited to the baseline and Scenario 1 (the no-dam scenario), as those are the results that closely resemble the assumptions made in this study. Table 8 shows the ton-miles for the baseline and scenario 1 in the Environmental Impact Assessment. Although there are some slight differences, these estimates are consistent with those estimated here (recall Table 6). Additionally, Table 9 shows the estimated emissions for their baseline and scenario. Here again, the two sets of emissions render contrasting results, with the TTI 2019 emissions resulting in a negative impact (increased emissions) except for CO, though the changes are 10% or less for the distinct pollutants. On the other hand, the M-580 rates result in overall reductions in emissions (a slight reduction for CO2, but large reductions for the other species).

Table 8. Estimated Ton-Miles from the Columbia River System Operations Environmental Impact Assessment Modeling

Mode	Baseline		Scenario 1		Change
Truck	463,956,569	20%	550,921,651	22%	19%
Rail	818,854,333	35%	1,523,803,400	62%	86%
Barge	1,086,083,464	46%	390,549,415	16%	-64%

Table 9. Emissions (metric tons) and Fuel (millions of gallons) for the Environmental Impact Assessment Results

	Mode	Diesel	CO2	Hydrocarbons	CO	NOx	PM
Baseline Emissions – TTI 2019	Truck	6.15	130,557	18.56	36.56	417.56	18.56
	Rail	1.73	17,663	6.80	46.18	178.67	4.34
	Barge	3.22	32,756	12.60	85.58	331.47	8.04
	Total	11.10	180,976	37.95	168.33	927.71	30.94
Alternative Scenario Emissions – TTI 2019	Truck	7.30	155,029	22.04	43.41	495.83	22.04
	Rail	3.23	32,868	12.65	85.94	332.49	8.08
	Barge	1.16	11,779	4.53	30.78	119.20	2.89
	Total	11.68	199,677	39.21	160.13	947.52	33.00
	Difference	**5.27%**	**10.33%**	**3.32%**	**-4.87%**	**2.14%**	**6.68%**
Baseline Emissions – M-580	Truck	7.69	78,259	5.61	32.33	196.14	4.52
	Rail	0.88	8,942	2.37	23.42	90.73	1.47
	Barge	3.36	35,963	20.42	593.00	481.79	27.80
	Total	11.93	123,164	28.40	648.75	768.65	33.79
Alternative Scenario Emissions – M-580	Truck	9.14	92,928	6.66	38.39	232.90	5.37
	Rail	1.64	16,640	4.42	43.58	168.84	2.73
	Barge	1.21	12,932	7.34	213.24	173.25	10.00
	Total	11.98	122,500	18.42	295.21	574.99	18.09
	Difference	**0.42%**	**-0.54%**	**-35.14%**	**-54.50%**	**-25.20%**	**-46.45%**

Although these results suffer from the same limitations of inconsistent emission rates seen in earlier studies, the overall results are similar to the ones estimated here. These results support the conclusion that, under the assumptions adopted and the limitations of the study, the removal of the dams may not have a large negative effect on overall emissions; and there is a potential for emission reductions. However, consistent across studies, the removal of the dams may result in an increase for growers in the direct transport costs for wheat. In fact, the Systems Operations analyses estimate an increase of about 10% in costs, compared to the 14% increase in costs found here.

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