Alternative Evaluations of a River Drawdown: Reassessing the Environmental Paradox

Previous attempts to determine the effect on energy consumption and emissions production as a result of breaching the dams in Washington used national coefficients. This paper compared the results using regional energy efficiency coefficients versus national coefficients, finding that a Snake River drawdown would decrease energy consumption for wheat transportation, and even more than in the earlier work. For wheat, emissions incur a dramatic turnaround, going from an increase of 1.29% to a decrease of 2.08%. When wheat and barley transportation are combined, energy consumption increases 1.61% under the breaching scenario. Transportation emissions were unchanged due to a decrease of emissions for wheat and an offsetting increase of emissions for barley. The regional coefficients analysis suggests that a drawdown of the Snake River for salmon restoration does not have a major negative energy or emissions environmental impact.

by Trent Ball and Kenneth Casavant

Salmon are an important component of the Pacific Northwest's Columbia-Snake River ecosystem. Human intervention has already contributed to several salmon species becoming extinct or endangered. A salmon run is the total number of mature salmon returning in a given year from ocean-rearing areas to fresh water. Numerous recovery efforts to restore the declining Columbia-Snake River salmon runs have been made, including fish hatchery releases and transporting juvenile salmon around dams. Because outcomes are not reaching federal survival and recovery goals, additional strategies are being considered. One proposal is to breach the four dams on the lower Snake River located in southeastern Washington.

Breaching a dam opens a river to a free-running status by removing the soil around the dams and draining the pools of water. Proponents of dams breaching envision that this will better meet the biological requirements of salmon, increasing migration and survival rates by (1) decreasing the time juvenile salmon spend swimming to the ocean; (2) decreasing exposure to diseases and predation caused by low currents in reservoirs' slack water pools; and (3) decreasing mortality caused by passage losses. River managers are discussing breaching the Lower Granite, Little Goose, Lower Monumental, and Ice Harbor dams on the lower Snake River situated above Tri-Cities (Pasco, Richland, and Kennewick), Washington.

The economic success of Pacific Northwest agricultural producers and other industries has been due largely to the cost effectiveness of transporting agricultural products and other freight efficiently. Snake River barge is an important mode of transportation for the eastern Washington grain industry, primarily wheat and barley destined for export loading facilities in Portland, Oregon. Barges on the Snake River rely upon the large draft and water pools created by the

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dams. A drawdown caused by breaching the four lower Snake River dams would result in a termination of barge traffic above the Tri-Cities. At Tri-Cities, the Columbia and Snake Rivers converge, allowing barge transport to Portland. The combination of truck-barge is responsible for 64% of Washington grain movement (Lenzi 1996). If the dams were breached, truck and rail would be required to haul the grain no longer handled by barge, affecting regional freight transportation. Modal shift is likely to have an economic and environmental impact because each mode (truck, rail, and barge) has different tariff rates, energy consumptions, and emission profiles.

Several recent studies were conducted to determine the potential effect on transportation issues if the lower Snake River dams were breached. The results of one study (Lee and Casavant 2002), published earlier in this journal, focused on the energy consumption and pollutant output changes that may arise if barge is no longer available to haul Washington grain. The study used national energy efficiency coefficients for truck, rail, and barge to investigate potential environmental effects of losing the barge mode. Energy efficiency data were obtained from the *Transportation Energy Databook: Edition 19* published by the Oak Ridge National Laboratory and edited by Stacey C. Davis (1999). Using the national aggregate Davis data, Lee and Casavant (2002) found that if breaching were to occur, there would be a small decrease in energy consumption and a slight increase in emissions, but not at a significant level.

Lee and Casavant (2002) noted that the use of regional firm specific coefficients on a point-to-point basis would provide a more comprehensive and accurate analysis of the actual energy consumption and emissions impacts to the Pacific Northwest. Further, several organizations and industry spokespersons argued that the use of national coefficients does not accurately depict the energy efficiency of the regional barges (Mack Funk 1999). It was felt that the national energy efficiency and emissions production coefficients do not reflect the type of river system in this region or the type of tow configuration utilized by the region's barges. Therefore, using national energy efficiency coefficients for barge transportation could misconstrue the impact of lower Snake River dams breachings. However, at the time of the Lee and Casavant study (2002), only national coefficients were available.

The study described in this paper updated and improved the earlier work by developing and using regional energy efficiency and emissions production coefficients. Study objectives were:

(1) Develop regional energy efficiency and emissions production coefficients;

(2) Apply the regional coefficients to the model used in the Lee and Casavant study (2002);

(3) Determine the impact of a Snake River drawdown on energy and emissions related to transportation; and

(4) Evaluate the implications of using regional versus national energy efficiency and emissions production coefficients in analyzing impacts of a Snake River drawdown.

METHOD OF ANALYSIS

For the purpose of this study, because trucks are a relatively homogeneous unit for energy efficiency measurement compared to rail and barge, the national coefficients for truck energy consumption were derived from the Lee and Casavant study (2002). A review of transportation literature and a survey of industry entities identified studies utilizing or producing coefficients specific to rail and barge for the Pacific Northwest. Regional sources were found that could produce useful estimates of rail and barge energy efficiency coefficients: firm specific self-reports (economic-engineering estimates on regional movements).

Rail

Three railroads are prominent in the Pacific Northwest for hauling grain. Burlington Northern Santa Fe (BNSF) and Union Pacific (UP) are dominant, with Blue Mountain Railroad acting as a gatherer/connector to the two major railways. The railways were contacted individually and guaranteed confidentiality. Data to determine the energy efficiency for each railroad were obtained. Energy efficiency was estimated from gallons of diesel fuel consumed and grain hauled over a specific distance on a typical movement in the region. The overall BTUs/ ton-mile based on the railroads' estimates averaged 278, with a range of 221 to 334 BTUs/ton-mile.

Barge

Barge data for this study were obtained from a survey of the four major barge firms that operate on the Columbia-Snake River system. Prior to this study, the barge firms were unwilling to release specific self-reports because of confidentiality and competition concerns. During initial contact, the study team explained that an objective of this study was to collect regional information. A commitment was made to all parties that they would remain anonymous and that data would be kept confidential. For each firm, data were obtained on the tons hauled, distance traveled, and fuel consumed in the typical roundtrip. The data provided by the individual barge firms were used to calculate the ton-miles/gallon consumed and then converted to BTUs/ton-mile. (A ton-mile is a ton of freight traveling one mile.) The average ton-miles/gallon consumed for the four major barge firms was 379. The barge firms had an overall average BTUs/ton-mile of 366, with a range of 347 to 407 BTUs/ton-mile.

ANALYTICAL MODEL

The energy efficiency coefficients utilized in the following analyses are based on the detailed economic-engineering firm specific reports from the railroads and the barge firms operating on the Columbia-Snake River system. These estimates are based on specific point-to-point movements and the associated energy consumed in those movements. These regional coefficients are slightly less energy efficient compared to national figures and can be considered reasonable for determining the magnitude of energy consumption and emissions production resulting from a Snake River drawdown.

The coefficients were applied to the wheat and barley movements in eastern Washington. Grains make up 71% of all downriver movement on the Columbia-Snake River system (Lee and Casavant 1996). For this study, the modal choice and resulting proportions of wheat and barley transported by truck, rail, and barge were based on a Geographic Information System (GIS) database and a Generalized Algebraic Modeling System (GAMS) model created by Eric Jessup at Washington State University (Jessup, Ellis, and Casavant 1996; Jessup 1998). Jessup's analysis utilized a Washington State Department of Transportation (WSDOT) database of eastern Washington roads with supplemental information from US Census Bureau Topological Integrated Geographic Encoding and Referencing (TIGER) databases to construct the network of road and transportation coverages within GIS. The GIS database contains information on the locations of Interstate, state, and county roads; wheat and barley farms (combined into "townships"); grain elevators with and without rail facilities; feedlots; railway systems; and river ports.

The Jessup GIS-GAMS model, as described by Lee and Casavant (2002), uses the GIS database and takes into consideration the appropriate truck, rail, and barge rates and constraints. Lee and Casavant (2002) used this model to determine the least costly wheat and barley transportation routes and modal choices for various barge and no-barge scenarios. The cost minimization function was optimized with the GIS-GAMS model shown below.

Transport Model

$$(1)\quad MinTC=\sum_{i}^{n}\sum_{j}^{m}\sum_{k}^{3}\left[\left(C_{ijk}X_{ijk}\right)+\left(C_{ijk}Y_{ijk}\right)\right]$$

Subject to:
Supply Balance Constraint

$$(2)\quad \sum_{j=1}^{n}\sum_{k=1}^{3}X_{ijk}\leq S_i \qquad \forall i$$

Node Balance Constraint

$$(3)\quad \sum_{i=1}^{n}\sum_{j=(l+1)}^{m}\sum_{k=1}^{3}X_{ijk}=\sum_{i=1}^{n}\sum_{j=(l+1)}^{m}\sum_{k=1}^{3}Y_{ijk} \qquad \forall j$$

Destination Balance Constraint

$$(4)\quad \sum_{i=1}^{n}\sum_{j=(l+1)}^{m}\sum_{k=1}^{3}X_{ijk}+\sum_{i=1}^{n}\sum_{j=(l+1)}^{m}\sum_{k=1}^{3}Y_{ijk}\leq D_j \qquad \forall j$$

Elevator Capacity Constraint

$$(5)\quad \sum_{i=1}^{n}\sum_{j=(l+1)}^{m}\sum_{k=1}^{3}X_{ijk}\leq E_j \qquad \forall j=1,\ldots\ldots,l$$

Where S_i is the supply of grain in the i^{th} region, X_{ijk} and C_{ijk} is the grain flow volume and transportation cost from the ith supply origin into the jth intermediate destination (elevators and river port) using mode k, and Y_{ijk} is the grain flow volume from the jth intermediate destination into the j^{th} final destination using mode k. E_j is the capacity at elevator j and D_j is the quantity demanded at each final destination j.

Explanation of constraints:

- *Supply Balance Constraint* ensures that the amount of shipments from any township does not exceed the amount of grain produced in that township.
- *Node Balance Constraint* ensures that the volume of grain flowing into an intermediate location, such as an elevator or river port, equals the amount flowing out. This constraint assumes that grain is not stored at the intermediate location for more than one year. For most years, grain from the previous year is marketed before the current harvest period.
- *Destination Balance Constraint* verifies that the sum of all shipments to final destinations is less than or equal to the grain demanded at each final destination.
- *Elevator Capacity Constraint* ensures that shipments to a given elevator do not exceed the capacity of the elevator.

The nine scenarios in Jessup's earlier GIS-GAMS model were various combinations of barge and no-barge simulations on the lower Snake River and associated rail and barge rate changes. The two scenarios used for the purpose of this study were:

- *Base Case*. Barge transportation is available on the lower Snake River, representing grain transportation conditions at the time of this study.
- *Breaching Case*. Barge is not available on the lower Snake River above Tri-Cities due to river drawdown.

Historically, rail grain car shortages and/or continued railroad abandonments have caused longer truck movements for grain transport. This can increase the energy and emissions impact since truck is the least energy efficient mode used in moving grain. In the Breaching Case, it was assumed that rail capacity for grain transport is not constrained. Grain car shortages would not be a factor in modal shift because potentially more cars could be acquired. Accordingly, the Jessup model should not be expected to track current grain distribution patterns.

The focus of Jessup's model was also wheat and barley transportation, centered on determining per bushel costs to shippers (farmers and elevator operators) and per ton-mile damage costs to Interstate, state, and county roads under the nine scenarios. The study described in this paper focused on the modal choice and traffic pattern shifts results for scenarios 1 and 2 from the Jessup model as used in Lee and Casavant (2002). The changes in energy consumption and emissions output resulting from termination of barge were determined. The modal share and grain volumes obtained from the model and expressed as ton-miles were then multiplied by the BTUs/ton-mile coefficients to determine energy and emissions results.

Utilizing the amount of energy consumed, the amount of emissions produced was directly derived. Since there are approximately 140,000 BTUs per one gallon of diesel fuel, gallons of fuel from the total BTUs consumed and emission production coefficients were expressed in pounds per 1,000 gallons of fuel. The components of diesel engine emissions include these five groups: nitrous oxides (NO_x), hydrocarbons (HC), carbon monoxide (CO), particulate matter (PM), and sulfur oxides (SO_x). The total amount of emissions produced for truck and rail in the Base Case and Breaching Case were then determined. The truck emissions are identical to the truck emissions as reported in the Lee and Casavant (2002) study since, as mentioned earlier, it is assumed that the energy consumption is represented by the national figures.

RESULTS USING REGIONAL FIRM SPECIFIC COEFFICIENTS

Wheat

As illustrated in Table 1, Jessup (1998) determined that termination of barge transport on the lower Snake River would lead to an overall increase in the amount of truck and rail usage for wheat transported from eastern Washington to Portland, Oregon. Truck movements would experience a ton-mile increase of 15%. Breaching the dams would result in a 94% increase in ton-miles of additional wheat transported via rail. Losing the dams would decrease barge transportation of wheat by 39% since barge movements to Portland would now only be feasible on the Columbia River at Pasco, near the middle of Washington. Summing across all modes, the total ton-miles barely decreases under the Breaching Case when compared to the Base Case, due largely to the elimination of some long hauls to the river and the use of shorter hauls to local elevators.

Table 2 illustrates the total amount of BTUs that are consumed for the individual modes of transportation in both the Base Case and the Breaching Case. As expected, truck and rail energy consumption increases by 15% and 94%, respectively, while barge energy consumption decreases 39%. Industry representatives (Funk 1999 and Port of Portland 1999) suggested that a decrease in barge use for grain increases the amount of energy consumed due to changes in transport. However, using regional data, the total

Table 1: Ton-Miles by Mode for Wheat

Mode	Ton-Miles (Base Case)	Ton-Miles (Breaching Case)	Percent Change
Truck	383,528,229	442,849,331	15.47
Rail	281,904,961	545,504,291	93.51
Barge	827,443,923	503,225,117	-39.18

Source: Jessup 1998

BTUs consumed decreases by 2% in the Breaching Case, signifying that loss of barge does not increase the amount of energy that is consumed despite the BTUs increase for truck and rail transportation.

As Table 3 illustrates, the loss of barge results in a total decrease of emissions by 2% from the Base Case. Sulfur oxide, an emissions component produced largely from barges, decreases almost 23%; nitrous oxide also decreases slightly. Particulate matter, CO, and HC all increase in the Breaching Case. However, the overall impact is a reduction in total emissions.

Emissions attributed to truck transportation are identical to the study by Lee and Casavant (2002) since the truck energy consumption is assumed to be the same as the national figures. Using rail to move additional wheat tonnage if a barge is not available increases each emission component by nearly 94%. Barge emissions decrease by 39% because of the elimination of extended hauls from Lewiston, Idaho. Since the effect of the increase in rail emissions does not quite exceed the decrease in barge emissions, the overall impact is a small decline in total emissions.

Barley

In addition to wheat, barley is also a key product transported by truck, rail, and barge in eastern Washington. Since the total amount of tons hauled is significantly less than wheat (9% of wheat), the percentage effects can be expected to be more dramatic (Lee and Casavant 2002). As seen in Table 4, both truck (107%) and rail (150%) more than double their amount of ton-miles, while barge experiences a decrease of 27%. Barley is predominately shipped via barge. Elimination of transport by barge on the lower Snake River would cause a major re-routing of barley to the nearest Columbia River ports by truck. As a result, energy consumption increases for truck and rail but decreases for barge. The overall effect on energy consumption across all modes is an increase of 41% (Table 5).

As illustrated in Table 6, elimination of barges on the lower Snake River will lead to a rise of 25% in total emissions production for barley transport. All the emissions components will increase in the Breaching Case except for sulfur oxide, which decreases by 17%. Looking at the individual effects of the transportation modes reveals interesting results. Truck emissions consistently increase by slightly over 107% in the Breaching Case. For rail, emissions components double and sometimes triple when there is no barge transportation. However, the actual amount (i.e., total pounds) of rail emissions is very small. As expected, the barge total emissions output declines (27%).

Overall, as seen in Tables 5 and 6, the effect on barley transportation due to the elimination of barge on the lower Snake River is an increase in the amount of energy consumed, as well as an increase in emissions.

Table 2: BTU per Ton-Mile and BTUs Consumed for Wheat (millions of tons)

Mode	BTU/ Ton-Mile	BTUs Consumed (Base Case)	BTUs Consumed (Breaching Case)	Percent Change
Truck	549	210,557	243,124	15.47
Rail	278	78,370	151,650	93.51
Barge	366	302,845	184,180	-39.18
Total		**591,772**	**578,954**	**-2.16**

Table 3: Emissions from Truck, Rail, and Barge for the Transportation of Wheat

Emissions Component	Base Case (Pounds)	Breaching Case (Pounds)	Percent Change
Truck Mode			
NO_x	139,870	161,504	15.47
HC	318,844	368,160	15.47
CO	34,592	39,942	15.47
PM	23,512	27,233	15.83
SO_x	8,748	10,143	15.95
Total	**525,566**	**606,982**	**15.49**
Rail Mode			
NO_x	33,027	63,910	93.51
HC	315,717	610,934	93.51
CO	12,315	23,831	93.51
PM	8,397	16,248	93.51
SO_x	20,152	38,996	93.51
Total	**389,608**	**753,919**	**93.51**
Barge Mode			
NO_x	123,301	74,988	-39.18
HC	906,370	551,226	-39.18
CO	41,100	24,996	-39.18
PM	19,469	11,840	-39.18
SO_x	162,238	98,668	-39.18
Total	**1,252,478**	**761,718**	**-39.18**
All Modes (Truck, Rail, and Barge)			
NO_x	1,540,932	1,530,319	-0.69
HC	88,008	88,769	0.86
CO	296,198	300,401	1.42
PM	51,377	55,321	7.68
SO_x	191,138	147,807	-22.67
Total Emissions	**2,167,653**	**2,122,617**	**-2.08**

Table 4: Ton-Miles by Mode for Barley

Mode	Ton-Miles (Base Case)	Ton-Miles (Breaching Case)	Percent Change in Ton-Miles
Truck	52,104,728	108,102,325	107.47
Rail	37,192	93,009	150.08
Barge	76,315,265	55,825,059	-26.85

Source: Jessup 1998

Table 5: BTU per Ton-Mile and BTUs Consumed for Barley (millions of pounds)

Mode	BTU/ Ton-Mile	BTUs Consumed (Base Case)	BTUs Consumed (Breaching Case)	Percent Change
Truck	549	28,605	59,348	107.47
Rail	278	10.3	25.9	150.08
Barge	366	27,931	20,432	-26.85
Total		**56,547**	**79,806**	**41.13**

SUMMARY

This study was designed to determine the potential impact on transportation energy consumption and emissions production as a result of a Snake River drawdown. An equally important objective was to determine the impact of using regional firm specific coefficients versus national coefficients in the energy and emissions analyses. The regional coefficients developed in this study and the national coefficients developed earlier by Jessup (1998) are compared in Table 7.

First, it is evident that estimates of modal energy consumption as a result of a Snake River drawdown decrease if regional firm specific coefficients rather than national aggregate figures are used. Both rail and barge modes have significantly (25% and 11%, respectively) better energy efficiency under regional estimates. Secondly, the relative energy competitive position between the two modes also shifts. Using national estimates, there is about an 11% advantage for rail over barge in contrast to a 24% advantage when using regional firm specific coefficients.

The potential impacts on energy consumption and emissions output for wheat and barley transportation from the proposed Snake River drawdown are summarized in Table 8 and Table 9, utilizing regional firm specific and national coefficient perspectives.

For wheat, a Snake River drawdown would decrease energy consumption. The amount of the decrease changes from -0.61% to -2.16% (4.0 billion BTUs to 12.8 billion BTUs) when using regional rather than national coefficients. Emissions production incurs a more significant turnaround, going from an increase of 1.29% to a decrease of 2.08% (a positive 32,000 pounds to a negative 45,000 pounds). For barley, a Snake River drawdown would increase energy consumption 41% using regional coefficients compared to an increase of 37% using the national coefficients. Further, using the regional coefficients, the emissions production for barley would also increase by 24.6% compared to 20.8% using the national coefficients.

Combined, wheat and barley transportation energy consumption increases 1.61%

Table 6: Emissions from Truck, Rail, and Barge for the Transportation of Barley

Emissions Component	Base Case (Pounds)	Breaching Case (Pounds)	Percent Change
Truck Mode			
NO_x	19,002	39,424	107.47
HC	43,317	89,870	107.47
CO	4,699	9,750	107.49
PM	3,268	6,782	107.53
SO_x	1,226	2,543	107.42
Total	**71,512**	**148,369**	**107.47**
Rail Mode			
NO_x	4	11	175.00
HC	42	104	147.62
CO	2	4	100.00
PM	1	3	200.00
SO_x	3	7	133.33
Total	**52**	**129**	**148.08**
Barge Mode			
NO_x	83,595	61,150	-26.85
HC	3,791	2,773	-26.85
CO	11,372	8,319	-26.85
PM	1,796	1,313	-26.85
SO_x	14,963	10,946	-26.85
Total	**115,517**	**84,501**	**-26.85**
All Modes (Truck, Rail, and Barge)			
NO_x	30,378	47,754	57.20
HC	126,953	151,124	19.04
CO	8,491	12,527	47.53
PM	5,065	8,098	59.90
SO_x	16,192	13,495	-16.65
Total Emissions	**187,079**	**232,998**	**24.55**

using regional coefficients under the breaching scenario. Transportation emissions were unchanged due to a decrease of emissions for wheat and an offsetting increase of emissions for barley. Thus, use of regional coefficients suggests that, looking narrowly at environmental concerns and contrary to industry expectations, a drawdown of the Snake River for salmon restoration would not have a significant negative energy or emissions environmental impact.

Table 7: Comparison of Barge and Rail BTUs/Ton-Mile Using Regional Firm Specific versus National Coefficients

Mode	National (BTUs/Ton-Mile)	Regional Firm Specific (BTUs/Ton-Mile)	Percent Difference
Barge	412	366	-11.2
Rail	368	278	-24.5

Table 8: Comparison of Wheat and Barley Transportation Energy Utilization, Regional Firm Specific versus National Coefficients (millions of BTUs)

	Wheat			Barley		
Coefficients	Base Case	Breaching Case	Percent Change	Base Case	Breaching Case	Percent Change
National	655,205	651,199	-0.61	60,061	82,382	37.16
Firm Specific	591,772	578,954	-2.16	56,547	79,806	41.13

Table 9: Comparison of Wheat and Barley Transportation Emissions Using Regional Firm Specific versus National Coefficients (thousands of pounds)

	Wheat			Barley		
Coefficients	Base Case	Breaching Case	Percent Change	Base Case	Breaching Case	Percent Change
National	2,473	2,505	1.29	202	244	20.79
Firm Specific	2,168	2,123	-2.08	187	233	24.60

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