Adrienne McKell

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CEE 6410

Linking fish habitat on the bear river

A MULTIPLE INTEGER PROBLEM

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## Abstract

The habitat for Bonneville Cutthroat Trout (BCT) in the Bear River is fragmented into multiple sections by three hydroelectric dams and the Rainbow Inlet Canal, significantly limiting connectivity and migration. This paper presents a solution using a Mixed-Integer Programming model to optimize habitat restoration by maximizing connectivity of these sections. The model evaluates options for dam removal or fish passage installation at each site to maximize habitat connectivity while considering associated costs. The goal is to provide decision-makers with a comprehensive framework to assess the ecological and environmental impacts of these barriers, aiding in determining the future of the dams and improving conditions for BCT conservation.

## Introduction

Fish passage barriers — such as hydropower dams, culverts, and diversions — significantly disrupt aquatic ecosystems by obstructing critical habitats and altering hydrological processes. In the Bear River system, these disruptions are exacerbated by aging infrastructure. For example, the Cove Dam was removed in 2006 during a Federal Energy Regulatory Commission (FERC) relicensing process. However, other dams in the system — Soda, Grace, and Oneida — remain operational with limited fish passage provisions.

This project evaluates strategies to enhance fish passage while balancing the ecological benefits with the economic impacts on PacifiCorp, the dam operator. Specifically, the study explores whether removing or retrofitting these three dams can improve habitat connectivity for native fish species while minimizing costs. A multiple-integer optimization model developed in GAMS is used to assess trade-offs between restoring aquatic habitat and reducing financial burdens. By integrating hydrological, economic, and ecological data, the model seeks solutions that benefit both fish populations and human stakeholders.

## Background

The Bear River, home to the Bonneville Cutthroat Trout (BCT), has experienced significant habitat fragmentation due to infrastructure for irrigation, flood control, and hydroelectric power. Initiated in 1907, the Bear River Project led to the construction of three hydropower dams — Soda, Grace, and Oneida — along with the Rainbow Inlet and Dingle (Telluride) Canals. Completed in 1927, these structures altered the river's natural flow and created barriers that disrupted the migratory and spawning behaviors of native fish species, particularly fluvial BCT.

These dams and canals have divided the river into isolated segments, hindering BCT migration and spawning success (Hillyard 2009). This project focuses on four key segments between the Rainbow Canal and Cutler Reservoir (see Figure 1 and 2). To restore connectivity and habitat, potential solutions include dam removal or installing fish passage systems at the dams and the Rainbow Inlet Canal.

Given that all three dams are over 100 years old and in need of substantial repairs, this study assesses the feasibility of similar measures to the 2006 removal of Cove Dam. By offering PacifiCorp a framework for removal or retrofitting with fish passage, the project also highlights potential eligibility for federal and state funding opportunities seen in comparable dam removal projects. This dual approach aims to balance ecological restoration with financial practicality.

A map of the state of idaho

Description automatically generated

Fish Barriers

Dam

 Canal

Figure 1 Map of Bear River identifying fish barriers (Hillyard 2009)

## Model Formulation

Although fish habitat improvement is deeply nuanced and have innumerable variables, one of the most important criteria for a suitable habitat is size of habitat. For this term project, I focused on habitat length specifically on connecting reaches of the bear river. This is important for BCT because of their migratory behavior throughout the year for spawning. By connecting the fish to more habitat they will have more opportunities to access clear, cold water sufficient for their life stage (Budy et al. 2007). Since barrier removal has already been experienced in this region (“2004-06-14\_Cove\_Feasibility\_Study” n.d.) and has been modeed before (Kraft et al. 2019). The narrative of strategic prioritization of barrier removal for river restoration is both developing and current.

To make this problem linear I chose a section of the river that was in line with each other. These reachers are from downstream of each dam or canal to the upstream of the next dam as shown in Figure 2. In this figure Rainbow and Cutler are both greyed out to denote that these are endcaps (i.e most upstream and most downstream) of the section of this project and are not being evaluated for this project. See further discussion on this decision in the discussion section of this report.

A red triangle with a blue arrow

Description automatically generated

Figure 2 Schematic of sites and reaches considered in the project

### Objective Function

The objective function in this model aims to maximize river connectivity by selecting the optimal set of fish passage options. Specifically, the function is defined below in equation (1) as:

( 1)

S.T ( 2)

Where represents different choices of connectivity (ranging from to ), denotes the total river length associated with each connectivity choice (measured in miles), and is a binary decision variable indicating whether a particular connectivity option is selected (1 for yes, 0 for no). This function ensures that the selected options maximize the length of connected river reaches for fish passage, thereby enhancing habitat availability. The optimization is subject to a budget constraint, ensuring that the total cost of implementing fish passage or dam removal remains within the available budget. By balancing connectivity gains and costs, this objective function helps identify the most effective strategies for restoring fish habitat.

### Decision Variables

The decision variables in this optimization problem are: the binary decision variable indicating whether to remove a dam or add fish passage at site i, the binary decision variable indicating which connectivity choice is selected, the binary decision to indicate whether a site i has been modified (by removal or passage), the total length of river reaches where fish passage is restored, and the total cost of implementing decisions, constrained by budget.

### Constraints

The optimization model relies on structured tables and constraints to evaluate potential strategies for improving fish passage while staying within budgetary limits. The tables provide essential data inputs: the Connectivity Table (see Table 1) maps each connectivity option to specific river reaches, which is used to sum up each of the river lengths in that choice. These length can be found in Table 2. The Conex Table links these choices to the corresponding dam sites, indicating where removal or fish passage installation occurs. Additionally, the Cost Parameter Table (see Table 3) specifies the cost of dam removal or fish passage for each site, ensuring financial impacts are quantified. The constraints ensure feasible solutions by enforcing budget limits, restricting each site to a single action (removal or passage), and requiring the selection of only one connectivity option. Collectively, these tables and constraints help balance ecological restoration goals with financial practicality, guiding decisions that maximize habitat connectivity within the available budget.

Table 1 Connection choices and their reach lengths

|  |  |
| --- | --- |
| Choices of  Connection ( | Sum of Reach Length |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

Table 2 Reaches (r) and their lengths

|  |  |
| --- | --- |
| Reach  (*r*) | Length of Reach (miles) |
|  | 40 |
|  | 6 |
|  | 50 |
|  | 70 |

Table 3 Cost of dam removal and fish passage for each site

|  |  |  |
| --- | --- | --- |
| Site | Dam Removal | Fish Passage |
| B | $1000 | $500 |
| C | $2000 | $1000 |
| D | $3000 | $1500 |

## Assumptions

This study is based on several general assumptions that simplify the problem for practical purposes. First, I assumed that fish cannot pass through barriers while traveling upstream or downstream, and each reach is considered insular. While this assumption holds for upstream travel (Hillyard 2009),it is less accurate for downstream migration. This assumption was made to simplify the model and convert it into a linear format. Additionally, I limited the number of connectivity options to seven within the specified reaches. Although there are more potential barriers—such as the Cutler Dam, Rainbow Canal, and numerous other fish passage obstacles that could be considered—this was done to make the project feasible and focused. Expanding the model to account for all possible barriers would certainly increase its robustness(Alafifi and Rosenberg 2020; Kraft et al. 2019), but was outside the scope of this analysis. Furthermore, the costs associated with dam removal and fish passage were treated as fixed, ignoring potential variations due to site conditions or unforeseen challenges in construction. The budget was also assumed to be fixed, without considering possible funding adjustments or phased investments over time. This simplification excludes the impact of temporal factors, such as the timing of actions and associated changes in costs, which would further complicate the model.

In terms of environmental assumptions, this model takes an all-or-nothing approach to connectivity restoration. When a connectivity option is selected, it assumes that all associated reaches are fully restored, with no consideration for partial or incremental improvements. The lengths of the river reaches between sites are treated as fixed values, unaffected by changes in hydrology or river morphology. Perhaps the most significant assumption is that dam removal or fish passage installation will fully restore fish passage across the affected reaches. While this assumption is necessary for the model's simplicity, it overlooks the reality that fish passage is rarely as effective as having no barrier at all (Schilt 2007).

While these assumptions may not fully capture the complexity of real-world scenarios, they are necessary to make the model computationally manageable and focused on the primary objective: evaluating the trade-offs between habitat restoration and cost. The assumptions also allow for the creation of a framework that can be expanded and refined in future studies. Despite their limitations, this model provides valuable insights into the decision-making process regarding fish passage in the Bear River system, offering a practical tool for guiding decisions and further research. By incorporating environmental, financial, and operational considerations, this study can inform both policy decisions and future research, even if it does not capture every nuance of real-world dynamics.

## Results and Discussion

I used the general algebraic modeling system (GAMS) to solve this optimization model. Figure 3 displays the results of this problem. Initially, as the cost increases, the habitat length also increases. However, after reaching a certain cost level, the graph levels off, indicating that further increases in cost no longer lead to additional habitat restoration. This suggests that the optimal investment point for maximizing habitat restoration occurs at a cost around the point where the graph transitions from an upward slope to a flat line. One thing to note is that between the cost of $2000 and $6000 the model picks fish passage for all of the sites and at $6000 then it switches to choosing all dam removal. This would probably change if the price constraints were more accurate.

Figure 3 Habitat Lenth vs. Cost

Overall, completing this project was both challenging and rewarding. The most significant challenge I faced, after selecting the topic, was simplifying the model to a linear format. I found two highly valuable examples of similar models, which, although more complex than mine, provided useful insights. These examples not only deepened my understanding of the subject but also assisted in the development and programming of my own model, making the process more manageable and enriching.

## Conclusion

In conclusion, this study presents a valuable framework for evaluating strategies to improve fish passage in the Bear River system, balancing ecological restoration goals with financial constraints. The optimization model effectively identifies the most cost-effective strategies for enhancing habitat connectivity, focusing on dam removal and fish passage installation at key sites. While the model's assumptions simplify the complexities of real-world scenarios, such as treating costs as fixed and assuming full connectivity restoration, these assumptions make the problem computationally feasible and provide a clear basis for decision-making. Despite these simplifications, the model offers important insights into the trade-offs between ecological benefits and financial considerations, serving as a useful tool for guiding future decisions in river restoration. This approach can be further refined in subsequent studies by incorporating more detailed cost and environmental data, providing a more nuanced understanding of the optimal strategies for BCT conservation.

## Appendix

### GitHub Project Repository

<https://github.com/adrienne-usu/CEE-6410-McKell/tree/main/Semester%20Project>

* [GAMS Code](https://github.com/adrienne-usu/CEE-6410-McKell/blob/main/Semester%20Project/SemesterProject.gms)
* [GAMS Solution Report](https://github.com/adrienne-usu/CEE-6410-McKell/blob/main/Semester%20Project/SemesterProject.lst)

### Model Formulation

Formulation for Multi-Objective Integer Program (MIP)

s.t.

Decision Variables

: Binary decision variable indicating whether to remove a dam or add fish passage at site i

: Binary decision variable indicating which connectivity choice is selected

: Binary decision to indicate whether a site i has been modified (by removal or passage)

: Total length of river reaches where fish passage is restored, this is the objective to maximize

: Total cost of implementing decisions, constrained by budget

#### *Parameters*

: The cost associated with removing the dam or adding fish passage at site *i* ($)

: The length of the river reach *r* between two sites (miles)

: The total budget available for implementing decisions ($)

#### *Tables*

; Denotes which choice (j) restore connectivity on specific reaches (r)

: Which sites (i) are modified (either removed or passage) for each choice (j)

#### *Equations/Constraints*

Objective:

Cost Constraint:

Link Choice:

Single Choice:

Passage Mutual Exclusivity:

Action At Site:

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