Lower Yellowstone Intake Diversion Dam Modification Project, Montana

DRAFT APPENDIX D

Lower Yellowstone Intake Fish Passage EIS

Fish Passage Connectivity Index and Cost Effectiveness and Incremental Cost Analysis

MAY 2016

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1.1 Introduction

Intake Diversion Dam has likely impeded upstream fish passage for pallid sturgeon and other fish species in the Yellowstone River since it was completed in approximately 1911. The best available science suggests that the diversion dam is a partial barrier to some fish species including shovelnose sturgeon (Bramblett, et al. 2015; Helfrich et al. 1999; Jaeger et al. 2004; Backes et al. 1994; Stewart 1986, 1988, 1990, 1991). It is essentially a total barrier to other fish species, such as pallid sturgeon, due to a high level of turbulence associated with the rocks at the dam crest and in the downstream boulder field and high velocities at the dam crest (Jaeger et al. 2005; Fuller et al. 2007; Helfrich et al. 1999; White and Mefford 2002; Bramblett and White 2001). Pallid sturgeon were tracked passing upstream of the dam via the existing high-flow side channel in 2014 and 2015 (Rugg 2014, 2015, 2016) during flows greater than 30,000 cfs. It is not known if passage has occurred before 2014 because this was the first year that fish were tracked swimming upstream of the dam.

Improving fish passage at Intake Diversion Dam accomplishes several things from a pallid sturgeon recovery perspective:

- It would provide access to approximately 165 miles of Yellowstone River habitat upstream of Intake Diversion Dam and additional miles on tributaries such as the Powder River that are currently inaccessible to the pallid sturgeon;
- The area to which access would be provided appears to include substantial areas of suitable spawning habitat for pallid sturgeon including bluff pools and other areas of swift water over gravel and cobble substrates (Jaeger, et al. 2005, Rugg 2014, 2015; Bramblett, et al. 2015);
- If 165 more river miles were accessible for spawning, it would provide longer drift distances and a larger area available for larvae to stop dispersal and seek rearing habitat before reaching Lake Sakakawea, which is currently thought to be unsuitable larval settling habitat due to the fine substrates and low dissolved oxygen levels (Braaten et. al. 2008, 2011; Guy et al. 2015; Bramblett & Scholl 2016)

While the primary purpose of a fish passage project at Intake Dam is to improve pallid sturgeon passage, other migratory species of fish are also likely to also benefit from the project. This includes fish that are important from a management perspective by the State of Montana, such as shovelnose sturgeon, paddlefish, sauger, and blue sucker, as well as a variety of native fish species that reside in the Yellowstone River and undertake shorter seasonal movements.

For an ecosystem restoration project such as this fish passage project, there is no monetary measure of benefits to compare alternatives in a traditional cost-benefit ratio. However, if benefits can be quantified in some dimension, cost effectiveness and incremental cost analysis can be used to assist in selecting a preferred plan. Cost effectiveness analysis evaluates which alternatives are the least-costly way of attaining the project objectives. Incremental analysis is then used to evaluate the change in cost from each measure or alternative to the next to determine their incremental costs and incremental benefits. This type of analysis helps identify which measures or alternatives provide the most benefit for the lowest cost and can be used as one element to inform the selection of a preferred plan.

1.2 Fish Passage Connectivity Index

The Fish Passage Connectivity Index (FPCI) was developed to evaluate ecosystem outputs (i.e. benefits) of alternative measures for fish passage improvements on the Upper Mississippi River and Illinois Waterway System for cost effectiveness and incremental analysis (Corps 2010). The model was developed for use in the plan formulation process for the Navigation and Ecosystem Sustainability Program for the Upper Mississippi River System Lock and Dam 22 fish passage improvement project. The model has subsequently been approved for use in the U.S. Army Corps of Engineers (Corps) planning context for fish passage projects on other river systems (Corps 2016). This model was used in an assessment of fish passage alternatives at Intake Diversion Dam in 2015 (Corps 2015).

The FPCI is a simple arithmetic index that is calculated as:

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

Where,

ϵ = 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.

Ei = Probability of encountering the fishway entrance is a calculated value ranging from 1 to 5, where 5 = highly likely; 3 = moderate probability; 1 = unlikely.

Ui = 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.

Di = Duration of availability, the fraction of the upriver migration period for fish species i that the passage pathway is available. Di 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 in the Upper Mississippi River, 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 minor adjustment, was used as a planning tool for comparing benefits of alternative measures for provide fish passage at Intake Dam. This memo describes the input data used and minor adjustments made to the model to demonstrate ecological benefits of the Yellowstone River Intake Diversion Dam fish passage alternatives.

1.3 Data Required for the Model

1.3.1 Identify fish to be included for analysis, and their associated habitat preferences, swimming behaviors, and swimming abilities.

1.3.1.1 The model was created with a list of 30 fish species that could be considered for use in the model. This list did not include pallid sturgeon. Additionally, the swimming performance data, critical current velocities (Ucrit) for prolonged swimming by adult fish used in the creation of the model were sourced from two primary studies on the Upper Mississippi River (Wilcox et al. 2004; Pitlow & Rasmussen 1995).More recent data on Yellowstone River fish and data available for the Missouri River were used to make minor changes to anticipated swimming speeds and swimming performance (example, Ucrit estimated for pallid sturgeon from tracking wild adults in the Yellowstone River; Braaten et al. 2014). Changes made to the list of species and their swimming performance are shown in Table 1-1 in italics, with selected species in bold.

1.3.1.2 For ensuring a good comparison of benefits across fish passage alternatives, the fish species used in the FPCI modeling effort were the same species used by the Corps in 2014 with the addition of pallid sturgeon, for a total of 14 species. The inclusion of pallid sturgeon does not change the ranking of alternatives, but provides a better differentiation between similar alternatives. For the Corps (2015) modeling, species were selected because they represent the migratory species typically found in the Yellowstone River at Intake Diversion Dam and 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)).

1.3.1.3 Habitat preferences/use for each species was considered acceptable as presented in the FPCI with one slight adjustment as noted by the Corps (2015); white sucker, blue sucker and river carpsucker were 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 Upper Mississippi River was defined as a navigation channel, which 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 Upper Missouri River systems, and as such, were associated with it for purposes of this study. In addition, pallid sturgeon was included and shown with a habitat preference for main channel and main channel border habitats similar to the habitat preferences provided for shovelnose sturgeon.

Table 1-1. Species Used in the FPCI Model for Intake Diversion Dam with Swimming Performance and Habitat Preference.

								Available Habitat in Yellowstone River above Intake[3]					
								A	B	C	D	E	
	Common Name	Scientific Name	Yellowstone Relative Abundance[1]	Swimming Behavior	Swimming Performance	Swimming Speed (Ucrit)	Habitat Preference	Contiguous Floodplain Lake - Abandoned Channel Lake (acres)	Main Channel-Channel Border (acres)	Main Channel - Navigation Channel (acres)	Secondary Channel (acres)	Tertiary Channel (acres)	Total Available Preferred Habitat (acres)
1	Silver lamprey	Ichtyomyzon unicuspis	Uncommon	Pelagic	Weak	1	B	x	5612	x	x	x	5612
2	Lake sturgeon	Acipenser fulvescens	Common	Benthic	Strong	2.9	B, C	x	5612	7025	x	x	12637
3	Shovelnose sturgeon	Scaphirhyncus platorynchu	Occasional	Benthic	Strong	2.7	B, C	x	5612	7025	x	x	12637
4	Paddlefish	Polyodon spathula	Occasional	Pelagic	Strong	4.2	B, C	x	5612	7025	x	x	12637
5	Longnose gar	Lepisosteus osseus	Common	Pelagic	Weak	0.7	A, B, D, E	x	5612	x	3181	10	8803
6	Mooneye	Hiodon alosoides	Occasional	Pelagic	Medium	1.9	A, B, D, E	x	5612	x	3181	10	8803
7	Goldeye	Hiodon tergisus	Occasional	Pelagic	Medium	2	A, B, D, E	x	5612	x	3181	10	8803
8	American eel	Anguilla rostrata	Occasional	Littoral	Weak	1	B, D, E	x	5612	x	3181	10	8803
9	Skipjack herring	Alosa chrysochloris	Occasional	Pelagic	Medium	1.9	B, C	x	5612	7025	x	x	12637
10	Bigmouth buffalo	Ictiobus cyprinellus	Common	Benthic	Medium	2.1	B, C, D, E	x	5612	7025	3181	10	15828
11	Smallmouth buffalo	Ictiobus bubalus	Common	Benthic	Medium	2.1	B, C, D, E	x	5612	7025	3181	10	15828
12	Blue sucker	Cycleptus elongatus	Uncommon	Benthic	Strong	2.6	B	x	5612	x	x	x	5612
13	White sucker	Catosomus commersoni	Stray	Benthic	Medium	2.1	B	x	5612	x	x	x	5612
14	Spotted sucker	Minytrema melanops	Rare	Benthic	Weak	1.8	A, B	x	5612	x	x	x	5612
15	Golden redhorse	Moxostoma erythrurum	Rare	Benthic	Weak	1.8	B	x	5612	x	x	x	5612
16	River carpsucker	Carpiodes carpio	Occasional	Benthic	Weak	1.5	B, D, E	x	5612	x	3181	10	8803
17	Quillback	Carpiodes cyprinus	Common	Benthic	Weak	1.6	B, D, E	x	5612	x	3181	10	8803
18	Shorthead redhorse	Moxostoma macrolepidotu	Occasional	Benthic	Medium	2	B	x	5612	x	x	x	5612
19	Silver redhorse	Moxostoma anisurum	Rare, Uncommon	Benthic	Strong	2.7	B	x	5612	x	x	x	5612
20	Blue catfish	Ictalurus furcatus	Occasional	Benthic	Medium	2.3	B	x	5612	x	x	x	5612
21	Channel catfish	Ictalurus punctatus	Common	Benthic	Strong	2.7	A, B, C, D, E	x	5612	7025	3181	10	15828
22	Flathead catfish	Pylodictis olivaria	Common	Benthic	Medium	2.2	A, B, C, D, E	x	5612	7025	3181	10	15828
23	Northern pike	Esox lucius	Occasional	Littoral	Weak	1.5	A, B, D, E	x	5612	x	3181	10	8803
24	White bass	Morone chrysops	Common	Pelagic	Strong	3.9	B, C, D, E	x	5612	7025	3181	10	15828
25	Yellow bass	Morone mississippiensis	Occasional	Pelagic	Strong	2.9	A, B, C, D, E	x	5621	7025	3181	10	15837
26	Largemouth bass	Micropterus dolomieu	Common	Littoral	Medium	2.3	A	x	5612	x	x	x	5612
27	Smallmouth bass	Micropterus salmoides	Uncommon	Littoral	Medium	2.1	A, B, D, E	x	5612	x	3181	10	8803
28	Walleye	Sander canadense	Occasional	Littoral	Strong	3	B, C, D	x	5612	7025	3181	x	15818
29	Sauger	Sander vitreum	Common	Littoral	Strong	2.6	B, C, D	x	5612	7025	3181	x	15818
30	Freshwater drum	Aplodinotus grunniens	Abundant	Benthic	Strong	2.7	A, B, C, D, E	x	5612	7025	3181	10	15828
31	Pallid sturgeon	Scaphirynchus albus	Occasional	Benthic	Strong	3.2	B,C	x	5612	7025	x	x	12637

[1] Pitlo, J., Jr., Van Vooren, A., and Rasmussen, J. (1995). "Distribution and relative abundance of Upper Mississippi River fishes," Upper Mississippi River Conservation Committee Fish Technical Section, Rock Island, IL.
[2] Wilcox, D.B. et al (2004) "Improving fish passage through navigation dams on the Upper Mississippi River system", ENV Report 54, U.S. Army Corps of Engineers, Rock Island, St. Louis, and St. Paul Districts
[3] Corps & YRCDC. 2015. Yellowstone River Cumulative Effects Assessment. U.S. Army Corps of Engineers, Omaha District.

1.3.2 Identify habitat acres made available by passage.

1.3.2.1 Habitat Units are calculated in the model by multiplying the fish passage index by the total acres of available preferred habitat upstream of Intake Diversion Dam for each species. For this analysis, the habitat acres used by the Corps (2015) were used. The Corps (2015) analysis used acreages in the Yellowstone River from Intake Diversion Dam to Cartersville Dam available from GIS data developed for the Yellowstone River Cumulative Effects Assessment (Corps & YRCDC 2015).

1.3.2.2 Habitat types from the CEA include the following primary categories:

Scour – (SC) Scour pool occurring in otherwise unconstrained river channel.

Bluff – (BL) Scour pool located at the base of a bedrock bluff. Indicates a relatively permanent pool location bounded by a geologic constraint.

Terrace – (T) Scour pool located at the base of a terrace (Quarternary Alluvium).

Riprap Bottom – (RRB) Scour pool occurring in riprap constrained channel where riprap is located in the middle of the active channel area.

Riprap Margin – (RRM) Scour pool occurring in riprap constrained channel where riprap is located at the edge of the active channel area.

Channel Crossover – (CC) A transitional unit where the river is translating from one bendway or pool to the next.

Bedrock – (BED) Channel is controlled by bedrock bed.

Secondary Channel – (2C) Undifferentiated low flow channel. No additional habitat typing is defined, though the channel likely contains areas of pool and riffle.

Secondary Channel Seasonal – (2CS) Secondary channel High flow channel

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.

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.

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.

Dry Channel – (DC) This is a general category for areas within the bank full boundaries that do not fit into Point Bar, Side Bar, Mid-channel Bar, or Island 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.

Dam – Habitat unit is influenced by a dam in the main channel.

1.3.2.3 As depicted in Table 1-2, the CEA habitat categories were cross-walked to the habitat categories as defined for the Upper Mississippi River in the FPCI, allowing Yellowstone River habitat acreages to be compatible with the existing layout as presented in the FPCI model. The habitats for the Upper Mississippi River were defined as:

- Contiguous Floodplain Lake
- Main Channel Border
- Main Navigation Channel
- Secondary Channel
- Tertiary Channel
- Tributary Channel

1.3.3 Identify Windows of Opportunity for Upstream Fish Passage

The timing of when fish passage is physically possible at a dam due to typical peak flows (and suitable depths and velocities) compared with the timeframe of when fish typically migrate is used to estimate the duration of availability (Di) for the baseline condition and each alternative in the FPCI. The Corps (2015) modified the "percent probability of open river conditions" in the original model (which referred to when the dam gates were open on the Upper Mississippi River) and used available literature (Jaeger, et al. 2005; Helfrich et. al. 1999), anecdotal information, and best professional judgment, to assign probabilities that passage opportunities exist 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). These same probabilities were used in this analysis for the existing conditions. Table 1-3 shows the probability of passage as entered into the FPCI model to represent the existing condition.

For the proposed alternatives, an assumption was made both by the Corps in 2015 and for this application that the duration of available for fish passage would be 100% during all flows for the bypass channel, modified side channel, and dam removal alternatives because suitable depths and velocities are available across a wide range of flows. For the rock ramp alternative, the depths and velocities are suitable at most times, but for some species at some flows, depths may be too shallow or velocities too high to have suitable passage. Thus, the 2D model results for the rock ramp were used to indicate the duration of availability for the median flows in each month of interest. Table 1-4 shows the probability of passage as used in the FPCI model for the rock ramp alternative.

1.3.3.1 Seasonality of Fish Migration

Basic information on fish migratory behaviors and timing from the original FPCI model was modified by Corps (2014) because the actual time of year when migration takes place on the Yellowstone River is different than on the Mississippi River. Movement and spawning periods 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 Diversion 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 1-5.

In addition, for this analysis, the migratory timing was adjusted for four fish species: shovelnose sturgeon, paddlefish, blue sucker, and sauger based on literature available for the Upper Missouri River basin (Rugg 2014, 2015, 2016; Bramblett et al. 2014). Pallid sturgeon timing was entered based on recent data (Delonay et al. 2015; Rugg 2014, 2015, 2016).

Table 1-2. Habitat crosswalk for area between Intake and Cartersville (Jaeger, et al. 2005 and mapped by DTM consultants on low flow 2001 aerials for Corps & YRCDC 2015).

		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**	**Trib Channe l**
2C - Secondary low flow 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 aggradation area within bankfull lines	772		772				
PB - Point Bar area in bankfull line showing aggradation	1062		1062				
SB - Side Bar area in channel showing aggradation at high flow lines at bank	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

Table 1-3. Opportunity for Fish Passage at Intake Diversion Dam for Existing Conditions (associated primarily with peak runoff).

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 1-4. Opportunity for Fish Passage for Rock Ramp Alternative

Month	Jan-Mar	Apr	May	June	July	Aug	Sept	Oct-Dec
Week	1-13	14-17	18-21	22-25	26-30	30-34	35-38	39-52
% Opportunity for Passage	1	95	97	100	97	95	95	1

Table 1-5. Migratory Timing for Species Used in FPCI.

	Pre-spawning movement period																																			
	Spawning period																																			
	Month of year:		Feb				Mar				Apr					May				Jun				Jul					Aug				Sep			
	Week of year:		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
	Probability intake dam is passable		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	25.0	50.0	100.0	100.0	100.0	100.0	100.0	50.0	25.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Average water temp (degrees C)		1	1.1	1.1	1.4	2.1	3.2	4.3	5	7.4	8.2	9.4	11.4	13.7	14.9	16.6	18.8	19.8	20.6	21.9	23.6	25.1	25.8	25.8	26.7	27.1	27.2	27.2	26.5	26.4	26.1	25.3	24.1	22.9	20.7
		Average fraction of time that upriver movement is feasible during migration period																																		
1	Shovelnose sturgeon	0.19																																		
2	Paddlefish	0.53																																		
3	Goldeye	0.53																																		
4	Smallmouth buffalo	0.86																																		
5	Blue sucker	0.53																																		
6	White sucker	0.01																																		
7	River carpsucker	0.47																																		
8	Shorthead redhorse	0.53																																		
9	Channel catfish	0.48																																		
10	Smallmouth bass	0.54																																		
11	Walleye	0.07																																		
12	Sauger	0.20																																		
13	Freshwater drum	0.54																																		
14	Pallid sturgeon	0.18																																		

1.3.4 Identity Potential Fish Passage Connectivity

1.3.4.1 Probability that Fish Encounters Fish Passage Alternative **(Ei)**

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 expressed as a value ranging from 1 to 5, with 5 being highly likely, and 1 being unlikely. The relationship is represented by the following equation: $E_i=(F_s+F_l)/2$

1.3.4.2 Determine Potential for Fish to Encounter Passage Alternative **(Fl)**

Fl 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, were generally used as developed by the Corps (2014) with the addition of pallid sturgeon and are shown in Table 1.5. To assign an Fl value to each guild, the Corps (2014) used the best professional judgment of federal and state biologists working on the Yellowstone River (Table 1.6). These values range from 5, indicating that the entrance would be encountered by a significant portion of the population, to 3, indicating that the entrance may be encountered (about 50:50 chance), to 1, indicating that it was unlikely that the entrance would be encountered by more than a very few fish.

1.3.4.3 Determining the Size of Fish Passage Alternative (Fs)

- This parameter is the size of the fishway relative to the discharge of the river under low flow conditions. For the Yellowstone River, Corps (2014) used the recommendation by the BRT that fish passage alternatives should be capable of conveying up to 30% of river flow. Therefore the following range of inputs for Fs were established by Corps (2014) for the Intake project; 5 was assigned to fishway designs that pass 30 percent or more of the low flow discharge, 4 = 25 percent, 3 = 20 percent, 2 = 15 percent, and 1 = equal to or less than 10%.
- More recent tracking of pallid sturgeon passing upstream of Intake Diversion Dam by pallid sturgeon in 2014 and 2015 (Rugg 2014, 2015) indicates that passage is possible when flow in the high-flow side channel is only 2-6% of the river flow (based on HEC-RAS modeling for this study at river flows from 30,000 to 63,000 cfs, which was the rage of river flows when passage occurred).
- The size of fishway for each alternative is listed in Table 1.7. The No Action, Rock Ramp, and dam removal alternatives all pass full flows of the river and received inputs of 5, whereas the Bypass Channel and High-Flow Channel alternatives pass 15% of the flow and received inputs of 2.

Table 1-6. Swimming Performance and Behavior Guilds.

Performance	Behavior		
	Benthic	**Littoral**	**Pelagic**
Strong	Pallid sturgeon	Walleye	Paddlefish
	Shovelnose sturgeon	Sauger	
	Blue sucker		
Medium	Channel catfish	Smallmouth bass	Goldeye
	Freshwater drum		
	Shorthead redhorse		
	Smallmouth buffalo		
	White sucker		
Weak	River carpsucker		

Table 1-7. Estimate of Probability of encountering the fishway entrance for each fish guild. (Values: 5 – fish would encounter, 3 – ~50% would encounter, and 1 – 10% or less would encounter)

Estimated Probability of Encountering Fishway Locations (Fl) for Each Fish Guild				
	Fishway Location			
Guild	**Main Channel – Rock Ramp**	**Main Channel Border – Bypass Channel (near dam)**	**Main Channel Border – Side Channel (downstream of dam)**	**No Dam**
Benthic – Strong -Pallid Sturgeon -Shovelnose Sturgeon -Blue sucker	5	4	2	5
Littoral – Strong -Walleye -Sauger	5	5	5	5
Pelagic – Strong -Paddlefish	5	4	2	5
Benthic – Medium -Channel Catfish -Freshwater Drum -Shorthead Redhorse -Smallmouth Buffalo -White Sucker	3	5	5	5
Littoral – Medium -Smallmouth Bass	1	5	5	5
Pelagic – Medium -Goldeye	1	5	5	5
Benthic – Weak -River Carpsucker	1	5	5	5
Littoral – Weak	1	5	5	5
Pelagic – Weak	1	5	5	5

Table 1-8. 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: Rock Ramp**	**Measure C: Bypass Channel 15% Flow**	**Measure D: High-Flow Channel 15% Flow**	**Measure E: Pumping**	**Measures F: Ranney Wells**
F_s - Size of Fishway: 5	F_s - Size of Fishway: 5	F_s - Size of Fishway: 2	F_s - Size of Fishway: 2	F_s - Size of Fishway: 2	F_s - Size of Fishway: 5

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

The potential for a fish to pass upriver past an obstacle is dependent on its swimming performance, the hydraulic conditions that are encountered, and the likely pathway a fish would use (i.e. main channel vs. bank zone). 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 1.1. The average current velocity at specific locations within each alternative (at 30,000 or 40,000 cfs) was compared to the U_{crit} speed for each migratory fish species. If velocities did not exceed the U_{crit} speed, the U_i was scored a 5. If velocities exceed U_{crit} speed, but was not likely to exceed burst speed it was scored a 3, and if velocity was likely to exceed burst speeds in a key location (i.e. inlet or outlet), or was widespread without potential for resting, it was scored a 1.

- The typical current velocities for each alternative are shown in the following figures and graphs.
- Scores for Ui can be found in Table 1.8. Explanation of the scores are provided below.
  a. Flow velocities over the existing dam face are well over 10 ft/sec, and has turbulent flow. As such, it scores 1 for the U_i variable for most fish, with the exception of shovelnose sturgeon, paddlefish, blue sucker, walleye and sauger that have been documented to pass over the dam occasionally (Rugg 2016; Bramblett, et al. 2015), thus getting a 2.
  b. The rock ramp has slightly reduced velocities as compared to the existing condition, but exceeds the U_{crit} of all species over a majority of the ramp (i.e. 8 ft/sec) and would likely have turbulent flow. The only fish likely to be able to pass consistently is paddlefish that have high U_{crit}, thus meriting a 5. Walleye and blue suckers are also strong swimmers that may be able to pass typically, thus meriting a 4. Fish that are more littoral or pelagic in behavior that may use the margins of the rock ramp received a 3, and strong benthic swimmers other than paddlefish also received a 3, since passage is likely to be somewhat improved and these species have occasionally shown an ability to pass over the dam. Pallid sturgeon are still unlikely to be able to swim through turbulent flows and uneven rocks over such a distance,

although slightly improved from the existing condition, thus receiving a 2 and river carpsucker are weak swimmers, thus receiving a 1.

c. The Bypass Channel and High-Flow Channel velocity modeling indicates velocities not greater than the U_{crit} for a large proportion of the channel, thus allowing passage for all species.
d. While not a consideration in the modeling, both the Bypass and High-Flow Channel 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.
e. The Pump and Non-Weir alternatives would return the channel to natural conditions, thus allowing passage for all species.

1.3.4.5 Duration of Availability (Di) 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.

Table 1.9 identifies when fish passage alternatives are available to fish for each alternative.

Di for the existing condition is calculated as the fraction of time that upriver movement may generally occur when the physical conditions at the dam allow for passage, typically during runoff. Thus, the Di is highly variable between each species of fish, depending on their migration timing in relation to the runoff period.

The Di for the rock ramp would be more passable with a low-flow channel through the replacement weir and ramp, but does not necessarily provide suitable depths and velocities at all times for all species and would not necessarily be the location where all species would seek passage. Thus, D_i was calculated from the opportunity for passage and migration timing of the species in relation to the runoff period.

The Di for all the other alternatives is available 100% of the time (ranked a 1) when passage is occurring. This is because the fish passage structures are all designed to be available for all but the lowest flows.

Table 1-9. Potential (Ui) for Fish to Use Alternative Fish Passage Measures.

Scores were provided on the following scale: Velocities do not exceed the U_{crit} speed for the majority of the alternative, the U_i was scored a 5; If velocities exceed U_{crit} speed but did not exceed burst speed it was scored a 3; and if velocity exceed likely burst speeds it was scored a 1.

Potential for Species to Use Fishway Type						
	Measure A: No Action	**Measure B: Rock Ramp**	**Measure C: Bypass Channel 15% Flow**	**Measure D: High-Flow Channel**	**Measure E: Pumping**	**Measure F: Ranney Wells**
Fish Species	Ui	Ui	Ui	Ui	Ui	Ui
Shovelnose sturgeon (and Pallid)	1	3 2	5	5	5	5
Paddlefish	2	5	5	5	5	5
Goldeye	1	3	5	5	5	5
Smallmouth buffalo	1	3	5	5	5	5
Blue sucker	2	4	5	5	5	5
White sucker	1	3	5	5	5	5
River carpsucker	1	1	5	5	5	5
Shorthead redhorse	1	3	5	5	5	5
Channel catfish	1	3	5	5	5	5
Smallmouth bass	1	3	5	5	5	5
Walleye	2	4	5	5	5	5
Sauger	1	3	5	5	5	5
Freshwater drum	1	3	5	5	5	5

Table 1-10. Duration Of Availability (Di) 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.

Potential of Availability of Fishway Alternatives						
	Measure A: No Action	**Measure B: Rock Ramp**	**Measure C: Bypass Channel 15% Flow**	**Measure D: High-Flow Channel**	**Measure E: Pumping**	**Measure F: Ranney Wells**
Fish Species	Di	Di	Di	Di	Di	Di
Shovelnose sturgeon (and Pallid)	0.194 0.18	0.97 0.98	1	1	1	1
Paddlefish	0.53	0.98	1	1	1	1
Goldeye	0.53	0.98	1	1	1	1
Smallmouth buffalo	0.86	0.99	1	1	1	1
Blue sucker	0.53	0.98	1	1	1	1
White sucker	0.01	0.95	1	1	1	1
River carpsucker	0.47	0.98	1	1	1	1
Shorthead redhorse	0.53	0.98	1	1	1	1
Channel catfish	0.48	0.98	1	1	1	1
Smallmouth bass	0.54	0.98	1	1	1	1
Walleye	0.07	0.72	1	1	1	1
Sauger	0.20	0.76	1	1	1	1
Freshwater drum	0.54	0.98	1	1	1	1

Table 1-11 shows the resulting fish passage connectivity index and habitat units for each alternative.

Table 1-11. Fish Passage Connectivity Index Scores and Habitat Units.

Alternative	W/ Pallid, 14 Species		
	€ = Fish Passage Connectivity (Avg.)	**Avg. Habitat Units**	**Δ HUs**
A: No Action	0.08	938	**0**
B: Rock Ramp	0.43	5158	**4220**
C: Bypass Channel	0.67	8054	**7178**
D: Modified Side Channel	0.61	7432	**6556**
E: Multiple Pump Alternative	1	11949	**11073**
F: Multiple Pumping with Conservation Measures	1	11949	**11073**

2.0 Cost Effectiveness and Incremental Cost Analysis

The plan evaluation process utilized in this study is based upon methods described in the Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (U.S. Water Resources Council 1983) referred to as the P&G and the associated Corps implementation guidance found in Engineer Regulation (ER) 1105-2-100 Planning Guidance Notebook (U.S. Army Corps of Engineers 2000). The specific plan evaluation and comparison methods applied are from the *Evaluation of Environmental Investments Procedures Manual, Interim: Cost Effectiveness and Incremental Cost Analysis* document (U.S. Army Corps of Engineers 1995). This methodology consists of a series of steps that provide an orderly and systematic approach to comparing the costs and benefits of a range of alternative plans to inform the selection of a recommended plan. Plan formulation and evaluation is a dynamic process, whereby the steps may be iterated one or more times as new information or new alternatives are developed, or as planning objectives are reevaluated.

When planning for the restoration of environmental resources, cost effectiveness (CE) and incremental cost analyses (ICA) may be used as tools for the comparison of alternative plans (CE/ICA). CE/ICA are comparisons of the effects of alternative plans; more specifically, they involve comparisons between the outputs and costs of different solutions. Information about alternative plans and their effects must be developed in order to conduct the CE/ICA comparisons.

Traditional benefit-cost analyses are not applicable to environmental planning because costs and benefits are expressed in different units; however, CE/ICA offers plan evaluation approaches that are consistent with the P&G evaluation framework. The Institute for Water Resources (IWR) Planning Suite software was used to assist in performing the CE/ICA. Alternative plans were evaluated and compared in terms of cost (e.g. construction, operation, and maintenance) and environmental outputs over a 50-year period of analysis. IWR Planning Suite helps determine and present the relative efficiency and effectiveness of alternative plans at generating environmental outputs. The most efficient plans are referred to as "best buys." The Corps' policies for cost effectiveness and incremental cost analysis, ER 1105-2-100, paragraph E.36, states:

> *Cost effectiveness and incremental cost analysis are two distinct analyses that must be conducted to evaluate the effects of alternative plans. First, it must be shown through cost effectiveness analysis that an alternative restoration plan's output cannot be produced more cost effectively by another alternative. "Cost effective" means that, for a given level of nonmonetary output, no other plan costs less and no other plan yields more output for less money. Subsequently, through incremental cost analysis, a variety of implementable alternatives and various-sized alternatives are evaluated to arrive at a "best" level of output within the limits of both the sponsor's and the Corps capabilities. The subset of cost effective plans are examined sequentially (by increasing scale and increment of output) to ascertain which plans are most efficient in the production of environmental benefits. The most efficient plans are called "Best Buys." They provide the greatest increase in output for the least increases in cost. They have the lowest incremental costs per unit of output.*

2.1 Methodology

The CE/ICA analysis utilized the Corps IWR Planning Suite model. The Corps-certified model provides a systematic method for testing all possible combinations of ecosystem restoration measures to identify combinations of measures (alternative plans) which are cost effective, and then ranks cost effective plans according to their efficiency to identify "best buy" plans. Because this analysis considered six complete alternatives which were mutually exclusive, no alternatives were combined in the model. Instead, the software will identified which plans were cost effective, and then ranked the cost effective plans by efficiency to identify "best buy" plans. The CE/ICA model required the following inputs:

<u>Average annual habitat units (AAHUs) for each alternative:</u> Because habitat benefits are non-monetary, the outputs are referred to as "units" of output. In order to compare action alternatives to the no action alternative, AAHUs are typically converted to "net AAHUs," which is the change in habitat units versus the no action. Thus, the no action alternative is always entered as zero net AAHUs, and each alternative is entered as the additional AAHUs that would be generated compared the no action. AAHUs were developed using the FPCI Model as detailed previously in this appendix.

<u>Average annual cost for each alternative:</u> Costs used in the analysis included construction, PED/CM, real estate, monitoring and adaptive management, interest during construction, and operation, maintenance, and rehabilitation (OM&R). Annualized costs are presented at an FY16 price level, amortized over a 50-year period of analysis using the FY16 Federal interest rate for Corps of Engineers projects of 3.125% (U.S. Army Corps of Engineers 2015). Costs are described in detail in the Cost Appendix B.

2.1.1 Annualized Costs and AAHU's

Table 2-1 summarizes AAHUs for each alternative, in total and on net. As defined above, AAHUs are average annual habitat outputs, and net AHHUs are the change in output versus the no action alternative. Table 2-2 summarizes the annualized cost for each alternative. For each alternative, inputs to the model were the net AAHUs and the total annualized project cost.

Table 2-1. AAHU's By Alternative

Alternatives	Habitat Output	
	AAHUs	Net AAHUs
No Action	938	-
Rock Ramp	5,158	4,220
Bypass Channel	8,054	7,116
Modified Side Channel	7,432	6,494
Multiple Pump	11,949	11,011
Multiple Pumps w/ Conservation Measures	11,949	11,011

Table 2-2. Annualized Cost by Alternative ($1000)

	No Action	Rock Ramp	Bypass Channel	Modified Side Channel	Multiple Pump	Multiple Pumps w/ Conserv. Meas.
Construction	$0	$90,454	$57,044	$54,166	$131,474	$474,425
LERRDs	$0	$0	$0	$275	$554	$3,500
Adaptive Management	$0	$796	$538	$476	$1,143	$4,144
Sub-Total Cost	**$0**	**$91,250**	**$57,582**	**$54,917**	**$133,171**	**$482,069**
IDC, Present Value	$0	$1,880	$2,002	$1,124	$6,557	$53,790
Annual O&M	$2,643	$2,840	$2,799	$2,907	$5,034	$4,386
O&M Present Value	$66,420	$71,370	$70,333	$73,046	$126,507	$110,212
Total Project Cost, Present Value	$66,420	$164,500	$129,917	$129,087	$266,235	$646,071
Total Annualized Project Cost	**$2,643**	**$6,546**	**$5,170**	**$5137**	**$10,594**	**$25,709**

LERRDs – lands, easements, rights-of-way, relocations, and disposal areas (real estate)
IDC – interest during construction
OM&R – operation, maintenance, and rehabilitation

2.2 Cost Effectiveness Analysis

Cost effectiveness analysis is a form of economic analysis designed to compare costs and outcomes (or effects) of two or more courses of action. This type of analysis is useful for environmental restoration projects where the benefits are not measured in monetary terms but in environmental output units such as the Habitat Units developed in this study. The purpose of the cost effectiveness analysis is to ensure that the least cost plan alternative is identified for each possible level of environmental output; and that for any level of investment, the maximum level of output is identified. Per IWR 95-R-01, an alternative is *not* to be considered cost effective if any of the following rules are met:

1. The same output level could be produced by another plan at least cost;
2. A larger output level could be produced at the same cost; or
3. A larger output level could be produced at less cost.

Table 2-3 provides the results of the cost effectiveness analysis sorted by increasing output. As shown in the table, alternatives were identified as cost effective only when no other alternative provided the same output for less cost, and no other alternative provided larger output at the same or less cost. The No Action, Bypass Channel, Modified Side Channel and Multiple Pump alternatives were identified as cost effective. The Rock Ramp alternative is not cost effective because the Bypass Channel alternative provides greater output for less cost. The Multiple Pumps with Conservation Measures alternative is not cost effective because the multiple pump stations alternative provides the same level of output for less cost.

Table 2-3. Cost Effectiveness by Alternative

Alternative	Annual Cost ($1000)	Net AAHUs	Cost per AAHU ($)	Cost Effective?
No Action	$0	0	$0	Yes
Rock Ramp	$6,546	4,220	$1,551	No
Modified Side Channel	$5,137	6,494	$791	Yes
Bypass Channel	$5,170	7,116	$727	Yes
Multiple Pump	$10,594	11,011	$962	Yes
Multiple Pumps w/ Conservation Measures	$25,709	11,011	$2,335	No

Figure 2-1 provides a graph of the total output and annualized costs for each of the alternatives while differentiating the cost effective plans from the non-cost effective ones. Per IWR 95-R-01, any alternatives that are not found to be cost effective “should be dropped from further analysis” in the CE/ICA process. Therefore the Rock Ramp and Multiple Pumps with Conservation Measures alternatives are not included in the ICA analysis that follows.

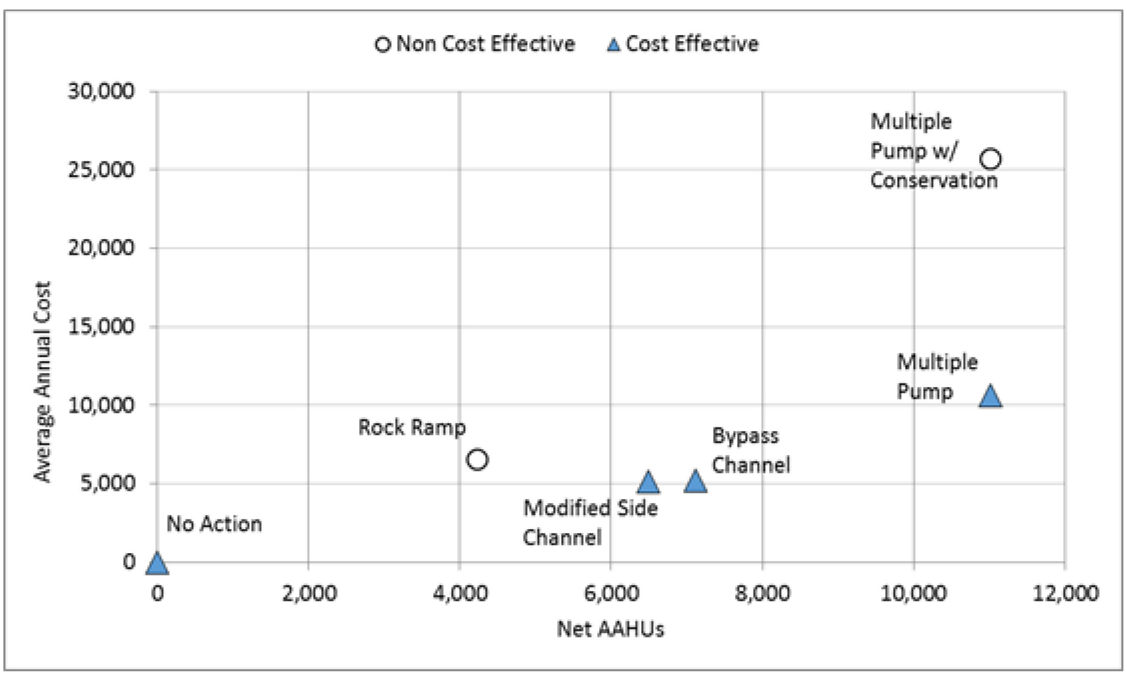

Figure 2-1. Cost Effectiveness Analysis Graph

2.3 Incremental Cost Analysis

Subsequent incremental cost analysis of the cost effective plans is conducted to reveal changes in costs as output levels are increased. Only plans that were deemed as cost effective in the CE analysis have been advanced to ICA. These cost effective plans are the No Action, Bypass Channel, Modified Side Channel and Multiple Pump alternatives. During the ICA, the cost effective plans are examined sequentially (by increasing scale in terms of net AAHUs produced) to ascertain which plans are most efficient in the production of additional environmental benefits.

The first step, per IWR 95-R-01, is to "smooth out fluctuations in incremental costs per unit as project scale increases such that incremental cost per habitat unit are continuously increasing." This is first completed by calculating the incremental cost per unit for each plan over the "baseline condition," which is the no action plan. Once the incremental costs per unit are calculated and sorted by increasing output, the alternative with the lowest incremental cost per unit will be selected as the first "best buy" alternative. Table 2-4 shows the calculation of the incremental costs per unit with the no action alternative set as the baseline for the cost effective alternatives.

Table 2-4. Identification of the First Best Buy Plan

Alternative	Annual Cost ($1000)	Net AAHUs	Incremental Output	Incremental Cost	Incremental Cost per Unit Output
No Action	$0	0	0	n/a	n/a
Modified Side Channel	$5,137	6,494	6,494	$5,137	$791
Bypass Channel	$5,170	7,116	7,116	$5,170	$727
Multiple Pump	$10,594	$11,011	$11,011	$10,594	$962

Table 2-4 indicates that the Bypass Channel alternative is the first best buy alternative because it has the lowest incremental cost per unit of output. At this step of the ICA the incremental cost per unit is equal to the average annual cost per unit values calculated in Table 2-3 because complete alternatives are being compared, not combinations of measures.

After selection of this best buy alternative, per IWR 95-R-01, all alternatives with lower average annual output are removed from further iterations of the incremental cost analysis. Thus the No Action and Modified Side Channel alternatives are removed from further analysis and are not considered best buy plans.

Next, the incremental process should be started anew with the first best buy plan. Thus the Bypass Channel is set as the new baseline. However, for this study only the Multiple Pump alternative is remaining, and is therefore a best buy plan as well since no other plans can produce more output for lower incremental cost per unit.

The final step in the ICA process is to analyze the incremental cost per incremental unit of output for the best buy alternatives only. This includes the No Action, Bypass Channel, and Multiple Pump alternatives. Incremental costs are calculated between each successive best buy plan. Table 2-5 shows the incremental cost per unit output between the three best buy alternatives.

Table 2-5. Incremental Cost Analysis Summary

Best Buy Alternative	Annual Cost ($1000)	Net AAHUs	Incremental Output	Incremental Cost	Incremental Cost per Unit Output
No Action	$0	0	0	n/a	n/a
Bypass Channel	$5,170	7,116	7,116	$5,170	$727
Multiple Pump	$10,5594	11,011	3,895	$5,424	$1,393

This table shows that the most efficient plan above No Action is the Bypass Channel alternative that provides 7,116 additional habitat units at a cost of $727 each. If more output is desired, the next most efficient plan available is the Multiple Pump alternative that provides an additional 3,895 habitat units, at a cost of $1,393 dollars for each additional unit. Figure 2-2 provides a visual representation of this increase in incremental cost. The figure graphically illustrates the incremental cost and output differences between the two best buy action alternatives. The width of each box in the chart represents the incremental output of that plan, and the height of each box shows the incremental cost per unit of that output. The relatively wide box for the Bypass Channel alternative shows that it provides about 65% of the total output possible at a cost of approximately $699 per unit. The box for the Multiple Pump alternative shows that to achieve the remaining 35% of total possible output would be more expensive per unit than the first 65%. Such breakpoints in incremental cost per unit typically require a higher level of justification if the study team is to recommend the larger output plan.

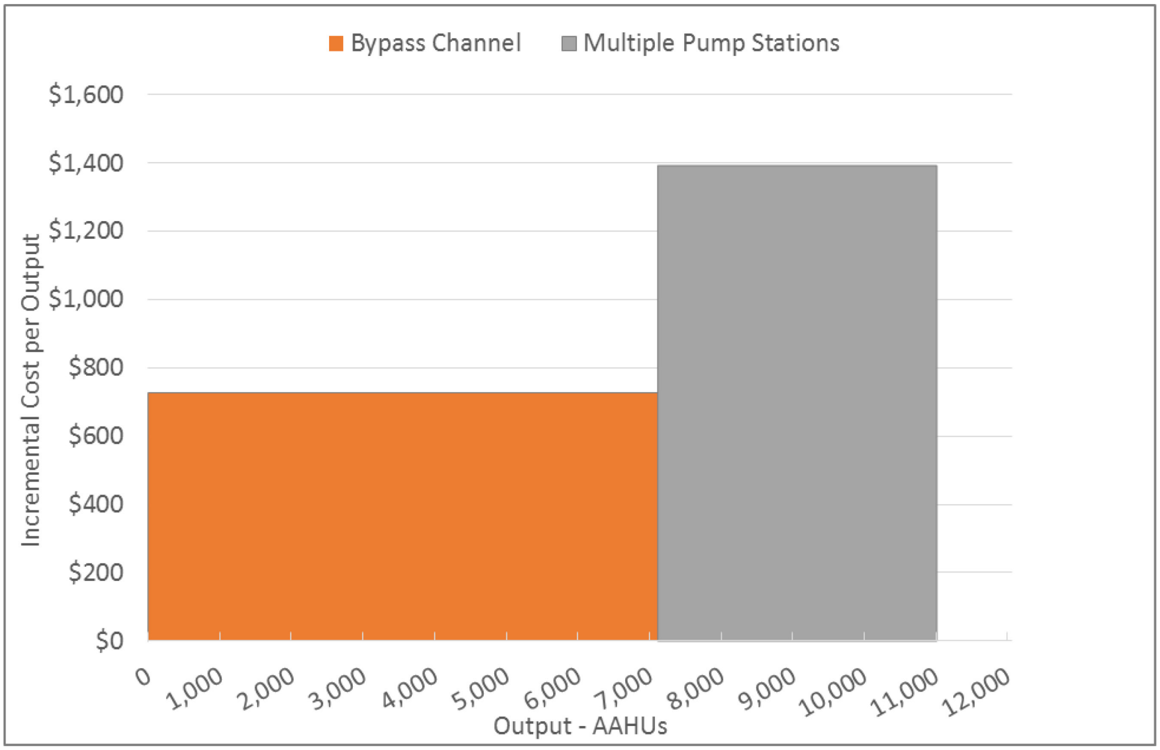

Figure 2-2. Incremental Cost Analysis Chart

2.4 Summary of Conclusions

The results of the CE/ICA do not provide a discrete decision for selecting the preferred plan, but rather they offer organized data on the effectiveness and efficiency of the range of alternatives under consideration to help inform a decision. For Corps ecosystem restoration projects, the selected plan should be the alternative having the maximum excess of non-monetary benefits (habitat output) over costs. This plan occurs where the incremental beneficial effects just equal the incremental costs, or alternatively stated, the recommended plan is selected by identifying the largest plan for which the extra habitat output is still worth the extra costs. Definition of the level of output that is "worth it" is a concern for the study team that will consider specific project factors and information.

Thus, a plan that reasonably maximizes ecosystem restoration benefits compared to costs, consistent with the Federal objective, can be identified as the selected plan. The selected plan should also be cost effective and justified in achieving the desired level of output. In practice, the selected plan is chosen from the suite of cost effective plans identified in the CE/ICA. While the selected plan is not required to be a best buy plan, this is typically the case.

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