Cost Effectiveness Incremental Cost Analysis

A cost-effectiveness incremental cost analysis (CE/ICA) is completed to compare the alternatives under consideration for the project site. The purpose of the analysis is to evaluate the effectiveness and efficiency of the site alternatives at producing environmental outputs, so the costs of the alternatives and the expected environmental outputs are inputs for CE/ICA. Since the No Action Alternative was assumed to continue operation of the existing Intake structure, a comparison of the average annual costs of the preferred alternative to the average annual benefits from irrigation was not completed. Instead the CE/ICA focuses on fish passage and habitat as expressed by HU's. Guidance on completing CE/ICA is in the Institute for Water Resource (IWR) Report #95-R-1, USACE, May 1995.

As described in previous sections, three plan alternatives are considered: the No Action Alternative, the Rock Ramp Alternative and the Bypass Channel Alternative. As shown in Table 1, different options exist for how management measures and scales are combined to construct either the Rock Ramp Alternative or the Bypass Channel Alternative. For CE/ICA, the various combinations of management measures and scales are referred to as 'plan alternatives' rather than just 'alternatives.' There are 12 plan alternatives associated with the Rock Ramp Alternative, and four plan alternatives associated with the Bypass Channel Alternative.

The following section provides a summary of the benefits used to evaluate environmental output and is followed by a section describing costs. Next the results of the CE/ICA are provided, including an evaluation of the effect of adaptive management (AM) on the CE/ICA results.

Benefits

The Fish Passage Connectivity Index (FPCI) is a simple arithmetic index that was originally developed to evaluate ecosystem outputs of plan alternatives for fish passage improvements at locks and dams on the Upper Mississippi River System. This model, with slight adjustments, is used to compare the benefits of plan alternatives for providing fish passage at the Intake Dam. Habitat units (HU's) are calculated by multiplying the FPCI by the total acres of available preferred habitat upstream of the Intake Dam, by species. A detailed description of the calculation of HU's is provided as an attachment to this analysis.

Table 1 shows the estimated HU's by plan alternative, organized by Rock Ramp Plan alternatives and Bypass Channel Plan alternatives. Refer to Appendix A1 Plan Formulation, for more details on the plan alternative configurations. The average annual net HU's are the values used for CE/ICA, and are net of the habitat units estimated for the No Action Plan Alternative.

Table 1. Habitat Units by Alternative Plan

Plan alternatives	Average Annual Habit Units	Average Annual Net Habitat Units
No Action Plan Alternative	978	0
Rock Ramp Plan Alternatives		
Original Rock Ramp with Crest 1 and Coffer Dam 1	8,627	7,649
Original Rock Ramp with Crest 1 and Coffer Dam 2	8,627	7,649
Original Rock Ramp with Crest 1 and Coffer Dam 3	8,627	7,649
*Original Rock Ramp with Crest 2	8,627	7,649
Shortened Rock Ramp with Crest 1 and Coffer Dam 1	5,657	4,679
Shortened Rock Ramp with Crest 1 and Coffer Dam 2	5,657	4,679
Shortened Rock Ramp with Crest 1 and Coffer Dam 3	5,657	4,679
Shortened Rock Ramp with Crest 2	5,657	4,679
Double Slope Rock Ramp with Crest 1 and Coffer Dam 1	3,126	2,148
Double Slope Rock Ramp with Crest 1 and Coffer Dam 2	3,126	2,148
Double Slope Rock Ramp with Crest 1 and Coffer Dam 3	3,126	2,148
Double Slope Rock Ramp with Crest 2	3,126	2,148
Bypass Channel Plan Alternatives		
Bypass Channel 15% Diversion, Weir 1	8,447	7,469
*Bypass Channel 15% Diversion, Weir 2	8,447	7,469
Bypass Channel 10% Diversion, Weir 1	7,087	6,109
Bypass Channel 10% Diversion, Weir 2	7,087	6,109

*Alternatives ultimately carried forward in EA

As described in the Social and Economic Existing Conditions and Social and Economic Impacts sections of the report, the Rock Ramp Alternative and Bypass Channel Alternative are part of a larger project aimed at ensuring continued irrigation of agricultural lands from the Yellowstone Intake Dam while avoiding jeopardy of ESA listed species. It's estimated that approximately 58,000 acres are irrigated with net annual revenues of $3.25 million (2009 dollars). Additionally, the Social and Economic Impacts sections evaluated regional economic impacts to the local economy due to increased expenditures stemming from the construction of the project. Therefore the benefits of this project include HU's, along with continued agricultural production, and the regional economic impacts that would occur during project construction.

Costs

Based upon the engineering designs for the various alternative configurations, project cost estimates were developed. Cost estimates were also calculated for interest during construction (IDC), operations and maintenance (O&M), monitoring, and AM features. Project cost estimates for two alternatives, a bypass alternative and a rock ramp alternative, were reviewed by the Cost Engineering Center of Expertise (Cost PCX). Based upon the updated cost estimates for the bypass alternative and the rock ramp alternative reviewed by the Cost PCX, a percentage adjustment was made to all bypass alternatives to adjust the cost of the alternatives in a manner similar to the reviewed bypass alternative, and likewise an adjustment was made to all other rock ramp alternatives. The adjustment was a 7.34% increase for rock ramp alternatives and 27.05% for bypass alternatives.

Table 2 shows the total construction costs, Interest During Construction (IDC) cost, and total project costs, as well as average annual costs for O&M, average annual monitoring costs and amortized average annual costs. IDC represents the opportunity cost of capital during the construction period. The total project cost, or investment cost is the sum of construction costs plus interest during construction. Average annual O&M costs were estimated based upon the management measures and scales that comprise the plan alternatives. Monitoring is anticipated for the project for the first 8 years only, and varies between $75,000 per year to $425,000 per year, with an annual average of $250,000 for the Rock Ramp Plan Alternative and $255,000 for the Bypass Channel Plan Alternative. The average annual cost includes the total project cost amortized over a 50-year period of analysis plus O&M and monitoring. O&M for both the bypass channel alternatives and the rock ramp alternatives include a combination of concrete weir repair, bank repairs, and one to five percent of rock replacement annually.

Table 2. Costs by Plan Alternatives

Plan Alternatives	Total Construction Cost	IDC (2 years, at 4.0%)	Total Project Cost	Average Annual O&M Cost	Average Annual Monitoring Cost (first 8 years only)	Average Annual Cost (amortized over 50 years, 4.0%)
Rock Ramp Plan Alternatives						
Original Rock Ramp with Crest 1 and Coffer Dam 1	$91,893,035	$3,828,876	$95,721,912	$282,028	$250,000	$4,724,645
Original Rock Ramp with Crest 1 and Coffer Dam 2	$93,537,038	$3,897,377	$97,434,415	$282,028	$250,000	$4,804,125
Original Rock Ramp with Crest 1 and Coffer Dam 3	$85,468,426	$3,561,184	$89,029,610	$282,028	$250,000	$4,414,044
*Original Rock Ramp with Crest 2	$77,088,181	$3,212,008	$80,300,189	$282,028	$250,000	$4,008,897
Shortened Rock Ramp with Crest 1 and Coffer Dam 1	$77,387,879	$3,224,495	$80,612,374	$248,128	$250,000	$3,989,486
Shortened Rock Ramp with Crest 1 and Coffer Dam 2	$79,031,881	$3,292,995	$82,324,876	$248,128	$250,000	$4,068,966
Shortened Rock Ramp with Crest 1 and Coffer Dam 3	$70,963,269	$2,956,803	$73,920,072	$248,128	$250,000	$3,678,884
Shortened Rock Ramp with Crest 2	$62,583,024	$2,607,626	$65,190,650	$248,128	$250,000	$3,273,737
Double Slope Rock Ramp with Crest 1 and Coffer Dam 1	$70,400,022	$2,933,334	$73,333,356	$231,028	$250,000	$3,634,554
Double Slope Rock Ramp with Crest 1 and Coffer Dam 2	$72,044,024	$3,001,834	$75,045,858	$231,028	$250,000	$3,714,034
Double Slope Rock Ramp with Crest 1 and Coffer Dam 3	$63,975,412	$2,665,642	$66,641,054	$231,028	$250,000	$3,323,953
Double Slope Rock Ramp with Crest 2	$55,595,167	$2,316,465	$57,911,633	$231,028	$250,000	$2,918,805
Bypass Channel Plan Alternatives without Adaptive Management						
Bypass Channel 15% Diversion, Weir 1	$53,927,667	$2,246,986	$56,174,654	$220,216	$255,000	$2,827,377
*Bypass Channel 15% Diversion, Weir 2	$52,198,027	$2,174,918	$54,372,945	$220,216	$255,000	$2,743,757
Bypass Channel 10% Diversion, Weir 1	$50,915,340	$2,121,473	$53,036,813	$217,372	$255,000	$2,678,901
Bypass Channel 10% Diversion, Weir 2	$49,185,700	$2,049,404	$51,235,104	$217,372	$255,000	$2,595,280

* Alternatives ultimately carried forward in EA

Cost-Effectiveness/Incremental Cost Analysis (CE/ICA)

Average annual HU’s and the average annual costs are the inputs into IWR Planning Suite 2.0.6.0. CE/ICA results in the identification of cost-effective plan alternatives. A cost-effective plan alternative is defined as one where no other plan alternative can achieve the same level of output at a lower cost, or a greater level of output at the same or less cost. A sub-set of cost-effective plan alternatives are identified as ‘best buy plans.’ Best buy plans are cost-effective plan alternatives that provide the greatest increase in environmental output for the least increase in cost per HU. The plan alternative with the lowest incremental costs per unit of output of all plans is therefore considered the first best buy plan. After the first best buy plan is identified, all larger cost-effective plan alternatives are compared to the first best buy plan in terms of increases in (increments of) cost and increases in (increments of) output. The plan alternative with the lowest incremental cost per unit of output (for all cost-effective plans larger than the first best buy plan) is the second best buy plan. This process of comparison continues until all best buy plan alternatives are identified.

The results of the cost-effective analysis completed for the plan alternatives are shown in Figure 1 and Table 3. The figure shows that there are four cost-effective plan alternatives within the array of 17 plan alternatives, and three of these four plan alternatives are best buy plan alternatives. The first best buy alternative identified in CE/ICA is always the No Action Plan Alternative. The second best buy alternative is the Bypass Channel Plan Alternative with 15% diversion and weir design two. The third best buy alternative is the Rock Ramp Plan Alternative with the original ramp design and crest design two. The Bypass Channel Plan Alternative with 10% diversion and weir design two is a cost-effective alternative, but because the Bypass Channel Plan Alternative with 15% diversion and weir design two has a lower cost per habit unit output it is not a best buy plan alternative.

Figure 1. CE/ICA Results for Yellowstone Intake Plan Alternatives

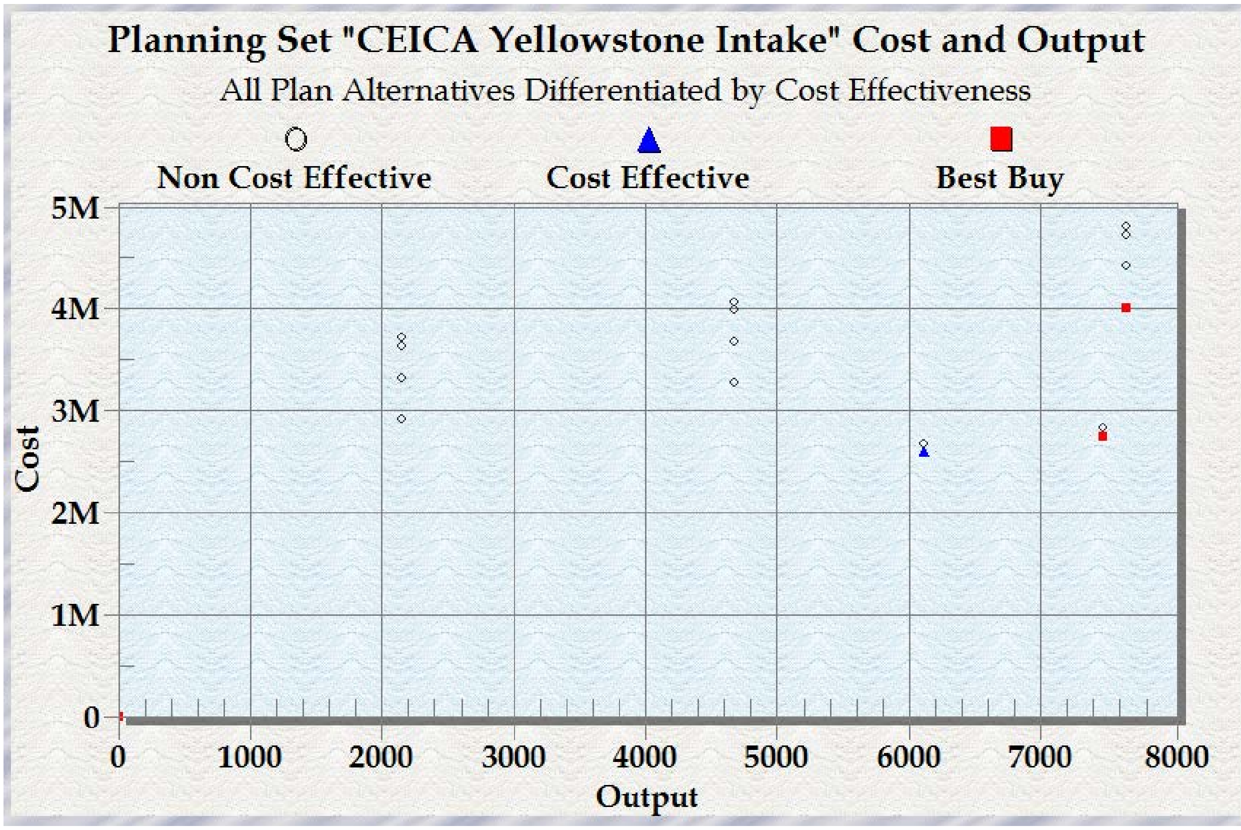


Table 3. CE/ICA Results for Yellowstone Intake Plan Alternatives

Plan Alternatives	Average Annual Cost	Output (HU's)	Cost Effective
No Action Plan	$0	0	Best Buy
Double Slope Rock Ramp with Crest 2	$2,918,805	2,148	No
Double Slope Rock Ramp with Crest 1 and Coffer Dam 3	$3,323,953	2,148	No
Double Slope Rock Ramp with Crest 1 and Coffer Dam 1	$3,634,554	2,148	No
Double Slope Rock Ramp with Crest 1 and Coffer Dam 2	$3,714,034	2,148	No
Shortened Rock Ramp with Crest 2	$3,273,737	4,679	No
Shortened Rock Ramp with Crest 1 and Coffer Dam 3	$3,678,884	4,679	No
Shortened Rock Ramp with Crest 1 and Coffer Dam 1	$3,989,486	4,679	No
Shortened Rock Ramp with Crest 1 and Coffer Dam 2	$4,068,966	4,679	No
Bypass Channel 10% Diversion, Weir 2	$2,595,280	6,109	Yes
Bypass Channel 10% Diversion, Weir 1	$2,678,901	6,109	No
Bypass Channel 15% Diversion, Weir 2	$2,743,757	7,469	Best Buy
Bypass Channel 15% Diversion, Weir 1	$2,827,377	7,469	No
Original Rock Ramp with Crest 2	$4,008,897	7,649	Best Buy
Original Rock Ramp with Crest 1 and Coffer Dam 3	$4,414,044	7,649	No
Original Rock Ramp with Crest 1 and Coffer Dam 1	$4,724,645	7,649	No
Original Rock Ramp with Crest 1 and Coffer Dam 2	$4,804,125	7,649	No

Incremental cost analysis was completed on the two plan alternatives identified as best buys through the cost-effective analysis. The first increment is the best buy plan alternative for the Bypass Channel Plan Alternative and the second increment is the best buy plan alternative for the Rock Ramp Plan Alternative. As shown in Figure 2 and Table 4, there is a steep increase in the cost per HU between the Bypass Channel Plan Alternative and the Rock Ramp Plan Alternative. The Bypass Channel Plan Alternative provides 7,469 HU's at an incremental cost per HU of $367, while the Rock Ramp Plan Alternative provides an additional 180 HU's (beyond the 7,469 HU's) at an incremental cost per HU of $7,029. Based upon the incremental cost analysis, along with consideration of the overall cost of the plan alternatives, the recommended plan for implementation is the Bypass Channel Plan Alternative with 15% diversion and weir option two. The total project cost for the Rock Ramp Plan Alternative with the original rock ramp and crest option 2 is $77,088,181, while the total project cost for the Bypass Channel Plan Alternative with a 15% diversion and weir option 2 is $52,198,027.

Figure 2. Incremental Cost Analysis for Best Buy Plan Alternatives

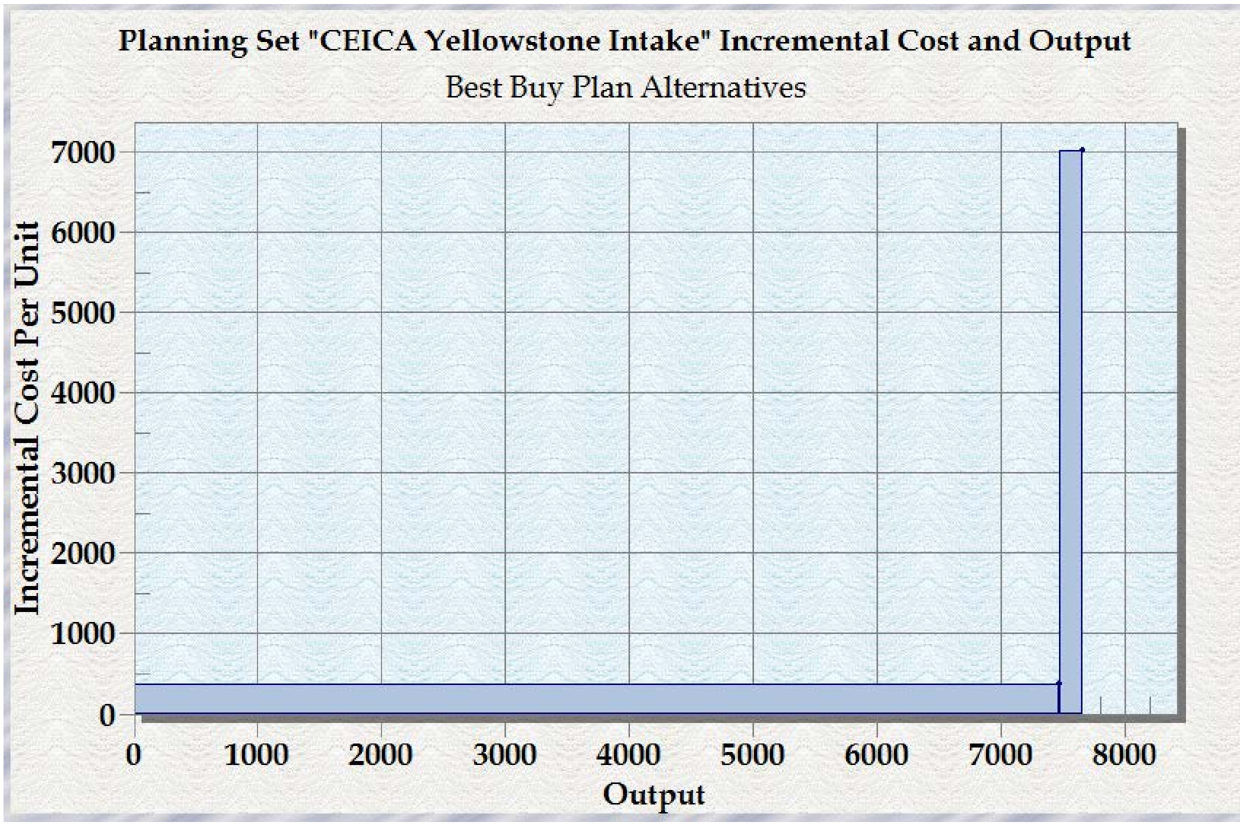


Table 4. Incremental Cost Analysis Results

Alternative Plan	Output (HU's)	Average Annual Cost ($1,000)	Average Cost ($1,000/HU)	Incremental Cost	Incremental Output (HU's)	Incremental Cost per Output
No Action	0	0				
Bypass Channel 15% Diversion, Weir 2	7,469	$2,743,757	$367	$2,743,757	7469	$367
Original Rock Ramp with Crest 2	7,649	$4,008,897	$524	$1,265,140	180	$7,029

CE/ICA with Bypass Channel Adaptive Management

As mentioned previously, monitoring of the project is anticipated. Monitoring will be conducted to determine if the project is functioning as expected and to see if any adjustments are needed. If necessary, changes to structures may be required to ensure that the desired project outcome is achieved. These changes are described in the AM Plan in Appendix J.

In order to evaluate the sensitivity of the CE/ICA results to the potential adoption of AM actions, the CE/ICA was recalculated with AM measures added to the Bypass Channel Plan Alternatives only. AM was added to these plans only to see how it would change the CE/ICA results in relation to the Rock Ramp Plan Alternatives with no AM. It should be noted, that AM features may also be needed, therefore a Rock Ramp Alternative Plan was constructed, but since the Rock Ramp Alternative Plan is not the preferred alternative, this analysis focused on verifying whether or not a Bypass Channel Alternative Plan would remain the preferred alternative even if AM features are required, rather than evaluating how all alternatives change with AM.

Monitoring of fish species, particularly pallid sturgeon, will be conducted for 8 years after construction is completed. Depending upon the monitoring results, potential AM measures may need to be completed to ensure the Bypass Channel Alternative is operating as expected. The AM measures and scales currently under consideration along with their associated costs are shown in Table 5. One or all of the options may be required, so for the purposes of the CE/ICA the total AM cost is included.

Table 5. Bypass Channel Adaptive Management

Adaptive Management Measures and Scales	Cost
Option 1 - Flow Augmentation Structure	$4,011,407
Option 2 - Rock Manipulation 1,000 ton	$102,223
Option 3 - Rock Manipulation 10,000 ton	$271,802
Option 4 - Riprap Replacement	$256,028
Total	$4,641,460

Table 6 shows the cost of the Bypass Channel Alternative Plans with the AM cost included. Since AM options would be added to the project, based upon monitoring results, it is assumed that the AM options would be constructed during year five of the project. This additional cost for year five has been factored in to the annual average cost amortized over the 50-year period of analysis, increasing the expected average annual cost for all Bypass Channel Alternative Plans by approximately $170,271 annually, over their average annual cost without AM features.

The results of the cost-effective analysis completed including AM for the Bypass Channel Plan Alternatives are show in Figure 3 and Table 7. Similar to previous results, the figure shows there are four cost-effective plan alternatives, with three of these four plan alternatives identified as a best buy alternative. The first best buy plan alternative identified in CE/ICA is always the No Action Plan Alternative. The second best buy plan alternative is the Bypass Channel Plan Alternative with 15% diversion and weir design two and AM options included. The third best buy plan alternative is the Rock Ramp Plan Alternative with the original ramp design and crest design two. The Bypass Channel Plan Alternative with 10% diversion, weir design two with AM, is a cost-effective alternative, but because the Bypass Channel Plan Alternative with 15% diversion and weir design two with AM has a lower cost per habit unit output it is not a best buy alternative.

Table 6. Costs by Alternative with Adaptive Management

Plan Alternatives	Total Construction Cost	Interest During Construction (2 years at 4 percent)	Total Project Cost	AM Cost	Average Annual O&M Costs	Average Annual Monitoring (first 8 years only)	Annual Average Costs (amortized over 50 years, 4.0%)
Bypass Channel Plan alternatives with AM							
Bypass Channel 15% Diversion, Weir 1 with AM	$58,381,631	$2,432,568	$60,814,199	$4,453,963	$220,216	$255,000	$2,997,648
Bypass Channel 15% Diversion, Weir 2 with AM	$56,651,990	$2,360,500	$59,012,490	$4,453,963	$220,216	$255,000	$2,914,028
Bypass Channel 10% Diversion, Weir 1 with AM	$55,369,304	$2,307,054	$57,676,358	$4,453,963	$217,372	$255,000	$2,849,280
Bypass Channel 10% Diversion, Weir 2 with AM	$53,639,663	$2,234,986	$55,874,649	$4,453,963	$217,372	$255,000	$2,765,660

Figure 3. CEICA Results for Yellowstone Intake Plan Alternatives with Bypass Channel Plan Alternatives including Adaptive Management

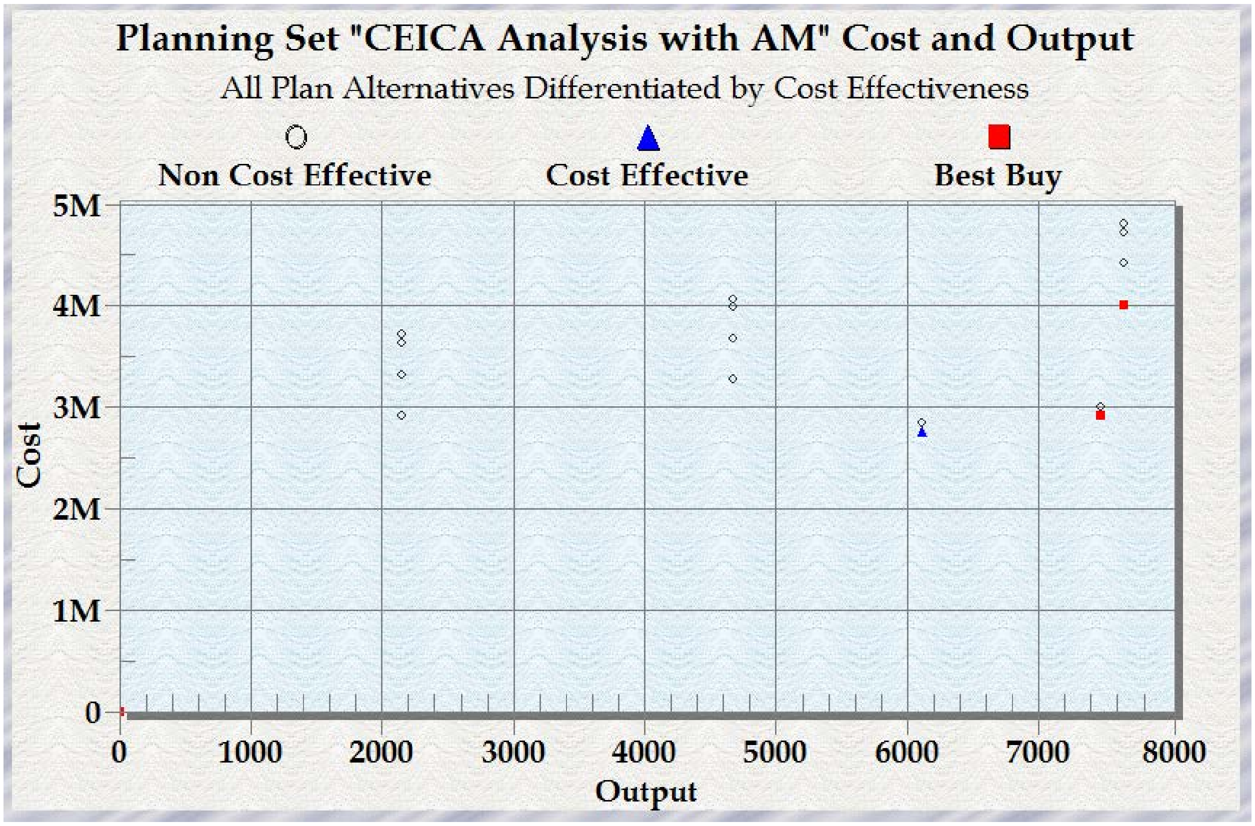


Table 7. CEICA Results for Yellowstone Intake Plan Alternatives, Bypass Channel Plan Alternatives with AM

Name	Average Annual Cost	Average Annual Net Output	Cost Effective
No Action Plan	$0	-	Best Buy
Double Slope Rock Ramp with Crest 2	$2,918,805	2,148	No
Double Slope Rock Ramp with Crest 1 and Coffer Dam 3	$3,323,953	2,148	No
Double Slope Rock Ramp with Crest 1 and Coffer Dam 1	$3,634,554	2,148	No
Double Slope Rock Ramp with Crest 1 and Coffer Dam 2	$3,714,034	2,148	No
Shortened Rock Ramp with Crest 2	$3,273,737	4,679	No
Shortened Rock Ramp with Crest 1 and Coffer Dam 3	$3,678,884	4,679	No
Shortened Rock Ramp with Crest 1 and Coffer Dam 1	$3,989,486	4,679	No
Shortened Rock Ramp with Crest 1 and Coffer Dam 2	$4,068,966	4,679	No
Bypass Channel 10% Diversion, Weir 2 with AM	$2,765,660	6,109	Yes
Bypass Channel 10% Diversion, Weir 1 with AM	$2,849,280	6,109	No
Bypass Channel 15% Diversion, Weir 2 with AM	$2,914,028	7,469	Best Buy
Bypass Channel 15% Diversion, Weir 1 with AM	$2,997,648	7,469	No
Original Rock Ramp with Crest 2	$4,008,897	7,649	Best Buy
Original Rock Ramp with Crest 1 and Coffer Dam 3	$4,414,044	7,649	No
Original Rock Ramp with Crest 1 and Coffer Dam 1	$4,724,645	7,649	No
Original Rock Ramp with Crest 1 and Coffer Dam 2	$4,804,125	7,649	No

Similar to the previous incremental cost analysis, incremental cost analysis was completed on the two plan alternatives identified as best buys through the cost-effective analysis. The first increment is the best buy plan alternative for the Bypass Channel Plan Alternative with AM and the second increment is the best buy alternative for the Rock Ramp Plan Alternative (without AM). As shown in Figure 4 and Table 8, there is still a steep increase in the cost per HU between the Bypass Channel Plan Alternative with AM and the Rock Ramp Plan Alternative. The Bypass Channel Plan Alternative with AM provides 7,469 HU's at per unit cost of $390, while the Rock Ramp Plan Alternative provides an additional 180 HU's (beyond the 7,469 HU's) at a per unit cost of $6,083. The original incremental cost analysis reported similar results, with the first 7,469 HU's with the Bypass Channel Plan Alternative (without AM) costing of $367, and the Rock Ramp Plan Alternative providing an additional 180 HU's with a per unit cost of $7,029. Thus, even with AM, a similar relationship exists between the two best buy plan alternatives, with the Rock Ramp Plan Alternative requiring a steep increase in expenditures in order to achieve a small increase in HU outputs.

Figure 4. Incremental Cost Analysis for Best Buy Plan Alternatives, Bypass Channel Plan Alternatives with AM

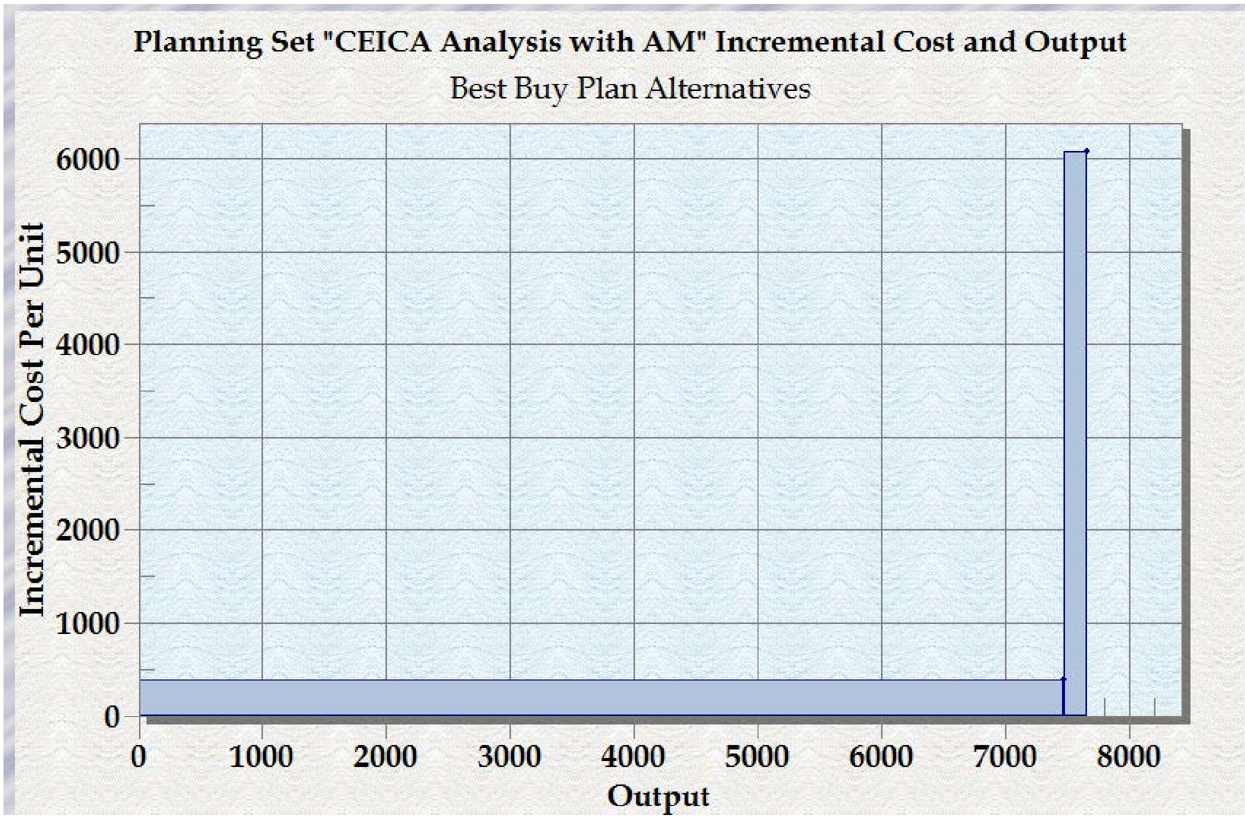


Table 8. Incremental Cost Analysis for Best Buy Plan Alternatives, Bypass Channel Plan Alternatives with AM

Name	Output (HU's)	Average Annual Cost ($1000)	Average Cost ($1,000/HU)	Incremental Cost	Incremental Output (HU)	Incremental Cost per Output
No Action	0	0				
Bypass Channel 15% Diversion, Weir 2	7,469	$2,914,028	$390	$2,921,028	7,469	$390
Original Rock Ramp with Crest 2	7,649	$4,008,897	$524	$1,094,869	180	$6,083

Conclusions

The CE/ICA was completed to compare plan alternatives under consideration for the project site. The average annual cost for the Bypass Channel Plan Alternative is between $2.7 million to $2.9 million annually depending upon whether AM measures are required. As discussed in the previous sections, the Bypass Channel Plan Alternative would provide 7,469 HU's, for an incremental cost between $367 to $390 depending on whether or not AM measures are necessary, while the Rock Ramp Plan Alternative would provide 7,649 HU's total for an incremental cost of between $6,083 to $7,029 for the 180 additional HU's. Considering the steep increase in incremental cost to achieve a slightly higher level of HU outputs, the Bypass Channel Plan Alternative with 15 percent diversion and weir design two is the preferred alternative, even if AM measures are required.

Because the No Action Alternative was assumed to continue operation of the existing Intake structure, no effort was made to compare average annual costs of the preferred alternative to average annual benefits from irrigation. Instead the CE/ICA focused on fish passage and habitat as expressed by HU's.

Fish Passage Benefits Analysis

Intake Diversion Dam Fish Passage Project, Lower Yellowstone River, Intake, Montana

Description: Intake Diversion Dam likely has impeded upstream migration of pallid sturgeon and other native fish for more than 100 years. The best available science suggests that the diversion dam is a partial barrier to some fish species (Helfrich et al., 1999; Jaeger et al., 2004; Backes et al., 1994; Stewart, 1986, 1988, 1990, 1991). It is likely a total barrier to other fish species, such as pallid sturgeon, due to increased turbulence and velocities associated with the rocks at the dam and downstream (Jaeger et al., 2005; Fuller et al., 2008; Helfrich et al., 1999; White & Mefford, 2002; Bramblett & White, 2001; U.S. Fish and Wildlife Service (Service), 2000, 2003, 2007).

Restoration of passage at intake accomplishes several things from a pallid sturgeon recovery perspective:

- it opens up an additional 165 miles of Yellowstone River habitat currently unavailable to the pallid sturgeon;
- much of this newly available habitat would consist of swift water over gravel and cobble substrates, thought to be important to pallid sturgeon for spawning (Service, 1993); and
- the additional river miles would provide longer drift distances and greater amounts of settling habitat for pallid sturgeon larvae between the point of spawn and the headwaters of Lake Sakakawea, which is currently thought to be unsuitable rearing habitat (Braaten et. al., 2008).

While the main focus of a fish passage project at Intake Dam is pallid sturgeon recovery, other migratory species of fish are likely to also benefit from the project, including fish that are important from a management perspective by the state of Montana, such as paddlefish, sauger, and blue sucker, all of which are listed as state species of concern.

In planning an ecosystem restoration project such as this fish passage project, there is no monetary measure of benefits to compare alternatives. However, where outcomes can be described and quantified in some dimension, cost effectiveness and incremental cost analysis can be used to assist on the plan selection process. Cost effectiveness analysis seeks to answer the question: given an adequately described objective, what is the least-costly way of attaining the objective? Incremental analysis is the process of examining increments of plans or project features to determine their incremental costs and incremental benefits, such that plans deserving of further consideration are identified in an efficient manner. Following this process helps reduce ambiguity in the identification of the most efficient and least-costly plans, and can be very useful in determining and describing whether an alternative should be recommended.

The Fish Passage Connectivity Index (FPCI) is a simple arithmetic index that was originally developed to evaluate ecosystem outputs of alternative measures for fish passage improvements at lock and dams on the Upper Mississippi River System (UMRS) for cost effectiveness and incremental analysis. The index is calculated as:

$$\epsilon = \frac{\Sigma \text{ i} \ldots \text{n } [(E_i \text{ x } U_i \text{ x } D_i)/25]}{n}$$

Where,

- Є = Fish Passage Connectivity Index
- i = A migratory fish species that occurs in pool or reach below the dam
- n = Number of fish species included in the index
- E_i = Chance of encountering the fishway entrance is a calculated value ranging from 1 to 5, where 5 = highly likely; 3 = moderate probability; 1 = unlikely
- U_i = Potential for species i to use the fish passage pathway or fishway (5 = Good, 3 = Moderate, 1 = Poor, 0 = None) considering adult fish swimming performance and hydraulic conditions within the fishway or fish travel pathway
- D_i = Duration of availability, the fraction of the upriver migration period for fish species i that the passage pathway is available. D_i incorporates a risk component (i.e., the potential failure of an alternative to perform or be available during a critical fish movement period)

Although the model was developed to measure benefits of fish passage afforded to fish in the UMRS, the model is applicable (with slight adjustments) to fish passage projects on other large river systems, especially those with very similar fish communities. This model, with very minimal adjustment, was utilized as a planning tool for comparing benefits of alternative measures for provide fish passage at Intake Dam. This report describes the steps taken (and adjustments that were made) in utilizing the FPCI to demonstrate ecological benefits of the Yellowstone River Intake Dam fish passage alternatives.

Information from experts in the field has been considered during the completion of the FPCI for Intake. In 2006 the Service created a Biological Review Team (BRT) of fisheries biologists and engineers with expertise in fish passage and pallid sturgeon to review preliminary alternatives for fish passage and canal headworks screening at Intake Dam. The BRT includes representatives from the U.S. Geological Survey (USGS), Service, Montana Fish Wildlife and Parks, and the Bureau of Reclamation. Among the numerous activities with which the BRT has been involved during the Intake Dam study, the BRT was tasked with analyzing how well the hydraulic performance of the alternatives developed for the initial Environmental Assessment (No Action, Rock Ramp, and Relocate Main Channel) met the passage needs of pallid sturgeon. The analysis used a scoring criteria developed by the BRT (2009) and hydraulic modeling (Corps, 2009) to score alternatives on relative comparison scales of the alternatives ability to facilitate pallid sturgeon passage. These criteria, while not incorporated into the FPCI model, are useful in confirming that variables in the FPCI captured important considerations previously considered by the BRT, or to help understand where the FPCI model might not have considered an important variable. For example, information provided by the BRT in its alternatives evaluation (2009) has been helpful in providing confirmation that swimming abilities as discussed in the FPCI model are in agreement with current thinking by scientists with specific experience with pallid and shovelnose sturgeon on the Yellowstone River. As another example, it has also been useful in highlighting that the FPCI does not consider depth as a fish passage variable, whereas the BRT considers this as an important consideration for pallid sturgeon, thus providing an opportunity to highlight this as an uncertainty needing consideration in decision making beyond the output from the FPCI. Although the FPCI variables include a fair level of uncertainty, the model is thought to provide a good relative comparison of benefits among alternatives for fish passage planning purposes. There are numerous areas within this report that attempt to capture BRT recommendations or comments received to date that help capture uncertainties.

1. **Description of Yellowstone River Intake Fish Passage Modeling Using FPCI model**
    a. <u>Identify fish to be included for analysis, and their associated habitat preferences, swimming behaviors, and swimming abilities.</u>
        i. Information for each of these parameters is found in Table 1.
        ii. For ensuring a good comparison of benefits across fish passage alternatives, fish species to be used in the FPCI modeling effort were selected based on two criteria. First, species were selected because they represent the migratory species typically found in the Yellowstone River at Intake Dam. Secondly, the species provide good representation of the various guilds of fish based on their various migration behaviors (benthic (8), pelagic (2), and littoral (3) and swimming abilities (strong (6), medium (5), weak (2)).
        iii. Critical current velocities (Ucrit) for prolonged swimming by adult fish used in the FPCI (Table 1) were estimated based on literature reports on fish swimming performance trials for the migratory fishes (Wilcox et al., 2004). These data were considered reasonable, and applied directly to the Yellowstone River. This information was used to estimate the potential (Ui) for species i to be physically and behaviorally able to travel upstream through the alternative fishways and travel pathways for the FPCI.
        iv. The association of species to habitat type was acceptable as presented in the FPCI with one slight adjustment. White sucker, blue sucker and river carpsucker are shown only to be associated with main channel border habitats in the original FPCI. However, for purposes of this study, these species were also assumed to utilize main channel habitats. The "main channel" habitat type in the UMRS (somewhat lentic navigation pool) is very different than main channel habitats in the Yellowstone River, and may be the reason those species were not associated with that habitat type. These three species are known to utilize main channel habitats available in the Yellowstone and Missouri River systems, and as such, were associated with it for purposes of this study.
        v. Fish species of special concern are well represented. Species of special concern that are utilized in this analysis include the shovelnose sturgeon (as surrogate to pallid sturgeon, which is federally-listed as endangered), paddlefish, sauger, and blue sucker. Habitat loss and the presence of migratory barriers are largely related to all of these fish being listed as a species of special concern to the state of Montana, and as such, make very good species for comparing between fish passage alternatives.
        vi. No fish species were added to the fish previously contained in the model, and therefore, no major work was required to adjust the species list, or

develop the biological data for new species that are required by the model to produce useful model outputs. While pallid sturgeon are not represented in the FPCI model for the UMRS, the assumption is being made that the shovelnose sturgeon, which is presented in the model, can represent both itself and the pallid sturgeon for planning purposes.

b. <u>Identify habitat acres made available by passage.</u>

   i. Habitat Units are calculated in the model by multiplying the FPCI by the total acres of available preferred habitat upstream of Intake Dam for each species. For purposes of this report, those habitat acres were figured for the river upstream to Cartersville Dam, the next migration barrier to fish. Habitat in this stretch of river is available from GIS data developed for the Yellowstone River Corridor Cumulative Effects analysis, a separate study being completed under the Corps' General Investigations authority.

   ii. Habitat types as laid out in the GIS fisheries habitat data include the following primary categories:

      1. ***Scour* – (SC)** Scour pool occurring in otherwise unconstrained river channel.
      2. ***Bluff* – (BL)** Scour pool located at the base of a bedrock bluff. Indicates a relatively permanent pool location bounded by a geologic constraint.
      3. ***Terrace* – (T)** Scour pool located at the base of a terrace (Quarternary Alluvium).
      4. ***Riprap Bottom* – (RRB)** Scour pool occurring in riprap constrained channel where riprap is located in the middle of the active channel area.
      5. ***Riprap Margin* – (RRM)** Scour pool occurring in riprap constrained channel where riprap is located at the edge of the active channel area.
      6. ***Channel Crossover* – (CC)** A transitional unit where the river is translating from one bendway or pool to the next.
      7. ***Bedrock* – (BED)** Channel is controlled by bedrock bed.
      8. ***Secondary Channel* – (2C)** Undifferentiated low flow channel. No additional habitat typing is defined, though the channel likely contains areas of pool and riffle.
      9. ***Secondary Channel Seasonal* – (2CS)** Secondary channel high flow channel
      10. ***Point Bar* – (PB)** Areas in the bank full lines that show aggradation associated with the insides of a bendway. Can include exposed gravel, or areas with vegetation, as long as they lie within the bank full area.
      11. **Side Bar – (SB)** Areas in the bank full lines that show aggradation along the sides of a channel. These bar areas create channel sinuosity at low flows but are inundated at higher or bank full flows. Can include exposed gravel, or areas with vegetation, as long as they lie within the bank full area.

12. **Mid-Channel Bar – (MCB)** Areas in the bank full lines that show aggradation, creating islands within the low flow area. Can include exposed gravel or areas with emergent vegetation, as long as they lie within the bank full area.
13. **Dry Channel – (DC)** This is a general category for areas within the bank full boundaries that do not fit into Point Bar, Side Bar, or Mid-channel Bar categories. They are generally associated with split flows around islands where there is exposed channel bed at low flow, but does not appear to be strictly depositional in nature, though they could still have some depositional characteristics. Can include exposed gravel or areas with vegetation, as long as they lie within the bank full area.
14. ***Dam*** – Habitat unit is influenced by a dam in the main channel.

iii. As depicted in Table 2, these data were cross referenced to the habitat categories as laid out for the UMRS, allowing Yellowstone River habitat acreages to be compatible with the existing layout as presented in the FPCI model. The habitats for the UMRS include:

1. Contiguous Floodplain Lake
2. Main Channel Border
3. Main Navigation Channel
4. Secondary Channel
5. Tertiary Channel
6. Tributary Channel

iv. Figure 1 presents an example of the fisheries habitat as represented in the Cumulative Effects GIS data.

c. Identify Windows of Opportunity for Upstream Fish Passage

i. The coincidence of when fish passage is physically possible at a dam with the timeframe of when fish migration occurs affects fish passage opportunity under existing and without-project future conditions. This information is used to estimate the duration of availability **(Di)** for the baseline condition and each alternative in the FPCI.

ii. Intake Dam Passability

1. Duration of fish passage availability for the No Action Alternative at locks and dams on the Mississippi River is influenced by the coincidence of open river (dam gates out of the water). Similarly, existing passage at Intake Dam appears to coincide with certain periods of time as well, mainly during high flow (Jaeger et al., 2005; Helfrich et. al., 1999). However, considerations are a bit different at Intake as it is not a lock and dam system, and thus, “percent probability of open river conditions” is not applicable.
2. In order to utilize the FPCI model as it is currently structured, it was necessary to establish a similar estimate of probability that fish passage conditions are available at Intake. Based on available literature (Jaeger et al., 2005; Helfrich et al., 1999), anecdotal information, and best professional judgment, probabilities that passage opportunities exist were assigned on a weekly basis as a

function of flow, with highest probabilities being associated with the peak of the typical hydrograph, and very small (1%) probabilities being attributable to the timeframes outside of the peak river flow (September-April). Table 3 shows the probability of passage as entered into the FPCI model to represent the existing condition.

iii. Seasonality of Fish Migration

1. Basic information on fish migratory behaviors and timing found in the FPCI model and associated model documentation is assumed to be transferable to the Yellowstone River. Information about the seasonal upriver movements of migratory fishes found in the FPCI (Lock & Dam (L&D) 22 location) are based on fisheries literature, consultations with fisheries managers and Mississippi River water temperature records (adapted from Wilcox et al., 2004). The estimated spawning periods are based on water temperatures reported in the fisheries literature (Becker, 1983; Pflieger, 1975, 1997; Scott & Crossman, 1973).
2. While the science behind migration timing is similar, the actual time of year when migration takes place on the Yellowstone River is different than on the Mississippi River as established in the FPCI for Saverton Missouri, L&D 22. Movement and spawning periods found in the FPCI (for the L&D 22, Saverton, Missouri) were pushed back 3-4 weeks later in the year as migrations tend to take place later in the year for cooler, more northern latitudes. Other information considered in establishing the migratory timeframes for the Yellowstone River at Intake Dam included data found in Elser et al. (1977), anecdotal data from George Jordan (Mike Backes, Montana Fish Wildlife and Parks survey data) and best professional judgment. Migratory timeframes as utilized in the FPCI modeling for the Intake Dam project are shown in Table 4.

d. <u>Fish Passage Connectivity Input Data</u>

i. Chance that Fish Encounters Fish Passage Alternative (E_i)

1. E_i simulates the relationship between fishway size (F_s) and ability of a fish to encounter the fishway entrance location (F_l) within the FPCI. (E_i) is a calculated value ranging from 1 to 5, with 5 being highly likely, and 1 being unlikely. The relationship is represented by the following equation: $E_i=(F_s+F_l)/2$.

ii. Determine Potential for Fish to Encounter Passage Alternative (F_l)

1. F_l is used to assess the suitability of the fishway entrance location for each fish guild based on swimming performance and behavior. As described in the FPCI, swimming performance and migration behavior are important because they indicate the route as well as vertical and horizontal position within the flow field that a fish would generally select. Guilds of fish species, as defined by swimming performance and behavior, are shown in Table 5. The pre-construction monitoring data and the professional judgment of

an interagency group of large river fisheries biologists was used for the FPCI development on the UMRS to assign a F_l value to each guild (Table 6). These values fell into three categories; 5 indicated that the entrance would be encountered by a significant portion of the population, 3 indicated that the entrance may be encountered, and 1 indicated that it was unlikely that the entrance would be encountered. Values for F_l as detailed for the FPCI on the UMRS require slightly different consideration for applicability to the Yellowstone River. While fish guilds would generally display similar behavior within both large river settings, habitats found on the Upper Mississippi as defined for this variable (i.e. main channel, main channel border, and so on) are much more distinct from one another than on the Yellowstone River. For example, the main channel and main channel border near shore areas are much more distinct from each other in a navigation pool setting which contains a lot of littoral area versus a setting such as the free flowing Yellowstone River, where the main channel, main channel border, and near shore areas are not nearly as segregated. As such, the full width rock ramp alternative, which is considered a main channel fishway, was scored as if it were a "main channel border-near channel" option, as those scores were considered to more truly reflect the likelihood of the fishway to be encountered by the guilds of fish being considered in this effort.

iii. Determining the Size of Fish Passage Alternative (F_s)

1. This parameter is the size of the fishway relative to the discharge of the river under low flow conditions. While fishways on small rivers might easily be designed to pass large fractions of total river discharge, it is much more difficult to capture large proportions of flow on larger river systems. For large systems, Larinier (2000) recommends for attractive flows that fishways be designed to capture 10% of minimum flow and 1-1.5% of higher flows. Based on Lariner, the FPCI originally established the following range of inputs for F_s on the UMRS: 5 was assigned to fishway designs that pass 10% of the low flow discharge, 4 = 8%, 3 = 5%, 2 = 2%, and 1 = less than 2%. These values were NOT used for the Intake Fish Passage project. On the Yellowstone River, it was recommended by the BRT that focus of fish passage alternatives should be on options capable of conveying up to 30% of river flow. Therefore the following range of inputs for F_s were established for the Intake project; 5 was assigned to fishway designs that pass 30% or more of the low flow discharge, 4 = 25% percent, 3 = 20%, 2 = 15%, and 1 = equal to or less than 10%.
2. This BRT recommendation was based primarily on migrating Yellowstone River pallid sturgeon using predominately mainstem habitats (i.e., those with a relatively high proportion of the river's discharge; Montana Fish Wildlife & Parks (MFWP) unpublished

data). Additional data that were considered by the team included monitoring of tagged fish in the Yellowstone and lower Missouri Rivers, pallid habitat usage studies (i.e. Bramblett, 1996; Bramblett & White, 2001) and the lack of shovelnose sturgeon passage at the Tongue &Yellowstone (T&Y) bypass on the Tongue River, MT (MFWP, unpublished data) which can convey approximately 6-8% of the river discharge.

3. The size of fishway for each alternative is listed in Table 7. The Rock Ramp Alternatives and the No Action Alternative all pass full flows of the river and received inputs of 5, whereas the main variation between bypass alternatives is percent of full flow passed. The 10% flow alternative received a 1, and the 15% flow alternatives received an input of 2.

iv. Determine the Potential (U_i) for Fish to Use Alternative Fish Passage Measures, and the Duration of Availability (D_i) of the Alternative Measures.

1. The potential for a fish to pass upriver past an obstacle is dependent on its swimming performance and the hydraulic conditions that are encountered. Critical current velocities (U_{crit}), or the speed at which a fish can maintain prolonged swimming by adult fish used in this analysis are found in Table 1. The minimum current velocity at the hydraulic steps for each alternative measure was compared to the U_{crit} speed for each migratory fish species. If velocities did not exceed burst speeds (generally 3 to 4 times the U_{crit} speed for prolonged swimming) in small areas and didn't exceed the U_{crit} speed for the majority of the hydraulic step area, the U_i was scored a 5. If velocities exceed U_{crit} speed in the majority of the hydraulic step area but did not exceed burst speed it was scored a 3, and if velocity exceeded burst speeds in the majority of the hydraulic step areas it was scored a 1.

   a. The current velocities for the existing condition and the bypass alternatives are shown in Figure 2. The No Action Alternative is shown for flow of 40,000 cfs, and is taken from the Reclamation's Lower Yellowstone Intake Diversion Dam Fish Bypass Channel Entrance and Exit Pre-appraisal Study (Reclamation, 2012). For purposes of this study, it is being used to show modeled flow velocities over the face of the existing dam. The Bypass Channel Alternative also provides a typical cross section of the bypass channel, as well as a plan view velocity map for the downstream bypass inlet. This information was taken from Appendix A2. Rock ramp alternatives are shown in Figure 3. The figure depicts information regarding water velocities and percent of the rock ramp areas containing ranges of velocities that generally coincide with U_{crit} values described in the FPCI. Figure 3 also shows depth contours, and areas containing velocities of 4 feet/second and depths of 1 meter for 40,000 cfs and 30,000 cfs discharge conditions. While not directly applicable to the FPCI, they directly relate to recommendations of the BRT, as they are considered to be conditions that together are important in facilitating pallid sturgeon migration. While important considerations, they are not utilized by the FPCI in calculating benefits.

    b. Scores for U_i can be found in Table 8. Explanation of the scores are provided below.
        i. Flow velocities over the existing dam face are well over 10 feet/second, although the existing rock field is much shorter than any of the other fish passage alternatives. As such, it does not score greater than 1 for the U_i variable.
        ii. Rock ramp fish passage structures all showed reduced velocities vs. the existing condition, but all options generally exceeded the U_{crit} of most species over a majority of the hydraulic step. Of the rock ramp options, the Original Rock Ramp C.1. alternative appears to be the most accommodating to fish passage, although it really only accommodates the U_{crit} of the two strongest swimming species over a majority of the hydraulic step.
        iii. The 10% and 15% fish bypass velocity modeling indicates that both provide velocities not greater than the U_{crit} for a large proportion of the channel.
        iv. While not a consideration in the modeling, both bypass alternatives would also have much less turbulence associated with them, as they would both provide channels that are very much like existing side channels of the Yellowstone River in terms of gradient and substrate.

2. Duration of Availability (D_i) of the fish passage structure is the proportion of time when both the fish passage structure is physically available for passage, and migration is actually occurring for a particular species of fish.
    a. Table 9 identifies when fish passage alternatives are available to fish for each alternative.
    b. D_i for the existing condition is calculated as the fraction of time that upriver movement may generally occur (Table 4) when the physical conditions at the dam allow for passage. This is why the Di is highly variable between each species of fish.

c. The D_i for all the other alternatives is available over 100% of the time (ranked a 1) when passage is occurring. This is because the fish passage structures are all designed to be available across most flows, especially during the migration season.

e. <u>Calculate Fish Passage Connectivity Index and Habitat Units for Each Alternative</u>

i. Data were input into the FPCI to calculate indices for each passage alternative. The connectivity index for each species by alternative is shown in Table 10.

1. Several results are interesting to note.

a. The model does indicate that the No Action Alternative has an FPCI greater than zero, indicating that some fish can currently pass.

b. All alternatives have a much greater connectivity index than the No Action Alternative.

c. Several species show a higher connectivity index (including shovelnose and pallid sturgeon) for the rock ramp alternatives over the bypass channel.

i. This is most strongly pronounced for the walleye and paddlefish, and appears to be tied to the fact that they are the strongest swimmers of all fish species evaluated.

ii. For species that show only moderately higher connectivity index, such as the sturgeon, are likely due to the fact that the rock ramp alternatives capture the full flow of the river.

d. The overall average connectivity indexes for all species combined are higher for the rock ramp alternatives than the bypass channel alternatives.

ii. To compute habitat units for each species of fish under each alternative, the FPCI is multiplied by total habitat that is newly available to each species of fish. The overall HUs computed for each alternative is the average of HUs figured for each species. Table 10 also summarizes this output.

f. <u>Other factors influencing fish passage success</u>

i. It should be mentioned that in addition to the basic considerations made in the FPCI scoring, other factors play a role in the ability of fish passage alternatives to be successful. As such, it would be recommended that these items be given some consideration in the adaptive management plan. These other factors include, but are not necessarily limited to the following:

1. Rock ramp fish passage structures are very long hydraulic steps, with lengths ranging from 1,000 to 1,600 feet. While the rock ramp modeling shows that a majority of the rock ramps might accommodate velocities in a range greater than the U_{crit}, but less than burst speeds, passage may still be problematic. It is likely that

for most fish, swimming in the range of their burst speeds over the length of these passage structures could lead to passage success less than indicated by this model variable.

2. Depth may also play an important role in accommodating passage from a physical and behavioral standpoint. The BRT recommended that designs of fish passage structures should not only target flows of less than 4 feet/second, but also accommodate depth of 1 meter (BRT, 2009).
3. The rock ramps likely include significant amounts of turbulence. While this may not be a significant factor for some fish, it is very much a factor for pallid and shovelnose sturgeon. Based on their physiology, shovelnose and pallid sturgeon are built to hold station and swim along the bottom of fast flowing rivers (body appression to flat, horizontal substrate), and have been shown to hold station, or have burst swimming speeds in currents between 15 – 25 feet/second (Hoover et al., 2011; Adams et al., 1999). Their body form however is likely not built for maintaining position in highly turbulent waters. Horizontal turbulence and vertical turbulence were tested by White and Mefford (2002) in pallid sturgeon fish passage studies. Although both types of turbulence ("eddies") were able to be negotiated, larger eddies tended to cause delays in upstream movement of the fish, with larger turbulence being most problematic.
4. The bypass channel will be fairly consistent with side channels found within the Yellowstone River, having similar substrate, gradient, and flows (see Appendix A2, Attachment 6 - Bypass Channel Hydraulics and Sediment). As such, the fishway alternative could be preferred by certain species of fish, including pallid sturgeon. However, this is not a consideration made within the FPCI model. Based on telemetry studies in the lower Missouri River and similar research conducted in 2011 on the Yellowstone River, it appears that pallid sturgeon migrate in a characteristic manner, migrating upstream primarily along the inside bends of the river and through side channels located on the inside bends in 2011 (Service, 2012). This pattern of behavior is consistent with that observed in reproductive pallid sturgeon tracked in the highly-modified, channelized lower Missouri River, where it appears that they optimize their allocation of energy by utilizing the energetically least-costly migratory pathways (McElroy et al., 2012).
5. Attractive flow, while considered in the FPCI as the percent of total flow, is likely a more complex issue than simply the amount of total flow diverted through a fishway, and will definitely require consideration in post project monitoring should the bypass channel be constructed. Formation of sheer flows or eddies near the mouth of the bypass channel could be problematic for allowing pallid

sturgeon passage. Migrating telemetry-tagged pallid sturgeon in the lower Missouri River have had difficulties and failed to pass exits in constructed side channels with high velocities, turbulent flow and deep scours. Near Intake Dam, conditions are complicated by complex flow patterns, turbulence, and boulder-sized substrate that pallid sturgeons are known to avoid. These complicating factors make it difficult to predict the ability of pallid sturgeon to search for and locate a potential bypass channel located close to the dam face.

6. Laboratory studies with paddlefish suggest that they can and will try to avoid metallic obstacles (Gurgens et al., 2000; Wilkens & Hofman, 2007). While the FPCI considers this by suggesting that the U_i for paddlefish should be 0 for measures that had substantial metal components, the actual severity of impacts on fish passage in the field remains an untested theory.

Table 1. Fish species selected for analysis, their associated habitat preferences, swimming behaviors, and swimming abilities. The species are considered representative of those that occur in the Yellowstone River at Intake Dam.

Species	Scientific Name	Swimming Behavior	Swimming Performance	Critical Swimming Speed (Ucrit)	Habitat Preference
Sturgeon spp. (Shovelnose and Pallid)	*Scaphirhyncus Spp.*	Benthic	Medium	2.7	B, C
Paddlefish	*Polyodon spathula*	Pelagic	Strong	4.2	B, C
Goldeye	*Hiodon tergisus*	Pelagic	Medium	2	A, B, D, E
Smallmouth buffalo	*Ictiobus bubalus*	Benthic	Medium	2.1	B, C, D, E
Blue sucker	*Cycleptus elongatus*	Benthic	Strong	2.6	B, C
White sucker	*Catosomus commersoni*	Benthic	Weak	2.1	B, C
River carpsucker	*Carpiodes carpio*	Benthic	Weak	1.5	B, D, E
Shorthead redhorse	Moxostoma macrolepidotum	Benthic	Medium	2	B, C
Channel catfish	*Ictalurus punctatus*	Benthic	Strong	2.7	A, B, C, D, E
Smallmouth bass	*Micropterus salmoides*	Littoral	Medium	2.1	A, B, D, E
Walleye	*Sander canadense*	Littoral	Strong	3.8	B, C, D
Sauger	*Sander vitreum*	Littoral	Strong	2.6	B, C, D
Freshwater drum	*Aplodinotus grunniens*	Benthic	Strong	2.7	A, B, C, D, E

Habitats:
A = Contiguous floodplain lake
B = Main channel border
C = Main channel
D = Secondary channel
E = Tertiary channel
F = Tributary

Table 2. Habitat between Intake and Cartersville – Habitat as defined by Jaeger (Personal communication; see also Jaeger et al., 2005) and mapped by DTM consultants on low flow 2001 aerial imagery. Yellowstone habitat types were cross cut with FPCI defined habitat types for purposes of this report.

		Habitats as Defined in UMRC FPCI Model					
Low Flow Fisheries Habitat	**Acres**	**Contiguous Floodplain Lake**	**Main Channel Border**	**Main Nav Channel**	**Secondary Channel**	**Tertiary Channel**	**Tributary Channel**
2C - Secondary lowflow channel	1251				1251		
2CS - Secondary high flow channel	1930				1930		
CC - Channel Crossover	3152			3152			
DC - Dry Channel not meeting PB, SB, MCB or I categories	1348					1348	
I - Islands - vegetated	6589						
MCB - Mid Channel Bar aggredation area within bank full lines	772		772				
PB - Point Bar area in bankful line showing aggredation	1062		1062				
SB - Side Bar area in channel showing aggredation at high flow lines at channel side	0						
RRB - Scour at riprap - mid active channel	722			723			
RRM - Scour at riprap - margin of active channel	723		723				
SC - Scour in unconstrained river	3099			3099			

T - Scour at base of terrace	1762		1762				
BL - Scour at base of bedrock bluff	1293		1293				
Trib - Large tributary confluences	10						10
Dam	51			51			
TOTAL		0	5612	7025	3181	1348	10

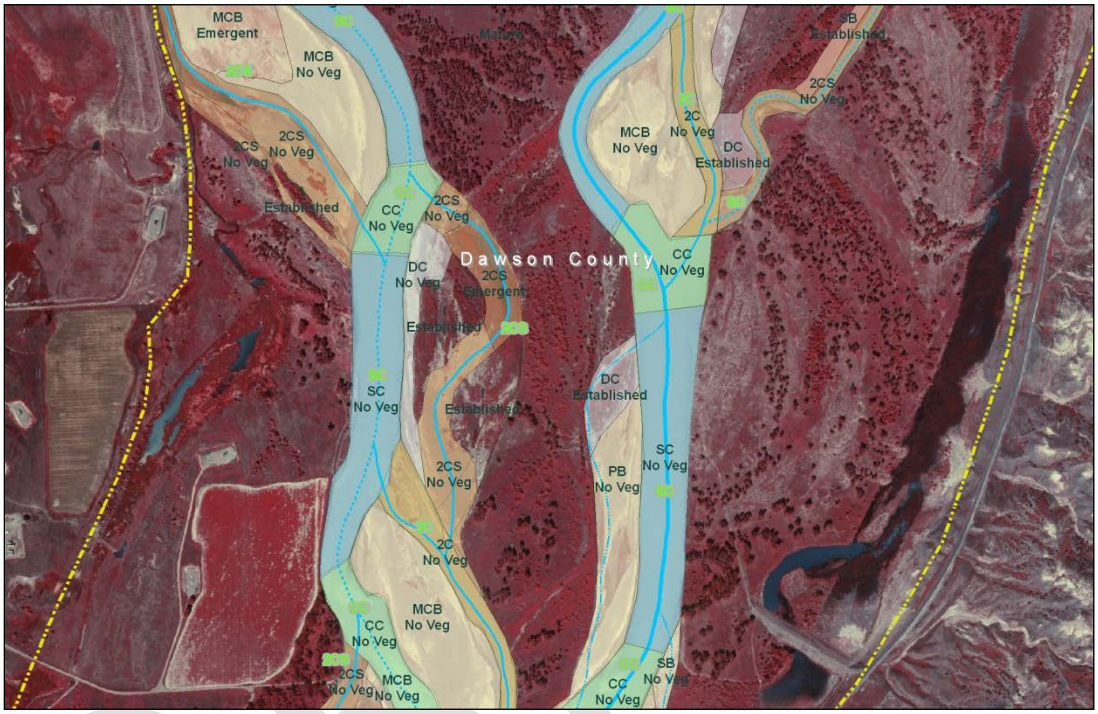


Figure 1 – Example Fisheries Habitat Mapping on Yellowstone River

Table 3. Opportunity for passage at Intake Dam. Opportunity is primarily associated with the peak hydrograph of the Yellowstone River.

Month	Jan-Apr		May				June					July			Aug-Dec
Week	1-17	18	19	20	21	22	23	24	25	26	27	28	29	30	31-52
% Opportunity for Passage	1	1	1	25	50	100	100	100	100	100	50	25	1	1	1

Table 4. Migratory Seasonality for Each Species and associated % of time that passage may occur relative to the probability that the opportunity of passage is available.

Month	Feb				Mar				Apr					May				Jun				Jul					Aug				Sep				Oct					No	
Prob. of Pass. Opp.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	25	50	100	100	100	100	100	50	25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Species	Avg % time pass. may occur
Shovelnose sturgeon	0.64
Paddlefish	0.47
Goldeye	0.53
Smallmouth buffalo	0.86
Blue sucker	0.40
White sucker	0.01
River carpsucker	0.47
Shorthead redhorse	0.53
Channel catfish	0.48
Smallmouth bass	0.54
Walleye	0.07
Sauger	0.22
Freshwater drum	0.54

Pre-Spawn
Spawn

Table 5. Grouping of fish species into guilds based on behavior and swimming performance. This information is an important consideration in estimating whether a species may encounter or use a fishway.

Swimming Performance	Behavior: Benthic	Behavior: Littoral	Behavior: Pelagic
Strong	blue sucker pallid sturgeon shovelnose sturgeon	walleye sauger	paddlefish
Medium	channel catfish freshwater drum shorthead redhorse smallmouth buffalo	smallmouth bass	goldeye
Weak	white sucker river carpsucker	-	-

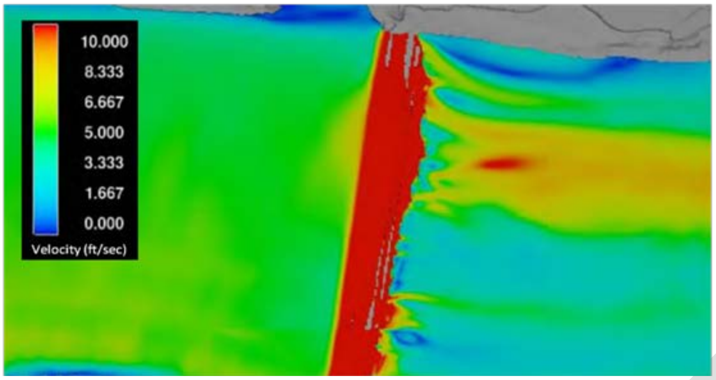
Table 6. Estimate of suitability of fishway locations for each fish guild based on swimming performance and behavior. values fell into three categories; 5 indicated that the entrance would be encountered by a significant portion of the population, 3 indicated that the entrance may be encountered, and 1 indicated that it was unlikely that the entrance would be encountered. Model input for the rock ramp alternatives utilized values found under the "main channel border-near channel" category, while the bypass alternative utilized values under the "Main Channel Border – Near Shore; Side Channel; or Bypass Channel" category.

Estimated Suitability of Fishway Locations (Fl) for Each Fish Guild Based Upon Swimming				
	Potential Fishway Location			
Guild	Main Channel	Main Channel Border – Near Channel	Main Channel Border – Near Shore; Side Channel; or Bypass Channel	Lock
Benthic – Strong -Pallid/Shovelnose Sturgeon -Blue Sucker	5	5	3	1
Littoral – Strong -Walleye -Sauger	5	5	3	1
Pelagic – Strong -Paddlefish	5	5	3	1
Benthic – Medium -Channel Catfish -Freshwater Drum -Shorthead redhorse -Smallmouth buffallo	1	5	5	1
Littoral – Medium -Smallmouth Bass	1	3	5	1
Pelagic – Medium -Goldeye	1	5	5	1
Benthic – Weak -White sucker -River carpsucker	1	5	5	1
Littoral – Weak -	1	3	5	1
Pelagic – Weak -	1	1	5	1

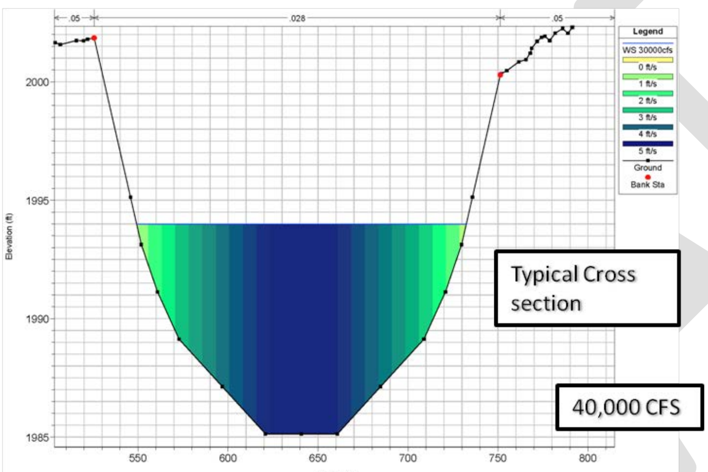
Table 7. FPCI input data for size of the fishway relative to flow (Fs). Range of inputs for Fs are as follows: 5 = ≥30% of low flow discharge of river, 4 = 25% to >20% percent, 3 = 20% to >15% percent, 2 = 15% to >10%, and 1 = ≤ 10%.

Size of Fishway (F_s)					
Measure A: No Action	**Measure B.1: Bypass Channel 10% Flow**	**Measure B.2: Bypass Channel 15% Flow**	**Measure C.1: Rock Ramp – Original Design 0.5% Slope**	**Measure C.2: Rock Ramp – Steepened Toe**	**Measure C.3: Rock Ramp – Doubled Slope**
F_s - Size of Fishway: 5	F_s - Size of Fishway: 1	F_s - Size of Fishway: 2	F_s - Size of Fishway: 5	F_s - Size of Fishway: 5	F_s - Size of Fishway: 5

Measure A: No Action



Measure B.1 and B.2: Bypass Channels



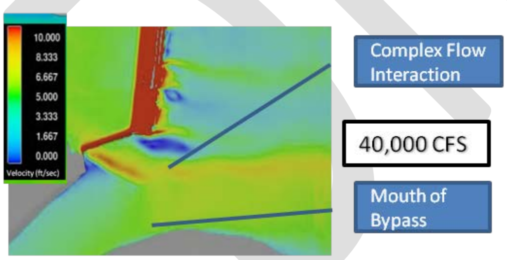


Figure 2 Modeling of intake dam existing condition and bypass alternative. Planview velocity maps are of the same figure, produced by Reclamation (2012) for purposes of modeling flow patterns associated with merging bypass channel flow, lateral weir flow and river flow at 40,000 cfs upstream of the bypass. However, for purposes of this report, the figure as represented for the No Action provides a good idea of the velocities that occur at the existing dam face during the migration season. The plan view velocity map, as represented under the bypass alternatives, shows a complex interaction of flows at the mouth of the bypass. The modeled velocity cross section for the bypass channel (Corps, 2012) shows flows that can accommodate the critical swimming velocities for all species across more than 50% of the channel cross section. Because the cross section is considered representative, it is likely that the channel will accommodate critical swim velocities throughout its length.

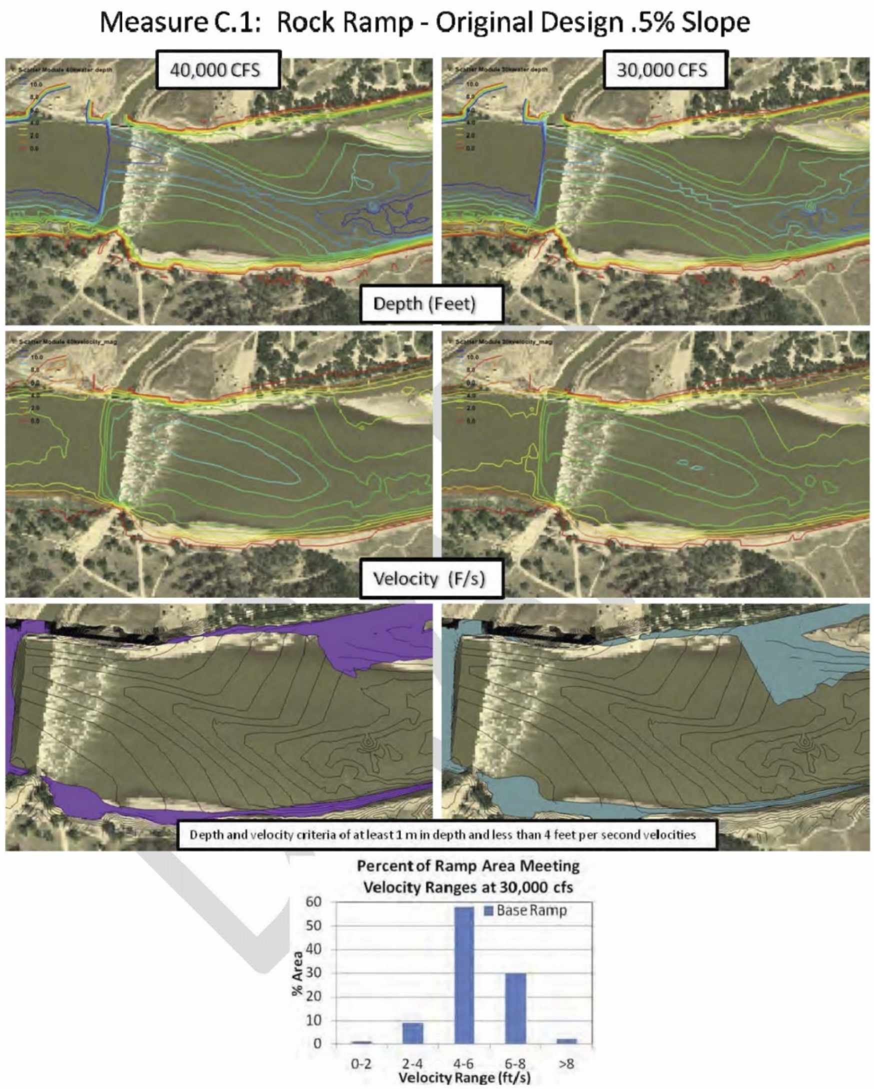


Figure 3. Rock ramp fish passage alternatives. Depth contours, velocities, and depth/velocity coverages are provided for 40,000 CFS and 30,000 CFS, which represent flows that occur during the spring migration. Percent of ramp meeting certain velocity criteria is also shown. Velocity across the fish passage structure is necessary in determining the Potential (U_j) for fish to use an alternative in the FPCI. Maps showing combined depth of 1m and velocities of 4 feet per second are based upon recommendations by the BRT for what velocity/depth combinations are necessary to facilitate pallid sturgeon migration.

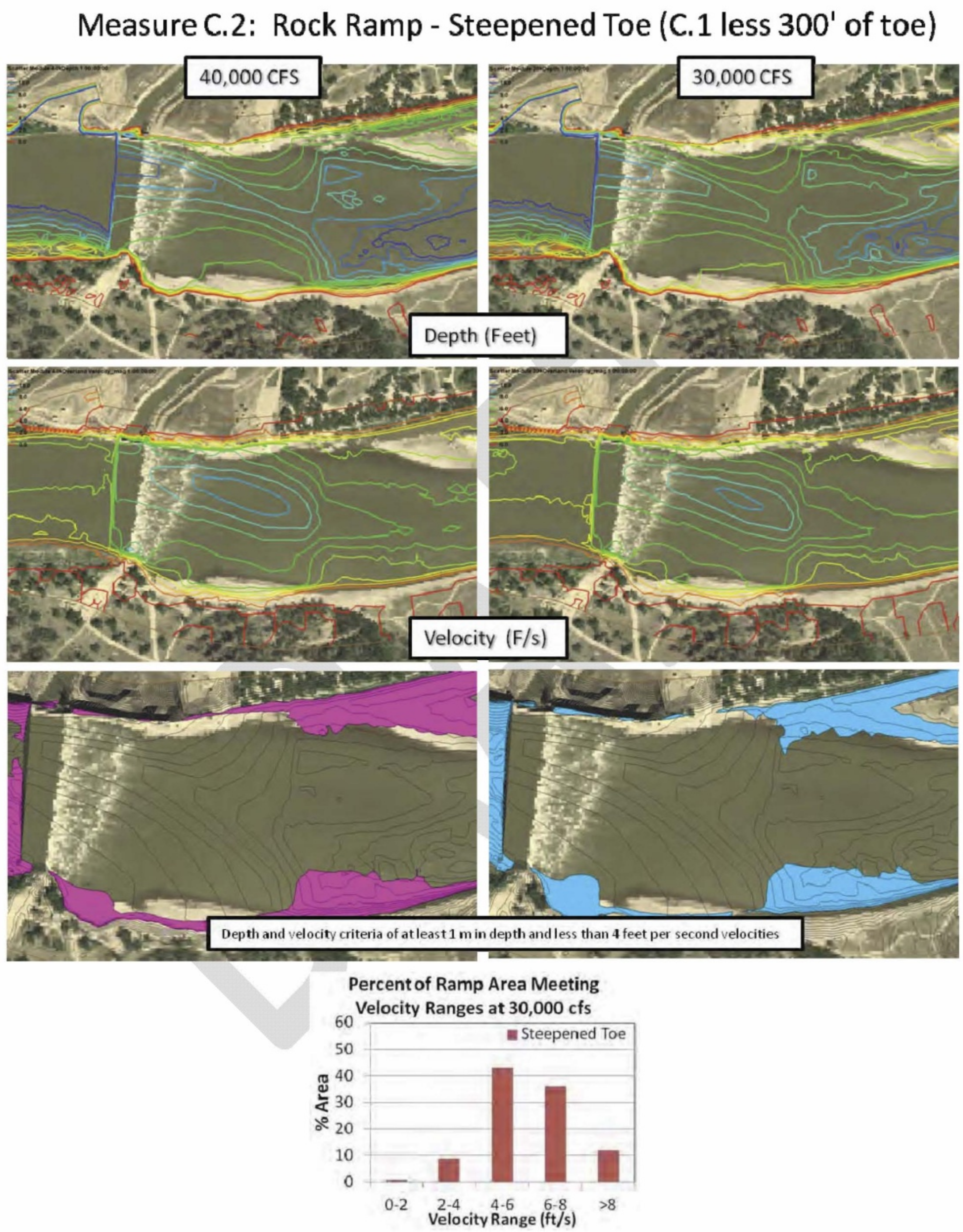


Figure 3. Continued

Measure C.3: Rock Ramp - Doubled Slope

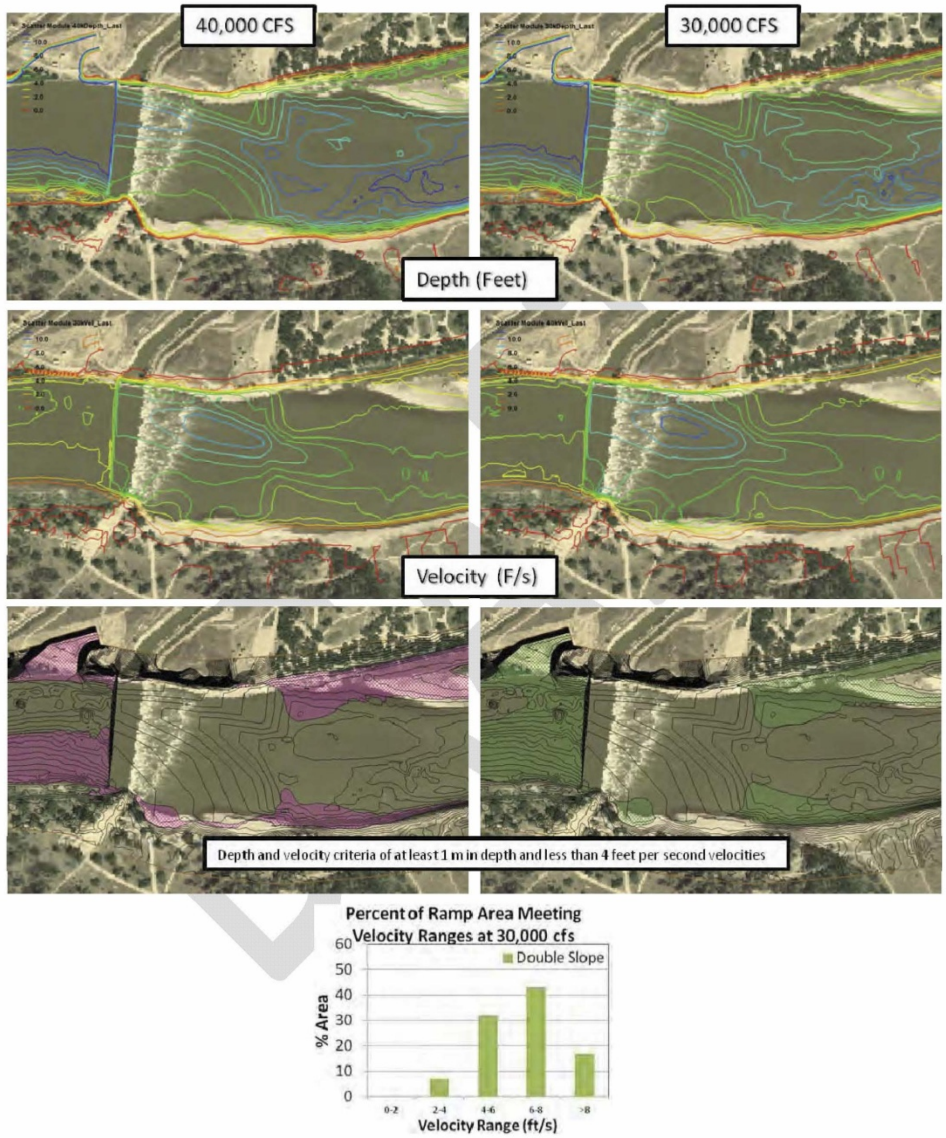


Figure 3. Continued

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Table 8. Potential (Ui) for Fish to Use Alternative Fish Passage Measures. Scores were provided on the following scale: Velocities did not exceed burst speeds (generally 3 to 4 times the U_{crit} speed for prolonged swimming) in small areas and didn't exceed the U_{crit} speed for the majority of the hydraulic step, the U_i was scored a 5; If velocities exceed U_{crit} speed in the majority of the hydraulic step area but did not exceed burst speed it was scored a 3; and if velocity exceeded burst speeds in the majority of the hydraulic step areas it was scored a 1.

Potential for Species to Use Fishway Type						
	Measure A: No Action	**Measure B.1: Bypass Channel 10% Flow**	**Measure B.2: Bypass Channel 15% Flow**	**Measure C.1: Rock Ramp - Original Design 0.5% Slope**	**Measure C.2: Rock Ramp - Steepened Toe**	**Measure C.3: Rock Ramp - Doubled Slope**
Fish Species	Ui	Ui	Ui	Ui	Ui	Ui
Shovelnose sturgeon (and Pallid)	1	5	5	3	2	1
Paddlefish	2	5	5	5	3	2
Goldeye	1	5	5	3	2	1
Smallmouth buffalo	1	5	5	3	2	1
Blue sucker	1	5	5	3	2	1
White sucker	1	5	5	3	2	1
River carpsucker	1	5	5	1	1	1
Shorthead redhorse	1	5	5	3	2	1
Channel catfish	1	5	5	3	2	1
Smallmouth bass	1	5	5	3	2	1
Walleye	2	5	5	5	3	2
Sauger	1	5	5	3	2	1
Freshwater drum	1	5	5	3	2	1

Table 9 Duration of Availability (D_i) of the fish passage structure is the proportion of time when both the fish passage structure is physically available for passage, and migration is actually occurring for a particular species of fish. For the no action, D_i is calculated as the fraction of time that upriver movement may generally occur when the physical conditions at the dam allow for passage. The D_i for all the other alternatives is considered to be available over 100% of the time when passage is occurring. This is because the fish passage structures are all designed to be available across most flows, especially during the migration season.

Potential of Availability of Fishway Alternatives						
	Measure A: No Action	**Measure B.1: Bypass Channel 10% Flow**	**Measure B.2: Bypass Channel 15% Flow**	**Measure C.1: Rock Ramp - Original Design 0.5% Slope**	**Measure C.2: Rock Ramp - Steepened Toe**	**Measure C.3: Rock Ramp - Doubled Slope**
Fish Species	Di	Di	Di	Di	Di	Di
Shovelnose sturgeon (and Pallid)	0.64	1	1	1	1	1
Paddlefish	0.47	1	1	1	1	1
Goldeye	0.53	1	1	1	1	1
Smallmouth buffalo	0.86	1	1	1	1	1
Blue sucker	0.40	1	1	1	1	1
White sucker	0.01	1	1	1	1	1
River carpsucker	0.47	1	1	1	1	1
Shorthead redhorse	0.53	1	1	1	1	1
Channel catfish	0.48	1	1	1	1	1
Smallmouth bass	0.54	1	1	1	1	1
Walleye	0.07	1	1	1	1	1
Sauger	0.22	1	1	1	1	1
Freshwater drum	0.54	1	1	1	1	1

Table 10 Connectivity Index and Habitat Unit Results.

Family Common Name	Total Available Preferred Habitat in Pool (acres)	Є = Fish Passage Connectivity	Habitat Units (Є X acres)	Є = Fish Passage Connectivity	Habitat Units (Є X acres)	Є = Fish Passage Connectivity	Habitat Units (Є X acres)	Є = Fish Passage Connectivity	Habitat Units (Є X acres)	Є = Fish Passage Connectivity	Habitat Units (Є X acres)	Є = Fish Passage Connectivity	Habitat Units (Є X acres)
Shovelnose/Pallid stu	12,637	0.13	1620	0.40	5055	0.50	6318	0.60	7582	0.40	5055	0.20	2527
Paddlefish	12,637	0.19	2388	0.40	5055	0.50	6318	1.00	12637	0.60	7582	0.40	5055
Goldeye	10,141	0.06	641	0.60	6085	0.70	7099	0.60	6085	0.40	4056	0.20	2028
Smallmouth buffalo	17,166	0.10	1766	0.60	10299	0.70	12016	0.60	10299	0.40	6866	0.20	3433
Blue sucker	12,637	0.08	1004	0.40	5055	0.50	6318	0.60	7582	0.40	5055	0.20	2527
White sucker	12,637	0.00	15	0.60	7582	0.70	8846	0.60	7582	0.40	5055	0.20	2527
River carpsucker	10,141	0.06	569	0.60	6085	0.70	7099	0.20	2028	0.20	2028	0.20	2028
Shorthead redhorse	12,637	0.06	798	0.60	7582	0.70	8846	0.60	7582	0.40	5055	0.20	2527
Channel catfish	17,166	0.06	996	0.60	10299	0.70	12016	0.60	10299	0.40	6866	0.20	3433
Smallmouth bass	10,141	0.07	662	0.60	6085	0.70	7099	0.48	4868	0.32	3245	0.16	1623
Walleye	15,818	0.03	448	0.40	6327	0.50	7909	1.00	15818	0.60	9491	0.40	6327
Sauger	15,818	0.04	691	0.40	6327	0.50	7909	0.60	9491	0.40	6327	0.20	3164
Freshwater drum	17,166	0.06	1109	0.60	10299	0.70	12016	0.60	10299	0.40	6866	0.20	3433
		Avg.	978	**Avg.**	7087	**Avg.**	8447	**Avg.**	8627	**Avg.**	5657	**Avg.**	3126

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