Fish Passage and Stream Barrier Management in the Bad River Watershed in Northern Wisconsin

A Case Study from the Structured Decision Making Workshop
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Decision Problem

The U.S. Fish and Wildlife Service's (Service) Fish and Wildlife Conservation Office in Ashland, Wisconsin (Ashland FWCO) works with local partners to restore habitat for fish and other aquatic species within the Bad River Watershed (BRW) in northern Wisconsin. There are over 1,100 perched culverts within the watershed and many of these are barriers to fish passage (Bad River Watershed Association 2007). The Service's restoration work in the BRW is conducted under the authority of the Great Lakes Fish and Wildlife Restoration Act (as well as other enabling federal legislation and policies) and is consistent with the culvert inventory and remediation component of the Bad River Watershed Association's Strategic Plan (Bad River Watershed Association 2008).

In general, the removal or modification of barriers to allow for fish passage has beneficial impacts to the watershed (e.g., improving connectivity, restoring hydrology, and increasing spawning access for fish). However, in certain cases, it may also be detrimental to ecosystem health (e.g., opening habitat for invasive species such as sea lamprey (*Petromyzon marinus*) and allowing passage of migratory fish with elevated contaminant levels that may subsequently impact piscivorous wildlife such as bald eagles (*Haliaeetus leucocephalus*)). In collaboration with local partners, the Ashland FWCO decides how to best manage barriers and restore fish passage within the BRW. Management options include: barrier removal, barrier replacement, barrier modification, and barrier construction. Funding proposals for barrier management activities are developed annually within the context of a ten year planning period for managing barriers within the watershed.

Decisions involving the potential to increase sea lamprey spawning habitat within the watershed must include concurrence from the Service's Sea Lamprey Control Program. Decisions should also be made in collaboration with the Service's Ecological Services Program to determine the risk of upstream migration of contaminants to fish-eating wildlife. We developed an initial

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prototype of a decision structure for solving this multiple objective decision problem at a workshop held at the National Conservation Training Center December 8-12, 2008.

This case study considers the Great Lakes tributary fish passage and barrier management problem from the perspective of Service decision making, e.g., where best to allocate Service funds and resources. It was developed as a rapid prototype at a one-week workshop. This report illustrates a way to structure this decision analysis to help the Service find the 'best' barrier management solutions. While we chose to focus on the Service's mandates and programs, we recognize that watershed management encompasses numerous issues important to other agencies and stakeholders in the region. Fortunately, the decision structuring approach that we prototyped will be useful to all partners in Great Lakes tributary watershed management because we face a common decision-making challenge—that is, figuring out how best to balance among multiple, sometimes conflicting objectives.

Background

Legal, regulatory, and political context

The mission of the Service is to work with others to restore, protect, and enhance fish, wildlife, plants, and their habitats for the continuing benefit of the American people. The Ashland FWCO conducts habitat and species restoration activities within the BRW under several federal fish and wildlife management authorities. The most relevant include: the Great Lakes Fish and Wildlife Restoration Act, the Fish and Wildlife Coordination Act, and the Partners for Fish and Wildlife Act. In addition to these, the Service's National Fisheries Program has seven key focus areas that guide its work, including: 1) Partnerships and Accountability; 2) Aquatic Species Conservation and Management; 3) Public Use; 4) Cooperation with Native Americans; 5) Leadership in Science and Technology; 6) Aquatic Habitat Conservation and Management; and 7) Workforce Management (U.S. Fish and Wildlife Service 2002).

The Service has at least five other key responsibilities within the context of the BRW and the Great Lakes Basin. First, is the Service's role in the management of interjurisdictional fish and wildlife species (species that cross state and country borders), such as migratory brook trout (*Salvelinus fontinalis*) and lake sturgeon (*Acipenser fulvescens*). Second, is the Service's role, along with the Department of Fisheries and Oceans, Canada and the Great Lakes Fishery Commission, in implementing a comprehensive program for sea lamprey control. Third, is the protection of species in the Great Lakes Basin listed as federally threatened and endangered (T&E) under the Endangered Species Act (ESA). Fourth, although the bald eagle is no longer listed under the ESA within the Great Lakes Basin, it is still protected via several statutes including the Bald and Golden Eagle Protection Act, which in part prohibits disturbance of eagles that leads to a "decrease in productivity by substantially interfering with normal breeding, feeding, or sheltering behavior." Finally, the Service's policy on working with Native Americans emphasizes the Service's role in providing technical assistance and support for fish and wildlife management to Native Americans (U.S. Fish and Wildlife Service 1994). A portion of the Bad River Band of Lake Superior Chippewa Indians' (Bad River Band) reservation is located within the BRW.

Stakeholder involvement includes Ashland, Bayfield, and Iron Counties, as well as the towns that own culverts and maintain road-stream crossing infrastructure within the BRW. A key and active partner with the Service is the Bad River Watershed Association, a community organization that assists citizens with gathering information, identifying problems, and implementing solutions to maintain the integrity of the watershed for future generations. They have been directly responsible for inventorying over 700 culverts in the watershed (Bad River Watershed Association 2007) and have identified culvert inventories and remediation as a focus in their Strategic Plan (Bad River Watershed Association 2008).

The Wisconsin Department of Natural Resources (DNR) is also a stakeholder and has designated almost 630 stream miles within the BRW as having potential cold water fishery stream use—of which 118 miles are designated as Outstanding Resource Waters and 140 miles are designated Exceptional Resource Waters (Wisconsin Department of Natural Resources 1999 and 2006). The DNR also lists two important Conservation Opportunity Areas in the Bad River watershed: the Superior Coastal Plain Ecological Landscape and the North Central Forest Ecological Landscape (Wisconsin Department of Natural Resources 2005). Coordination with the DNR and the Bad River Band's fishery program has been essential to addressing fish population and habitat goals of each resource agency involved in the BRW. Other stakeholders in the BRW include: Northland College, Trout Unlimited, and the Chequamegon-Nicolet National Forest. The Service's Fish Passage, Partners for Fish and Wildlife, and Coastal Programs have provided matching funds and technical expertise for restoration activities.

Ecological context

The BRW is a sparsely populated, largely forested area of northern Wisconsin that covers 700,000 acres (1,094 square miles) in the Lake Superior Basin (Figure 1). With about 1,140 miles of streams, the BRW supports one of the most diverse fish assemblages in the basin. There are seven sub-watersheds within the BRW: the Upper Bad River, the Lower Bad River, the White River, the Marengo River, the Potato River, Tyler Forks, and Bear Trap Creek. The watershed is characterized by gently sloping clayey landscapes with steep, incised ravines. Land use changes, predominantly road building, land clearing, and logging practices, have contributed to increased stream runoff, erosion, and non-point source pollution. Barriers to fish passage are also a problem. There are over 1,100 road crossings in the watershed and many are perched culverts presenting barriers to fish passage (Bad River Watershed Association 2007).

Tributaries to the Great Lakes are critical for fish production. Barriers (culverts and other man-made barriers such as dams) negatively impact populations of fish and other aquatic organisms by limiting movement into and within tributaries, reducing available habitat, altering ecological functions, and reducing genetic diversity. The removal or modification of barriers can have beneficial impacts on a stream ecosystem. First, it allows free upstream and downstream movement of fish and other aquatic organisms. Second, it can provide access to quality spawning and rearing habitats. Third, remediation of perched culverts (the most prevalent barrier type in the BRW) and bank stabilization can reduce sedimentation into streams and help redistribute sediment that has been deposited upstream. Finally, restoring stream connectivity could reduce population fragmentation and ultimately improve the genetic integrity of fish and other aquatic

species populations. In the case of the BRW, improved upstream habitats will eventually result in improved habitat downstream and in the Kakagon sloughs.

Although removing and modifying barriers can provide many benefits to the aquatic ecosystem, these activities, depending on a barrier's location, can also present certain hazards. The hazards we focused on for this case study are: 1) the introduction and spread of non-native fish species—with a focus on sea lamprey, and 2) the upstream transfer of contaminants from Lake Superior fish. Both have consequences that would ultimately reduce ecosystem health. There are several other hazards associated with removing or modifying barriers, which we acknowledged but did not explore as part of this first prototype case study. These include: the downstream release of contaminated sediments, the spread of pathogens and diseases, increased competition between native and non-native fish, and genetic introgression of naturalized hatchery-origin fish with native heritage strains.

The BRW is one of the largest sea lamprey producing watersheds in the Lake Superior Basin. Adult sea lamprey spawn within the BRW and their larvae grow for approximately three years in the streambed before migrating back to Lake Superior. Once in the lake, sea lamprey parasitize and kill adult fish, especially lake trout (*Salvelinus namaycush*). As barriers are removed to improve fish passage in the BRW, sea lamprey might also benefit by gaining access to additional spawning habitat. Methods used to control sea lamprey in the Great Lakes include: trap and removal of adult spawning lamprey, the release of sterilized males, applying lampricides to streams to kill larvae, and the construction and maintenance of sea lamprey barriers to deny upstream access to spawning habitat. If left uncontrolled, sea lamprey would destroy tens of thousands of lake trout annually, which would have a devastating impact on the Lake Superior fishery and ecosystem.

There are also concerns of other invasive species moving upstream into the watershed such as Eurasian ruffe (*Gymnocephalus cernuus*), rainbow smelt (*Osmerus mordax*), carp (*Cyprinus carpio*), round gobies (*Neogobius melanostomus*), and zebra mussels (*Dreissena polymorpha*). Removal of migration barriers could also open tributary streams to movement of naturalized non-native salmonids, such as coho salmon (*Oncorhynchus kisutch*) from Lake Superior. Recent research points to competition between non-native salmonids and native brook trout for food, nursery areas, and spawning habitat (Huckins et al. 2008).

The other major concern we addressed related to increasing fish passage is the transport of toxins through fish movement from Lake Superior into the upper reaches of the BRW. Fish in Lake Superior contain several contaminants, including: polychlorinated biphenyls (PCBs), mercury, and chlordane, which present human and environmental health concerns. Negative impacts, such as reduced productivity, may occur when contaminant laden fish from the Great Lakes migrate upstream and are eaten by piscivorous species (e.g. black bear (*Ursus americanus*), bald eagle, American crow (*Corvus brachyrhynchos*), mink (*Neovison vison*), river otter (*Lontra canadensis*), etc.). Contaminants found in Great Lakes fish flesh have been shown to impact productivity of bald eagles nesting in coastal areas or rivers in which fish can pass to upstream areas (Best et al. 1994 and Bowerman et al. 1995). Therefore, proposing fish passage from Lake Superior to interior upstream areas requires carefully weighing the benefits of allowing fish passage against the potential risk to upstream piscivorous species.

Decision Structure

Objectives

We used brainstorming to identify a set of five fundamental objectives and associated means objectives for the long-term decision of how to best manage the barriers in the BRW. *Fundamental objectives* and sub-objectives (which are still fundamentally important) are ultimate desired endpoints and *means objectives* help to achieve fundamental objectives (Hammond et al. 1999). The objectives are based on the Service's mission and specific management needs within the BRW. Figure 2 outlines the fundamental objectives, means objectives, and the measurable attributes that were identified for this preliminary prototype. We recognize that these objectives would be reviewed, revised and expanded as needed in collaboration with watershed partners for subsequent implementation of the decision process.

Fundamental objectives:

A. **Maintain or Restore Native Fish and Other Aquatic Species**: We decided to focus on the brook trout fishery under this objective as our primary sub-objective since this species is a focal species for barrier management activities in the BRW. The objective supports healthy native fish populations, which entails: increasing available spawning and rearing habitat for native fish and other aquatic species, minimizing spread of fish disease, and minimizing loss of native species genetic diversity. To achieve this objective, we wanted to maximize the habitat available for brook trout.

B. **Manage Total Costs:** The Service and its partners contribute funding to barrier management activities. It is in the interest of all stakeholders to minimize total costs and maximize resource benefit so that more can be accomplished with the limited funding available. Total costs were divided into the following three means objectives associated with the range of barrier management actions: 1) culvert removal, replacement, or modification costs; 2) sea lamprey control costs; and 3) major project costs (e.g., dam removal and building barriers). To achieve this objective, we wanted to minimize costs.

C. **Manage Trust Species:** This objective covers the Service's mandates to protect, conserve, and recover or restore healthy populations of trust species and species of tribal importance (e.g., T&E species, migratory birds, inter-jurisdictional species such as lake sturgeon). Three sub-objectives were identified: 1) lake trout in relation to sea lamprey impacts on the population; 2) bald eagles as a sentinel species in relation to potential impacts of contaminants on the watershed; and 3) estuary health as a measurement of interjurisdictional species and species of tribal interest, such as wild rice (*Zizania palustris*). To achieve this objective, we wanted to: minimize populations of sea lamprey, minimize the availability of contaminated fish from Lake Superior to bald eagles nesting inland that do not currently feed directly from Lake Superior, and minimize the deposition of sediments in the BRW estuary to protect important spawning and rearing habitat of several trust resources and prevent negative effects on wild rice beds that are significant resources to the Bad River Band.

D. **Allow for Public Use:** We are interested in maximizing opportunities for public use within the BRW. We focused on angler use as a measure of public use. We have data for angler use from the DNR for the White River Fishery Area (Toshner and Manz 2008). Most anglers in this area target brown trout. We separated this objective into two means objectives: 1) the anadromous fishery, restricted to below first barriers[9], and 2) the brown trout fishery, restricted to above first barriers. To achieve this objective, we wanted to maximize angler use of the BRW.

E. **Foster Stakeholder Support:** All barrier management activities in the BRW are conducted in collaboration with partners. None of the fish passage projects can be completed without stakeholder support. All roads and dams are owned by other stakeholders and the streams are a public resource. We decided to divide this objective into means objectives that would address: 1) active opposition and 2) active support. To achieve this objective, we wanted to minimize active opposition and maximize active engagement and support of partners.

One constraint associated with developing these objectives was the limits of the stakeholder interests represented at the workshop. The workshop was conducted in part as a training opportunity for Service employees working on these issues within the Great Lakes Basin. Our goal was to develop an initial draft decision structure that could then be used as a starting point for future discussions in the BRW. We attempted to capture a range of possible stakeholder interests within the BRW in our prototype to demonstrate how divergent interests can be addressed in the decision structure; however, we recommend that a broad group of stakeholders engage in future decision making on this issue (see Recommendations section on page 11). Several additional constraints exist with respect to pursuit of these fundamental objectives. The first is uncertainty due to lack of information on: 1) the physical dynamics of sediment movement within the BRW as a response to barrier remediation, and 2) the community and population impacts of competition between native brook trout and non-native salmonids where they overlap—or could overlap—in the future within the BRW (see Uncertainty section on page 9). Second are the fiscal constraints—whether from the Service or partnering agencies—that can limit our ability to pursue and achieve these objectives on an annual basis.

Alternative actions

We used the objectives to help identify the following four general types of management actions: 1) removing, replacing, or modifying culverts that are obstructing fish passage *above or upstream* of the 1st barrier; 2) dam removal or fishway[10] construction at a dam site; 3) culvert removal, replacement or modification *below or downstream* of the 1st barrier[11]; and 4) build a new barrier with a fishway. For each of these management action categories, we identified specific implementation options (including no action) and from this developed a strategy table

[9] A 1st barrier is defined as the first barrier upstream from Lake Superior which prevents all fish and other aquatic species from passing upstream. First barriers in the BRW include three natural falls, four man-made dams, and numerous perched culverts.
[10] A fishway is defined as a manmade structure that allows passage of all fish with the exclusion of sea lamprey.
[11] We assume that most adult salmonids from Lake Superior can pass through culverts that are below or downstream of the 1st barrier.

(Table 1). Similar to an 'al a carte' menu organized by meal courses (e.g., appetizer, soup/salad, main course, dessert, and drinks), strategy tables organize management actions by logical categories and under each category identify a range of available actions. This organization helps us to select a mix of actions from across the categories to design strategic 'meals' or decision alternatives. Table 1 highlights the range of management action categories and the suite of implementation options for each management action that we identified for the BRW. Note that this is not an exhaustive list of possible BRW management actions or implementation options for those actions. Our group developed this as a place to start and as a basis for developing a preliminary decision framework for this issue. We expect that this table will be modified in the future to address different or additional stakeholder management interests.

Next, we created seven decision alternatives by developing simple portfolios of management actions with strategic themes, as highlighted in our alternatives table (Table 2) and further described below. These alternatives represent management actions favorable to specific stakeholder or resource interests and were constructed by selecting the appropriate implementation option(s) from each of the four types of management actions:

A. **Status Quo Alternative:** This alternative would replace culverts both above and below the 1st barrier. 1st barriers would remain in place where they prevent sea lamprey access to additional spawning habitat. Quality habitats would be targeted and culvert replacement would start downstream, and work upstream on streams that have a series of barrier culverts. Sea lamprey control would not change from the current status. There would be no new barriers added and no dam modifications for fish passage.

B. **Tribal Interest Alternative:** This alternative focuses on the Bad River Tribe's desire to reduce or eliminate lampricide application for sea lamprey control, provide fish passage where practical, and maintain the integrity of the Kakagon Sloughs. Culvert replacement would be done below the 1st barrier, starting with culverts closest to Lake Superior. Sea lamprey barriers would be built, with selective fish passage provided at strategic locations on the Bad River or sea lamprey-infested tributaries.

C. **Recreational Fishing Alternative:** This alternative prioritizes the brown trout fishery which is of high recreational and economic value to Wisconsin and regional anglers (Toshner and Manz 2008). The White River above the White River hydroelectric dam is managed for brown trout by the Wisconsin DNR. Barrier removal upstream of the dam for fish passage would be a priority. This alternative also emphasizes improving other fish populations that are valued by anglers, such as steelhead (*Oncorhynchus mykiss*), coho salmon and walleye (*Sander vitreus*). Culvert removal, replacement, or modification would start at the lower most barrier both above and below the 1st barrier. Fishways would also be built for all existing dams to allow passage of all fish species, excluding sea lamprey. New sea lamprey barriers would be built in targeted stream reaches that are high lamprey producers and passage of select species would be allowed.

D. **Native Fish Recovery Alternative:** This alternative prioritizes the native brook trout fishery and reduces competition with naturalized anadromous salmonids by replacing culverts above the 1st barriers only. Brown trout might be excluded from select streams

as barriers are removed, starting at the uppermost culvert in a stream system. New barriers for sea lamprey control and selective native fish passage would be built on select streams, especially where sea lamprey are abundant.

E. **Stream Structure & Function Alternative:** This alternative would restore a natural hydrologic regime for the watershed. All culverts that are barriers would be considered for removal, replacement, or modification, starting with culverts closest to Lake Superior. All dams would be removed. No sea lamprey barriers would be built.

F. **No Barrier Management Alternative:** This alternative was included as the 'no action' alternative. Removal and replacement of failing culverts would be done by towns and counties without consideration for fish passage or erosion reduction. No barrier management by the Service or its partners would be considered.

G. **Multi-Partner Alternative:** This alternative attempts to meet multiple objectives by focusing specific actions within select sub-watersheds. The White River above the White River dam would be managed for recreational angling (brown trout fishery) by helping the DNR remove barriers. A sea lamprey barrier on the Marengo River would be built that would allow selective passage of native fish. Culvert replacement below the 1st barrier would be done in select streams and set up to monitor fish use and competition between native and naturalized salmonids. Culvert replacement in the Tyler Forks and Upper Bad Rivers (which are above the 1st barrier) would focus on brook trout management—starting at the headwaters or upper reaches of the waterways—and would include monitoring for brook trout response in relation to competition with brown trout. Longer stream reaches would receive priority for culvert replacement. No modifications or removals of dams would be considered.

We expect that subsequent implementation of this approach, with partner participation, would result in new strategy tables and resulting alternatives. Our alternatives simply illustrate the approach for crafting portfolios of actions into alternatives. In particular, it is important to see that the alternatives could be developed with very different strategic themes, not specifically linked to single stakeholder preferences.

Predictive models

We used the information and expertise available to us at the workshop to predict the impacts or consequences of the various alternatives on our objectives (Table 3). First, we defined specific, measurable attributes for each of our objectives (Figure 2 and Table 3). We then developed influence diagrams for the following: 1) brook trout population; 2) contaminant impacts on bald eagles; 3) estuary health; 4) the brown trout fishery; and 5) the anadromous species fishery, in order to help identify the key factors influencing our fundamental objectives and to assist with predictive model development. Figures 3 and 4 are included as examples of our draft influence diagrams.

At the workshop we filled in most of the consequence predictions in Table 3 based on 'best guesses,' although we were able to quickly estimate some values from a geographical

information system (GIS) model of the BRW (e.g., average connected miles of brook trout habitat). We ran the GIS model with only partial data in order to demonstrate a process that could be further developed with additional information and expertise. Thus, our predictive modeling is not comprehensive and does not reflect all of the best available information that would be applied in an actual decision process. We identified several key data gaps in BRW predictive modeling capacity, including the need for enhanced: GIS connectivity models, fish distribution data, and angler use data for the BRW. In addition, a better understanding of sediment dynamics as well as the significance of competitive interactions between native brook trout and non-native salmonids would be useful for strengthening the predictive modeling.

Decision Analysis

We conducted a decision analysis to help elucidate which alternatives would best achieve our many objectives. We used the Simple Multi-Attribute Ranking Technique (SMART) (Goodwin and Wright 2004) to develop over-all scores for the alternatives. These SMART scores combine predictions for how each alternative performs on every objective, letting us assign different weights to the objectives depending on how important they are to us. We started with the table of predicted outcomes for each BRW alternative (Table 3). Then we normalized the scores within each objective by converting all performance measures to a scale of 0 to 1, with the best-performing alternative for a given objective scoring a 1 and the least desirable alternative scoring a 0 (Table 4).

At the workshop we called on our local "BRW expert" to provide tentative weights for the objectives (on a scale of 100 for the most important to 0 for the least important) to illustrate how SMART scoring works. Given these weights, we then multiplied the normalized scores for each alternative by the objective weights and summed the objective-weighted scores for each alternative (Table 5). Finally, by dividing each alternative's *sum of weighted scores* by the *sum of <u>all</u> the objective weights* we calculated a *final score* for each alternative.

In this analysis, the native species alternative scored the highest and was identified as our preferred alternative, followed closely by the status quo alternative. We also had other experts on our team suggest objective weights from a regional office and a sea lamprey control perspective. In each case, the status quo alternative scored the highest, followed closely by the native species alterative. The physical structure and function alternative scored the lowest for all three weighting scenarios. Of course, these results are only meant to illustrate the decision analysis methods since the workshop setting provided only 'placeholders' for the range of potential management alternatives, predictive modeling, and stakeholder objectives and weights.

Uncertainty

In this decision problem, there are several areas of uncertainty. The underlying causal relationships between barrier removal and the measureable attributes we identified (Figure 2)—and ultimately, our fundamental objectives—are not known with certainty. We have a better understanding of how some actions would impact our objectives than we do about others. For example, we have only a very general understanding of sediment dynamics in the BRW and the significance of competitive interactions between native brook trout and non-native naturalized

salmonids. More data and a better understanding of both would be useful for strengthening our predictive modeling.

In addition, our prototype is subject to the following types of epistemic uncertainty as described by Regan et al. (2002) and Burgman (2005): measurement error, natural variation, model uncertainty, and subjective judgment. For example, the predicted attribute values in the consequence table are in-part based on subjective expert opinion. The accuracy of expert opinion is difficult to assess and this should be considered. Most importantly, to what extent does uncertainty affect our ability to identify the best options for managing barriers in the BRW? Using simulation in the predictive modeling and sensitivity analysis in the SMART calculations would help us evaluate the effect of variability on the selection of portfolios.

Discussion

Value of decision structuring

Our decision structure provides several advantages to how this problem has been approached in the past. First, we focused on identifying objectives before deciding on (or automatically jumping to) alternatives. Having identified our objectives, our decision structure allowed us to further analyze the various factors that influence our objectives (influence diagrams) and thus helped us to better understand the potential results of various alternatives. Second, our commitment to start with identifying objectives—even though it was part of a quick, preliminary prototype—compelled our whole group to communicate its various desires and concerns and to stay engaged throughout the process. Third, as we developed our decision structure, our problem shifted from a focus on *barrier removal* only to *barrier management*. This shift opened up a set of alternative actions that were not previously being considered within the context of solving this problem. Also, the process of portfolio development was important for grouping the various alternative actions to represent the range of possible management approaches or themes. Finally, our decision structure placed our problem into a realistic ecological context. It forced us to acknowledge which ecological functions or structures have changed substantially over time within the watershed. This helps us better understand what we can do to influence change toward our desired ecological functions or structures.

Further development required

This prototype was our first effort to create a decision structure for this problem. It was useful because it increased our understanding of the problem and helped to clarify what might be the most appropriate barrier management actions in the BRW; however, it needs further development. Specifically, future efforts to address this problem would benefit from a broader representation of BRW stakeholders. A workshop could be held to clarify objectives, explore and develop potential action alternatives, and identify available information to enhance the predictive modeling. As mentioned in our discussion of the predictive modeling, several data gaps were identified as part of the process, including the need for enhanced: GIS connectivity models, fish distribution data, bald eagle nest site locations, and angler use data for the BRW. In addition, a better understanding of sediment dynamics and the significance of competitive interactions between native brook trout and non-native naturalized salmonids would be useful. This

information would improve our ability to predict the consequences of various barrier management actions within the BRW and would be helpful in working through similar barrier management challenges in other watersheds within the Great Lakes Basin. We recognize that gathering this information will take time and additional resources.

Prototyping process

We gained considerable value and insight from the prototyping process. Our mid-week deadline for moving through the PrOACT steps (Problem, Objectives, Alternatives, Consequences, and Tradeoffs—Hammond et al. 1999) at the workshop pushed our team to overcome obstacles that would have otherwise blocked progress. Although our draft decision structure will need further development, the process ended with a template that could reasonably guide decision making for barrier management. We learned the following lessons from the process:

- Identifying our objectives was key to clarifying the problem statement, which evolved through the process;
- The sequence of the PrOACT process was important—while it is an iterative process, it was best not to skip to alternatives development before thoroughly working through objectives;
- It was important to define critical variables to ensure we were all speaking the same language;
- The process helped to illustrate where more research or monitoring is needed to assist with decision making;
- Our two-day deadline for completing a preliminary rapid prototype helped us avoid getting too entrenched in the details and gave us a better idea of what we needed to address more specifically throughout the rest of the week;
- We observed that—from an ecological perspective—there may not be one right way to approach the process. For example, our objectives were focused on population levels, while another group's objectives were focused on habitat; we wondered if we would have gotten to the same place with habitat-oriented objectives; and
- The process helped with improving cross-programmatic Service collaboration on this issue.

Recommendations

This multiple objective decision problem is an interesting application of the PrOACT (Hammond et al. 1999) and SMART (Goodwin and Wright 2004) methods. The decision structure we have outlined is a good first step toward pursuing this issue in the BRW or in other watersheds within the Great Lakes Basin with similar barrier management challenges. We recommend that the Ashland FWCO and their partners pursue the following to further develop and implement this decision structure within the BRW:

- Hold a workshop or a series of workshops with a broader group of BRW stakeholders to address this issue using the PrOACT process and this decision structure as an example;
- Identify available information and expertise and provide support to address the need for enhanced: GIS connectivity models, fish distribution data, bald eagle nest site locations, and angler use data for the BRW; and
- Gather additional information on sediment dynamics and the significance of competitive interactions between native brook trout and non-native naturalized salmonids in the BRW as part of an adaptive management framework.

We also recommend that the Service work with its partners to:

- Conduct a rapid prototype with multi-stakeholder participation using similar methods on the Manistique River and other watersheds of interest with barrier management challenges in the Great Lakes Basin;
- Identify a proper forum to engage a larger Great Lakes Basin stakeholder community to discuss basin-wide barrier management challenges and possible development of a decision structure for working through these challenges—given the range of stakeholder interests and possible resource benefits and risks; and
- Develop an interactive GIS connectivity model linked to the Service's Fish Passage Decision Support System (http://fpdss.fws.gov) (with user friendly data download and upload capabilities) to help guide barrier management decisions within the Great Lakes Basin.

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Tables

Table 1. Strategy table highlighting the categories of management actions (second row) and a suite of implementation options for each category (columns)—developed as part of a preliminary prototype to assist with barrier management decision making in the Bad River Watershed.

STRATEGY TABLE			
Culvert replacement above 1st barrier	**Dam removal or fish passage**	**Culvert replacement below 1st barrier**	**Build new barrier with fishway**
None	None	None	None
High Quality Habitat	Remove all dams	High Quality Habitat	High Quality Habitat
Start from uppermost barrier	Build fishway all dams	Start from uppermost barrier	Target reaches hard to treat for lamprey
Start from lowermost barrier	Remove WR dam	Start from lowermost barrier	Partner Requests
In select subwatersheds	Build fishway WR dam	In select streams	Marengo River
	Remove lowhead dams		
	Build fishway lowhead dams		

Table 2. Alternatives table representing seven strategic decision alternatives (and associated management actions) (rows)—developed as part of a preliminary prototype to assist with barrier management decision making in the Bad River Watershed.

		STRATEGIC ALTERNATIVES - PORTFOLIOS OF ACTIONS			
	Alternatives	**Culvert replacement above 1st barrier**	**Dam removal or fishway**	**Culvert replacement below 1st barrier**	**Build new barrier with fishway**
A	**Status Quo**	High quality habitat– start lower	none	High quality habitat– start lower	none
B	**Tribe**	none	none	High quality habitat– start lower	High quality habitat for lamprey and hard to treat streams; address Tribal interest in barrier
C	**Recreational Fishing**	High quality habitat– start lower	Build passage at lowhead dams and provide select passage at White River Dam, but don't remove	High quality habitat– start lower	High quality habitat for lamprey
D	**Native Fish**	High quality habitat– start lower	none	none	High quality habitat for lamprey with native fish passage only
E	**Stream Structure & Function**	All– start lower	Remove all dams, including White River Dam	All– start lower	none
F	**No Barrier Management**	none	none	none	none
G	**Multi-Party**	In select steams– Tyler Forks and Upper Bad River subwatersheds– start upper & monitor effect on brook trout	none	In select streams– start lower & monitor effect on salmonids	Marengo River with selective passage

Table 3. Consequences table highlighting the output of our predictive models (in this example, subjective judgments and some GIS modeling) for each sub-objective—developed as part of a preliminary prototype to assist with barrier management decision making in the Bad River Watershed.

			ALTERNATIVES (PORTFOLIOS OF ACTIONS)							Performance measures (or surrogates)	
Objectives	**Sub-objective**	**Goal**	**Status quo**	**Bad River Tribe**	**Rec fishing**	**Native spp**	**Physical structure and function**	**No barrier mgt**	**Multi-Party**	**Units**	
Native fish and aquatic spp	**Brook trout**	Max	7.1	4.6	5.9	16.0	5.4	4.6	12.8	avg mi	Avg connected miles in brook habitat (with decrements where overlap)
Cost	**Culvert cost**	min	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	0	4,000,000	$	Total cost over 10 yrs
Cost	**Lamprey cost**	min	900,000	1,210,000	1,310,000	1,210,000	2,700,000	900,000	1,210,000	$	Total cost over 10 yrs
Cost	**Major project cost**	min	0	1,000,000	1,400,000	1,000,000	3,100,000	0	1,000,000	$	Total cost over 10 yrs
Trust spp	**Estuary health**	min	2	2	2	2	1	3	2	1-3	1= natural level, 2=moderate sediment load, 3 = high
Trust spp	**Bald eagle**	min	2	3	3	1	4	1	3	1-4	New anadramous into eagle habitat, 1= non, 2=min, 3=moderate, 4=max (all system)
Trust spp	**Lake trout**	min	720,000	360,000	360,000	360,000	2,160,000	720,000	360,000	lbs	Estimated trout mortailty from sea lamprey
Public use	**Anadramous fishery**	Max	500	500	557	500	757	500	500	miles	Stream length open to anadramous
Public use	**Brown Trout fishery**	Max	12,000	7,000	14,900	10,000	9,500	7,000	8,400	hours	Hours fished (total)
Stakeholder Support	**Active opposition**	min	1	2	2	2	3	2	2	1-3	1 = none, 2 = some, 3 = deal breaker
Stakeholder Support	**Active engagement**	Max	4	3	2	2	2	1	3	1-4	1 = none, 2 = low support, 3 = medium, 4 = exceeds capacity

Table 4. Normalized scores SMART table highlighting the performance for each sub-objective (row), converted to a scale of 0 to 1, with the most desirable option scoring 1 and the least desirable option scoring a 0—developed as part of a preliminary prototype to assist with barrier management decision making in the Bad River Watershed. Scores are normalized from consequence measures shown in Table 3.

			ALTERNATIVES (PORTFOLIOS OF ACTIONS)						
Objectives	**Sub-objective**	**Goal**	**Status quo**	**Bad River Tribe**	**Rec fishing**	**Native spp**	**Physical structure and function**	**No barrier mgt**	**Multi-Party**
Native fish and aquatic spp	**Brook trout**	Max	0.219	0.000	0.114	1.000	0.070	0.000	0.719
Cost	**Culvert cost**	min	0.000	0.000	0.000	0.000	0.000	1.000	0.000
Cost	**Lamprey cost**	min	1.000	0.828	0.772	0.828	0.000	1.000	0.828
Cost	**Major project cost**	min	1.000	0.677	0.548	0.677	0.000	1.000	0.677
Trust spp	**Estuary health**	min	0.500	0.500	0.500	0.500	1.000	0.000	0.500
Trust spp	**Bald eagle**	min	0.667	0.333	0.333	1.000	0.000	1.000	0.333
Trust spp	**Lake trout**	min	0.800	1.000	1.000	1.000	0.000	0.800	1.000
Public use	**Anadramous fishery**	Max	0.000	0.000	0.222	0.000	1.000	0.000	0.000
Public use	**Brown Trout fishery**	Max	0.633	0.000	1.000	0.380	0.316	0.000	0.177
Stakeholder Support	**Active opposition**	min	1.000	0.500	0.500	0.500	0.000	0.500	0.500
Stakeholder Support	**Active engagement**	Max	1.000	0.667	0.333	0.333	0.333	0.000	0.667
			6.819	**4.505**	**5.323**	**6.218**	**2.720**	**5.300**	**5.402**

Table 5. SMART weighted scores table highlighting the normalized scores for each sub-objective weighted according to the local BRW expert's perspective (the normalized score from Table 4 times each objectives' assigned weight, by row). The summed scores and final score for the seven alternatives (columns) are tallied at the bottom, followed by the final scores (from a different table) weighted from the perspective of workshop participants from the Service's Regional Office and the Service's Sea Lamprey Control Program. The highest final score indicates the best alternative, given the objective weighting preferences: the native species and status quo alternatives (portfolios of actions) rated highest for all three objective weightings shown—developed as part of a preliminary prototype to assist with barrier management decision making in the Bad River Watershed.

				ALTERNATIVES (PORTFOLIOS OF ACTIONS)						
Objectives	**Sub-objective**	**Goal**	**Weight**	**Status quo**	**Bad River Tribe**	**Rec fishing**	**Native spp**	**Physical structure and function**	**No barrier mgt**	**Multi-Party**
Native fish and aquatic spp	**Brook trout**	Max	100	21.930	0.000	11.404	100.000	7.018	0.000	71.930
Cost	**Culvert cost**	min	33.3333	0.000	0.000	0.000	0.000	0.000	33.333	0.000
Cost	**Lamprey cost**	min	33.3333	33.333	27.593	25.741	27.593	0.000	33.333	27.593
Cost	**Major project cost**	min	33.3333	33.333	22.581	18.280	22.581	0.000	33.333	22.581
Trust spp	**Estuary health**	max	33.3333	16.667	16.667	16.667	16.667	33.333	0.000	16.667
Trust spp	**Bald eagle**	Min	33.3333	22.222	11.111	11.111	33.333	0.000	33.333	11.111
Trust spp	**Lake trout**	Min	33.3333	26.667	33.333	33.333	33.333	0.000	26.667	33.333
Public use	**Anadramous fishery**	Max	50	0.000	0.000	11.089	0.000	50.000	0.000	0.000
Public use	**Brown Trout fishery**	Max	50	31.646	0.000	50.000	18.987	15.823	0.000	8.861
Stakeholder Support	**Active opposition**	Min	50	50.000	25.000	25.000	25.000	0.000	25.000	25.000
Stakeholder Support	**Active engagement**	Min	50	50.000	33.333	16.667	16.667	16.667	0.000	33.333
Sum of Weights (for all objectives)			499.9998							
Sum of weighted scores (for each alternative)				285.80	169.62	219.29	294.16	122.84	185.00	250.41
Final Score reflecting "BRW Expert" Perspective (sum of weighted scores/sum of weights)				**0.57**	**0.34**	**0.44**	**0.59**	**0.25**	**0.37**	**0.50**
	"Regional Office" Perspective			0.59	0.38	0.43	0.57	0.20	0.51	0.49
	"Sea Lamprey Control" Perspective			0.64	0.45	0.48	0.62	0.20	0.54	0.54

Figures

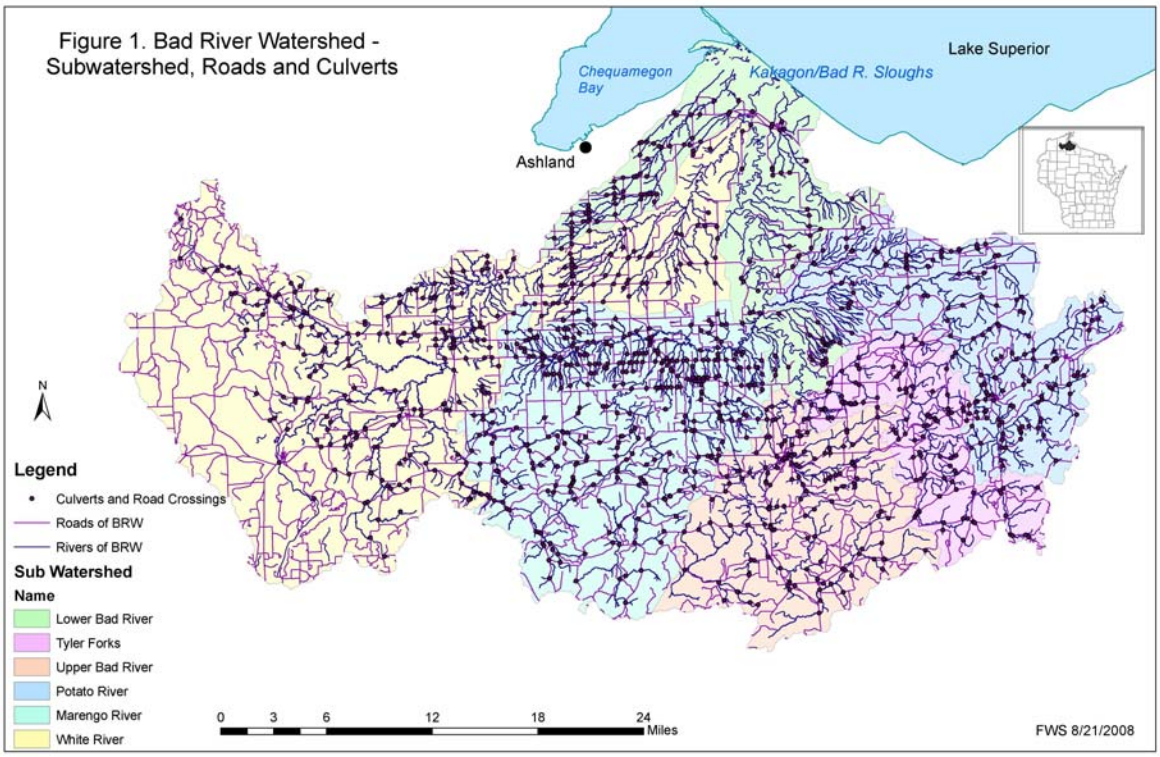

Figure 1. Map of the Bad River Watershed in northern Wisconsin.

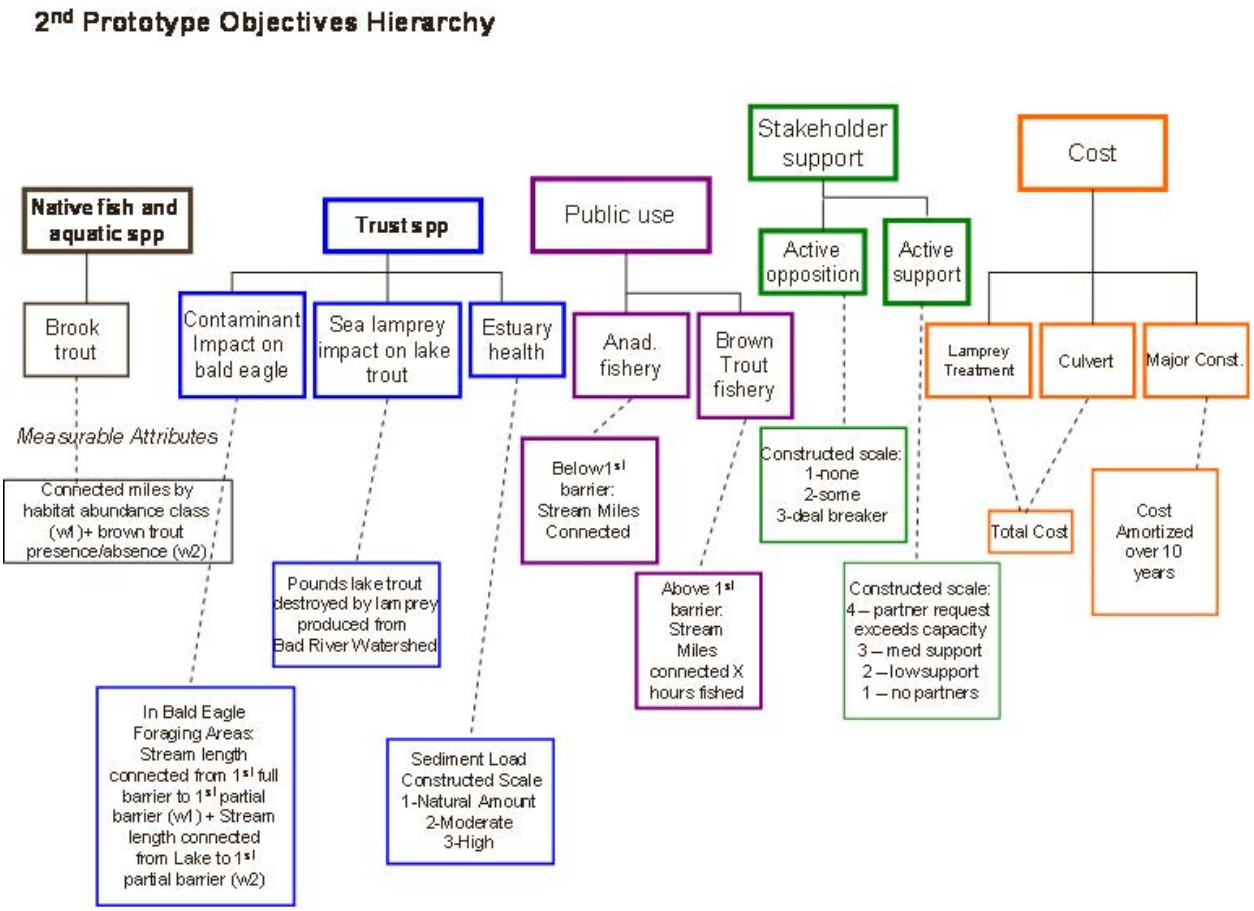

Figure 2. Objectives hierarchy highlighting: 1) Fundamental objectives (top row of boxes); 2) Sub-objectives for the "native fish and aquatic species" and "trust spp." objectives and means objectives for the "public use," "stakeholder support," and "cost" objectives (second row of boxes); and 3) Associated measurable attributes (lower boxes, connected with dashed lines)—developed as part of a preliminary prototype to assist with barrier management decision making in the Bad River Watershed.

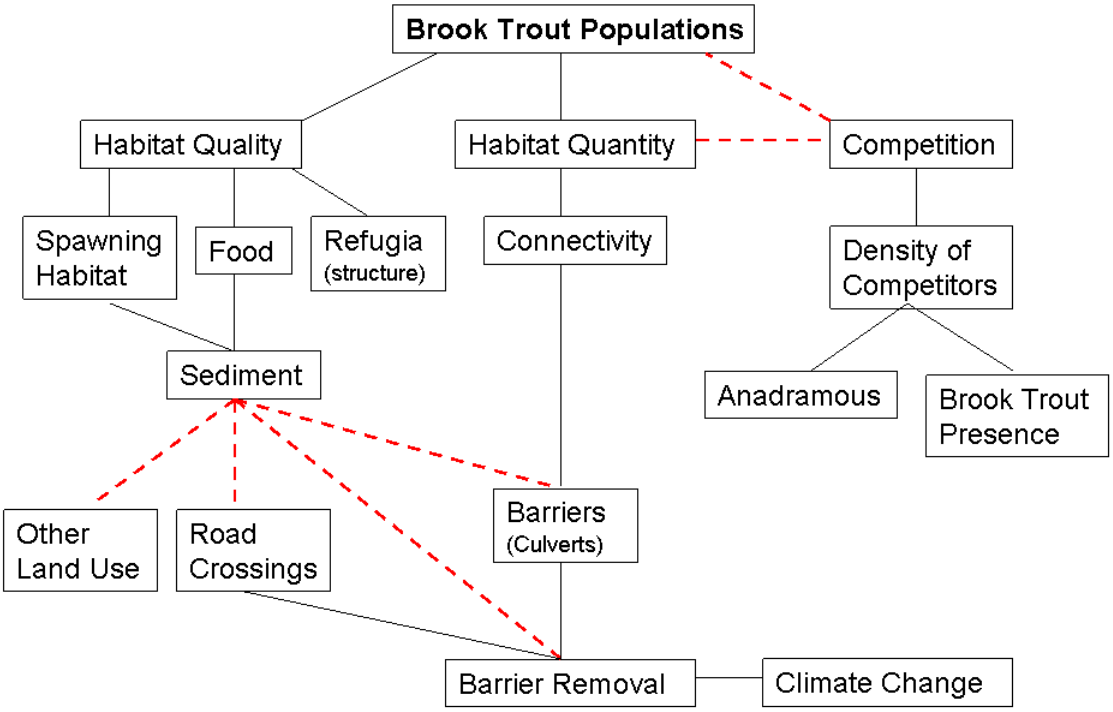

Figure 3. Influence diagram highlighting key factors influencing brook trout populations—developed as part of a preliminary prototype to assist with barrier management decision making in the Bad River Watershed. Lines represent cause-and-effect relationships (from bottom to top in this diagram); dashed lines show relationships with the most uncertainty in our knowledge.

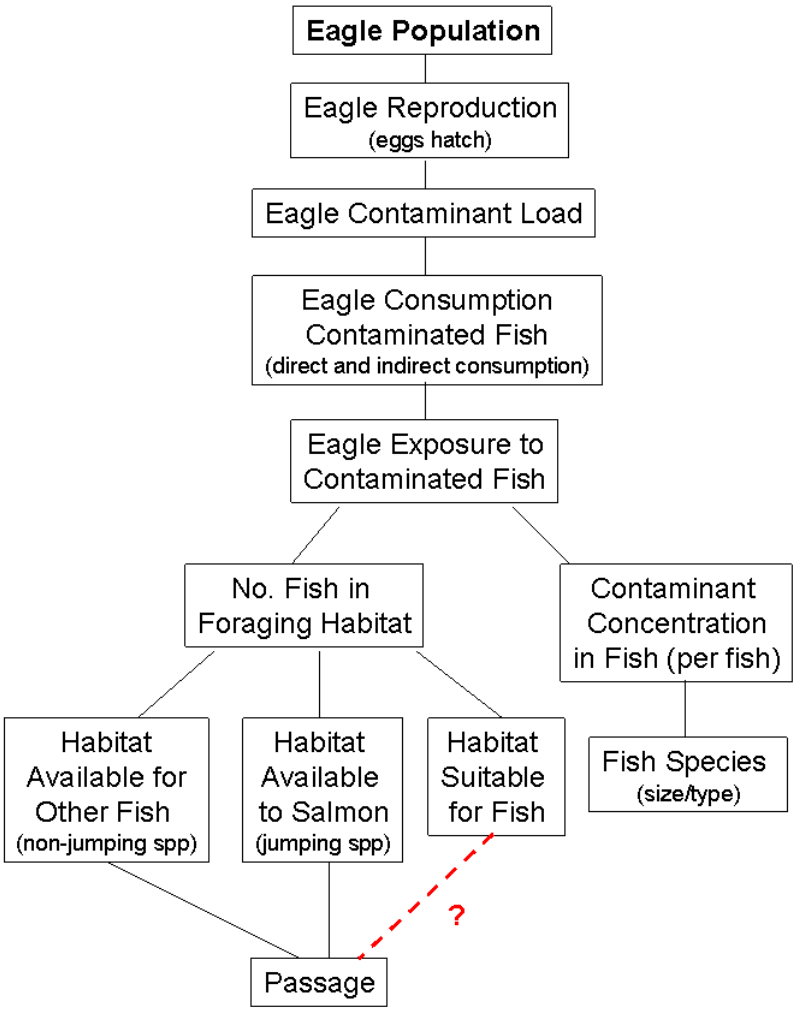

Figure 4. Influence diagram highlighting key factors influencing the bald eagle population—developed as part of a preliminary prototype to assist with barrier management decision making in the Bad River Watershed.