# Decision-Making for Centennial Valley Arctic Grayling (*Thymallus arcticus*) Conservation on Red Rock Lakes National Wildlife Refuge

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# Introduction

The evaluation of conservation actions as part of a United States (U.S.) National Environmental Policy Act of 1969 (NEPA; 43 U.S. Code Section 1638) process can be time-sensitive and require a decision maker to quickly integrate many complexities including system uncertainties, conflicting or competing values, and limited authorities, to identify the best course of action (Hemming et al. 2022). In some particularly challenging settings, these decisions also require decision makers to wrestle with complex trade-offs associated with existing land protection mandates (e.g., Wilderness Act of 1964; 16 U.S. Code Section 1131), long-term viability of imperiled species, effects on other biota, and stakeholders. There are methods from decision analysis that help decision makers navigate such complexities and provide transparency to stakeholders on how and why conservation decisions were made. This report describes a decision analysis process that was conducted in support of a U.S. Fish and Wildlife Service (USFWS) Environmental Assessment (EA) on Arctic grayling (*Thymallus arcticus*) on Red Rocks Lake National Wildlife Refuge (hereafter, the Refuge) in the Centennial Valley, Montana. Centennial Valley grayling (hereafter, CV grayling) have been in decline since 2016 (Warren and Jaeger 2017). Actions to improve their long-term survival required USFWS to consider and evaluate a range of alternatives intended to benefit CV grayling conservation while minimizing impacts to a designated wilderness area, refuge biota, and stakeholders.

Arctic grayling are a cold-water salmonid species that once occupied a large geographic distribution in the Upper Missouri River (UMR) drainage of the U.S. As of the 1990s, this Distinct Population Segment (DPS) of UMR grayling had declined to less than 5% of its historic distribution and has continued to decline in recent years (Warren and Jaeger, 2017). The causes of UMR grayling decline are many, including restricted range from river and stream impediments, water management activities that reduce or alter natural stream flow and temperature regimes, increased occurrence of high-heat and drought conditions, disease, and predation. Efforts to address the decline of UMR grayling are ongoing, and this DPS has been considered for listing under the U.S. Endangered Species Act of 1973 (16 U.S. Code Sections 1531-1544) three times over the past decade.

The CV grayling population on the Refuge is one of the few remaining UMR grayling populations that still exhibits the full spectrum of life history behaviors. The Refuge is situated within a mosaic of federal, state, tribal and private lands in the Centennial Valley in Montana and covers over 48,955 acres, of which 32,350 are designated wilderness under the Wilderness Act. The physical, cultural, and biological resources on the Refuge are expansive and diverse. The cultural resources include artifacts and outbuildings resulting from its history as the traditional lands of Native American Tribal Nations (including the Nez Perce Tribe, Confederated Salish and Kootenai Tribes, Shoshone-Bannock Tribes, and Blackfeet Nation), and colonial hunters and trappers. The physical resources include upland habitat, wetlands, rivers, streams, and two lakes. The Refuge provides habitat for many resident and migratory species including grizzly bear (*Ursus arctos*), gray wolf (*Canis lupus*), Shiras moose (*Alces alces*), trumpeter (*Cygnus buccinator*) and tundra swans (*Cygnus columbianus*), and bald eagle (*Haliaeetus leucocephalus*).

In recent years, CV grayling have declined from a high of 1131 spawning individuals in 2015 (95% Confidence Interval [CI]: 1,069 – 1,210) to a low of 88 spawners in 2021 (95% CI: 26 – 176) (Warren and Jaeger, 2022). The current estimated abundance is far below the 1000 fish recovery goal specified in a multi-agency Centennial Valley Arctic Grayling Adaptive

Management Project (AMP) first developed in 2017 (Warren and Jaeger 2017, Warren et al. 2022).

There have been a series of targeted studies as part of the AMP that were designed to evaluate three primary mechanisms of CV grayling population decline. The hypotheses were that: (1) hypoxic overwinter conditions in Upper Red Rock Lake (URRL) on the Refuge limits survival, (2) spawning habitat limits their propagation, and (3) competition with Yellowstone Cutthroat trout (*Oncorhynchus clarkii bouvieri*) limits productivity. While each of the three mechanisms are supported by empirical observation, overwinter habitat conditions in URRL are expected to be the greatest driver of decline (Warren et al. 2022).

Extensive conservation efforts related to all three mechanisms have been implemented by both federal and state agencies, and by private citizens as part of a Candidate Conservation Agreement with Assurances program (CCAA). The agreement between USFWS and private entities asks property owners to engage in voluntary activities to maintain or improve conditions on their lands specifically for populations of UMR grayling. If UMR grayling are eventually listed under the ESA, based on the CCAA, participants limit their exposure to further regulatory requirements that are enacted in response to any change in status (USFWS 2018). Specific to CV grayling, the voluntary actions asked of property owners by USFWS include localized improvements to streamflow, protection of riparian habitats, and removal of entrainment threats and barriers to movement (CCAA 2021). Other actions taken by federal and state agencies include targeted removals of non-native hybrid Yellowstone cutthroat trout, efforts to remove instream obstructions and increase spawning and rearing habitat, and pilot studies to understand how to improve the quantity and quality of overwinter habitat in URRL (Warren et al. 2022).

There is also concern that angler handling of CV grayling results in additive mortality. However, regulations restrict angler opportunity during months when CV grayling are accessible to anglers in-stream and thus reduce potential mortality. Access point and postcard surveys associated with the AMP indicate <2% of the grayling population are caught by anglers prior to the seasonal closure, a value corroborated by incidence of hook scars from monitoring data (MFWP and USFWS unpublished data). Catch and release mortality of salmonids is low at water temperatures below 20° C (Boyd 2008), a value that has been exceeded on only a single day in the past 7 years (2016 – 2022), which triggered a full closure to angling on Red Rock Creek in the summer of 2021. Despite all these efforts, CV grayling populations remain critically low (88 spawning fish in 2021 (95% CI: 26 – 176)) and actions on URRL are expected to be important to improve the persistence of this population (Warren and Jaeger 2022).

Given the continued decline of CV grayling, the conservation-focused mission of the Refuge, and its important overwinter habitat, USFWS sought out an evaluation of actions that could improve conditions for CV grayling while also achieving other mission-critical objectives. To guide their decisions, USFWS used structured decision making (SDM) to inform an environmental assessment disclosure process required under NEPA. In this report, we describe the decision context as well as the effects of actions on the natural and physical resources of the Refuge and stakeholders.

## Problem Statement

Decisions on how to manage CV grayling habitat on the Refuge are under the direct authority of the refuge manager and other USFWS leadership; however, close partnerships and authorities exist with state partners, notably Montana Division of Fish, Wildlife & Parks (MFWP) who are authorized to manage the states' fish and wildlife. To guide USFWS decisions on RRLWR, there are several refuge-specific acts of Congress, including Executive Order 7023 (1935) which first established the refuge for breeding birds and other wildlife species. Beyond the establishing (enabling) legislation, other acts of Congress affect management decisions for the Refuge, including the National Wildlife Refuge System Administration Act of 1966 (16 U.S. Code 668dd et seq.), Improvement Act of 1997 (20 U.S. Code § 1400), Endangered Species Act, and the Wilderness Act. In combination, these legislative acts require the Refuge to manage for human recreation, conservation of threatened, endangered and other fish and wildlife resources, and wetlands (Refuge Recreation Act 1962 (16 U.S. Code 460k-460k-4), Emergency Wetlands Resources Act 1986 (16 U.S. Code 3901), Fish and Wildlife Act 1956(16 U.S. Code 742(a)-754)), and to maintain it as a wilderness area.

The decision was whether and how to improve the overwinter conditions in URRL to ultimately improve the long-term viability of CV grayling. The scale of the decision was 25 years and included all areas of the Refuge, including most notably, the 32,350 acres of designated wilderness. The U.S. Geological Survey (USGS) worked with USFWS staff and used guiding documents and legislation to identify fundamental objectives and measurable attributes that were important to consider in their decision on CV grayling.

## Fundamental Objectives

Fundamental objectives describe the full range of concerns that a decision maker has when selecting among a set of management actions. In this decision setting, USFWS and stakeholders identified a hierarchy that included four higher-order objectives broken down into eight unique fundamental objectives for consideration. Higher-order objectives are numbered, and corresponding fundamental objectives are lettered:

1. Manage resources to maintain and enhance the population of CV grayling:
    A. Maximize CV grayling probability of persistence over 25 years.
2. Preserve character of wilderness on Red Rocks Lake National Wildlife Refuge:
    A. Minimize the manipulation or control of the biophysical environment (untrammeled character).
    B. Minimize the authorized development of wilderness (undeveloped character).
    C. Minimize disturbance to plant and animal species and communities (natural character).
    D. Minimize the sights and sounds of people inside of wilderness (solitude or primitive character).
3. Preserve and enhance stakeholder values:
    A. Minimize disturbance to refuge users and neighbors.
4. Consider monetary cost of management activities:
    A. Minimize cost of management activities.

## Measurable Attributes

Measurable attributes are the currency by which the fundamental objectives are evaluated. Each fundamental objective from the hierarchy presented in the previous section was further developed into a measurable attribute and an associated scale used to quantify the magnitude and direction of change projected under each of the decision alternatives (Table 1).

Objective 1A. *Maximize CV grayling probability of persistence over 25 years.* According to the Comprehensive Conservation Plan (USFWS 2009), the Refuge has an objective to "restore declining fish and other aquatic resource populations before they require listing under the Endangered Species Act (1973)". Furthermore, CV grayling were specifically listed in the initial designation of parts of the Refuge as a wilderness area in 1976. As a result, management decisions on and around CV grayling habitat, including URRL, should consider the long-term implications for CV grayling populations on the Refuge.

> Measurable attribute 1A1. Probability of CV grayling extinction. A population model is used to project the probability of CV grayling extinction after 25 years. CV grayling extinction is determined by the sum of model runs out of the total where one of two thresholds is met. The first threshold is met (i.e., the population is considered extirpated) when the adult population size drops below 25 individuals for at least one year. One year below 25 adults would result in a high expected chance of extirpation based on stochastic demographic and environmental processes. Further, a population size of 25, even for a single spawning event, would lead to a marked reduction in the genetic effective population size, loss of genetic variation, and increased inbreeding. The second

threshold is met when the adult population size drops below 50 individuals for three consecutive years. A sustained bottleneck below 50 adults would result in an effective population size below 10, resulting in an expected dramatic loss of genetic variation and adaptive potential, and considerable risk of extirpation through inbreeding depression.

Measurable attribute 1A2. Probability of CV grayling recovery. The probability that the abundance surpasses 400 individuals by 2047. Reaching a population size greater than 400 would reduce chances of extinction due to stochastic processes. Additionally, four hundred adults would be expected to result in an effective population size greater than 50 (Ne/Nc ratio = 0.133; Kovach et al. 2020), reducing the short-term threats of extirpation owing to inbreeding depression (50/500 rule; Jamieson and Allendorf 2012).  Population recovery and conservation goals can be realized if abundances are above this level.

Objective 2A. *Minimize the manipulation or control of the biophysical environment (untrammeled character).* A large proportion of the Refuge, including URRL, was designated as a wilderness area in 1976 (32,350 out of 48,955 acres are designated wilderness). As a result, Refuge management is mandated to protect the 5 wilderness characters (untrammeled, undeveloped, natural, and provide solitude and primitive experiences to humans, and preserve features of value) of these lands according to the Wilderness Act of 1964. Four measurable attributes were developed to evaluate the degree of impact that each alternative requires on the designated wilderness area of the Refuge. We did not develop a measurable attribute for features of value because there were no existing features identified in the wilderness area of the Refuge.

Measurable attribute 2A1. Constructed scale for disturbance to lacustrine ecosystem. The constructed scale supports values from 0 – 7 across three different categories: permanence, scale, and degree. A value of 0 indicates no change to ecosystem processes or functions, whereas 7 represents permanent, large-scale changes to ecological processes or functions.

Measurable attribute 2A2. Constructed scale for disturbance to wetland ecosystem. The constructed scale supports values from 0 – 7 across three different categories: permanence, scale, and degree. A value of 0 indicates no change to ecosystem processes or functions, whereas 7 represents permanent, large-scale changes to ecological processes or functions.

Measurable attribute 2A3. Constructed scale for disturbance to riverine ecosystem. The constructed scale supports values from 0 – 7 across three different categories: permanence, scale, and degree. A value of 0 indicates no change to ecosystem processes or functions, whereas 7 represents permanent, large-scale changes to ecological processes or functions.

Measurable attribute 2A4. Constructed scale for disturbance to upland ecosystem. The constructed scale supports values from 0 – 7 across three different categories: permanence, scale, and degree. A value of 0 indicates no change to ecosystem processes or functions, whereas 7 represents permanent, large-scale changes to ecological processes or functions.

Objective 2B. *Minimize the authorized development of wilderness (undeveloped character).* Like objective 2A, management decisions on and around the designated wilderness area must preserve wilderness qualities of the Refuge. One measurable attribute was developed to evaluate the degree of development that each alternative requires on the designated wilderness area of the Refuge.

> Measurable attribute 2B1. Penalized disturbance index from infrastructure on designated wilderness. The basic measure for structures will be measured in total volume  ($m^3$). The basic measure will then be multiplied by the length of time that infrastructure will be present. Seasonal infrastructure will get a penalty factor of 1 and year-round infrastructure, 2.  For materials, the penalty factor will be 1 for earthen disturbance; manufactured (human) materials that are buried, 1; and manufactured (human) materials that are above ground, 2.

Objective 2C. *Minimize disturbance to plant and animal species and communities (natural character).* Red Rocks Lake National Wildlife Refuge provides habitat for many resident and migratory species including grizzly bear, black bear, elk, deer, wolves, swans, eagles, cranes, and waterfowl. Three measurable attributes were developed to evaluate the disturbance to the natural character of the Refuge under each alternative.

> Measurable attribute 2C1. Percent maximum of a constructed scale for the effects to the distribution and abundance of Montana Species of Concern. Species of Concern included a mammal (grizzly bear), three bird species (trumpeter swan, Franklin's gull, trumpeter swan (*Leucophaeus pipixcan*)), and five plants (Idaho sedge (*Carex idahoa*), Platte cinquefoil (*Potentilla plattensis*), mealy primrose (*Primula incana*), alkali-marsh ragwort (*Senecio hydrophilus*), and slender thelypody (*Thelypodium sagittatum*)). The constructed scale supports values from

-4 – 4 (i.e., a decline or increase in condition) and is the sum of scores from two different categories: distribution and abundance. A value of 0 indicates no change to distribution or abundance, whereas a value of 4 (or -4) represents permanent, large-scale changes in distribution and abundance for many individuals.

Measurable attribute 2C2. Percent maximum of a constructed scale for the effects to the distribution and abundance of invasive biota. Invasive biota included two non-native grasses that are a focus of the Conservation Plan (USFWS 2009), Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermus*). The constructed scale supports values from -4 – 4 (decline or increase in condition) and is the sum of scores from two different categories: distribution and abundance. A value of 0 indicates no change to distribution or abundance, whereas a value of 4 (or -4) represents permanent, large-scale changes in distribution and abundance for many individuals.

Measurable attribute 2C3. Percent maximum of a constructed scale for the effects to the distribution or abundance of other biota of the Refuge. Biota considered included four mammals (beaver, gray wolf, otter (*Lontra canadensis)*, Shiras moose) and birds (bald eagle, coots (spp.), ducks (spp.), grebe (spp.)). The constructed scale supports values from -4 – 4 and is the sum of scores from two different categories: distribution and abundance. A value of 0 indicates no change to distribution or abundance, whereas a value of 4 (or -4) represents permanent, large-scale changes in distribution and abundance for many individuals.

Objective 2D. *Minimize the sights and sounds of people inside of wilderness (solitude/primitive character).* Each year there are around 12,000 visitors to the Refuge (USFWS 2009). Visitors of the Refuge engage in a diversity of activities including, recreation, education, wildlife viewing, camping. Two measurable attributes were developed to evaluate the disturbance to the solitude and primitive character to the visitors of the Refuge and wilderness area.

> Measurable attribute 2D1. Penalized days of disturbance from construction equipment on designated wilderness. The number of days of construction or maintenance will represent the basic measure and will be multiplied by a penalty factor related to the intensity of activities. The penalty factor will be 0 for construction or maintenance that can be done without equipment; use of light duty vehicles, 1; and use of large construction equipment, 2.

> Measurable attribute 2D2. Penalized days of sound from construction, maintenance, or operation of equipment or infrastructure on designated wilderness. The number of days of construction, maintenance, or operation will represent the basic measure and will be multiplied by a penalty factor related to the sound required for each alternative. The penalty factor will be 0 for activities that can be done without sound-emitting equipment; activities that require sound-emitting equipment in the range of 0-50 decibels (dBa), 0; activities that require equipment that emits sound between 50 -70 dBa, 1; activities with emissions between 70-90 dBa, 2; activities with emissions above 90 dBa, 3.

Objective 3A. *Minimize disturbance to refuge users and neighbors.* Red Rocks Lake National Wildlife Refuge is valued by a diversity of recreational user-groups, including campers, boaters, big game and waterfowl hunters, anglers, and education, interpretation, and research users. The Refuge is also important as grazing habitat for livestock and is part of a connected watershed. Thus, actions on the Refuge to conserve CV grayling may affect recreational value, access to rangeland, and water availability for downstream water users. Three measurable attributes were developed to evaluate the localized effects to stakeholders of the Refuge.

> Measurable attribute 3A1. Total number of construction, operation, and maintenance days during summer months (May – October) on the Refuge. This metric will measure the effect of alternatives on users of the Upper Lake Campground on the south shore of the URRL (hereafter, the Campground; latitude, longitude [lat/lon]: 44.59334, -111.72983) including, campers, boaters, anglers, day users, activities associated with education, interpretation, and outreach activities, and livestock grazers.
>
> Measurable attribute 3A2. Total number of construction, operation, and maintenance days during hunting seasons (October – December) on the Refuge. This metric will measure the effect of alternatives on seasonal users of the Campground including big game and waterfowl hunters.
>
> Measurable attribute 3A3. Change in water storage capacity of URRL measured in cubic meters per second. A change in storage capacity can affect the amount and seasonal availability of water to downstream water users. The change in capacity of URRL will be measured in acre feet.

Objective 4A. *Minimize cost of management activities.* The restricted operating budget of Red Rocks Lake National Wildlife Refuge requires USFWS to consider the monetary costs of management actions on Refuge.

Measurable attribute 4A1. Total cost of construction for each alternative measured in U.S. Dollars.

Measurable attribute 4A2. Total cost of operation for each alternative measured in U.S. Dollars.

**Table 1.** Fundamental objectives and measurable attributes for a U.S. Fish and Wildlife decision on whether and how to improve the overwinter conditions of Upper Red Rock Lake (URRL) in the Centennial Valley (CV) of Beaverhead County, Montana improve the long-term viability of CV grayling (*Thymallus arcticus*).

[CV, Centennial Valley; URRL, Upper Red Rock Lake]

| **Fundamental Objective** | **Measurable attribute** |
|---|---|
| *1. Manage resources to maintain and enhance the population of CV grayling* | |
| A. Maximize CV grayling probability of persistence over 25 years | 1A1. Probability of CV grayling extinction<br>1A2. Probability of CV grayling recovery |
| *2. Preserve character of wilderness on Red Rocks Lake National Wildlife Refuge* | |
| A. Minimize the manipulation or control of the biophysical environment (untrammeled character) | 2A1. Constructed scale for disturbance to lacustrine ecosystem<br>2A2. Constructed scale for disturbance to wetland ecosystem<br>2A3. Constructed scale for disturbance to riverine ecosystem<br>2A4. Constructed scale for disturbance to upland ecosystem |
| B. Minimize the authorized development of wilderness (undeveloped character) | 2B1. Penalized disturbance index from infrastructure on designated wilderness |
| C. Minimize disturbance to plant and animal species and communities (natural character) | 2C1. Percent maximum of a constructed scale for the effects to the distribution and abundance of Montana Species of Concern.<br>2C2. Percent maximum of a constructed scale for the effects to the distribution and abundance of invasive biota.<br>2C3. Percent maximum of a constructed scale for the effects to the distribution or abundance of other biota of the Refuge. |
| D. Minimize the sights and sounds of people inside of wilderness (solitude or primitive character) | 2D1. Penalized days of construction on wilderness<br>2D2. Penalized days of sound on wilderness |
| *3. Preserve and enhance stakeholder values* | |

| | |
|---|---|
| A. Minimize disturbance to refuge users and neighbors | 3A1. Days of disturbance to refuge users<br>3A2. Days of disturbance to waterfowl and big game hunters<br>3A3. Water storage capacity of URRL |
| *4. Consider the monetary costs of management activities* | |
| A. Minimize cost of management activities | 4A1. Total costs of construction ($)<br>4A2. Total costs of operation ($) |

## Alternatives

The USFWS developed seven action alternatives from a previous engineering report and discussions with stakeholders (Flynn et al. 2019). The alternatives were composed of actions to improve overwinter conditions for CV grayling and that represent a gradient of intensity (e.g., wilderness characters) for the other objectives. The seven action alternatives are: A) No action, B) Electric-powered splashers ($B_1$) or diffusers (B2), C) Pumped aeration, D) Shambow Pond diversion pipeline, E) Permanent barrier from Elk Springs Creek to the lake center, and F) Dredge and berm Elk Springs Creek. The design criteria for these alternatives are specified in the following sections and generally matches the description of alternatives in the EA that this report supports. Most geographic features referred to in the alternatives are shown in Figure 1.

### *Alternative A – No Action*

Under Alternative A (No action, hereafter "status quo"), the current management strategies, which include water releases from Widgeon Pond (lat/lon: 44.64362, -111.65164) into Upper Red Rock Lake, beaver dam notching in CV grayling spawning tributaries (to improve spawning habitat), and seasonal fishing closures (to reduce stress associated with angler handling) continue. In 2016, greater than 50 beaver dams were notched along spawning tributary reaches including Red Rock, Odell, Tom, and Elk Springs Creek (Warren and Jaeger 2017). The seasonal fishing closures are enacted from May 1 to June 15 along tributary reaches where CV grayling spawning occurs and catch and release regulations restrict angler opportunity and reduce potential mortality during other times of the year.

Widgeon Pond is a human-made wetland outside of designated wilderness on the Refuge. Water releases from Widgeon Pond (and sometimes Culver Springs Pond lat/lon: 44.63020, -111.62854) provide oxygenated water to areas of URRL where CV grayling overwinter. Widgeon Pond has a water control structure that regulates water levels by the addition or subtraction of stop logs. When Widgeon Pond is full and stop logs are removed, water plunges several feet out of the water control structure and into Picnic Creek (lat/lon: 44.64657, -111.65464). The plunging action oxygenates the released water and provides additional streamflow.  At the mouth of Picnic Creek, the water flows into Elk Springs Creek and ultimately into URRL. Elk Springs Creek is spring-fed, and its flow remains relatively strong during winter. The amount of water released in previous years range from 150–205-acre feet over a period of 2-3 weeks.

*Alternative B – Electric Powered Splashers or Diffusers*

Alternative B uses electric powered splashers or diffusers to increase oxygen levels in URRL and may improve winter habitat suitability for CV grayling overwinter survival. Due to its remote location and wilderness designation, URRL does not have electrical power. Alternative B would require the installation of a reliable power source for continuous operation of reoxygenating equipment. The nearest electric utility connection is 5.33 km (3.31 miles) to the west near the town of Lakeview along the road alignment at the intersection of South Valley Road and a private road that serves a residence in Odell Creek (fig. 1). The proposed direct-bury underground alignment would follow the non-wilderness right-of-way on South Valley Road through the existing wilderness to the Campground on the south shore of the lake. In coordination with the local electric provider, this has been deemed feasible and reasonably achievable.

*B1 – Splashers*: A splasher is a type of mechanical aerator that floats on the surface of the water. Splashers continuously circulate and splash surface water to increase the level of oxygen in the surrounding water and create an area of open water in the ice (hereafter polynya) where additional oxygen transfer can occur from the atmosphere. High-powered electric surface aerators (splashers) cannot be located far offshore given submersible electric cable length limitations (Ashley & Nordin, 1999). A single dedicated submersible electrical wire would be required per electric aerator and would remain in the lake year-round with the splashers to aerate the 25-hectare minimum area goal. Based on distances measured in geographic information systems software (ESRI, 2021), we assumed that the total distance of wire from the Campground to the deployment site to be 1,220 meters for each splasher, and that the area affected by the physical infrastructure to be three cubic meters per splasher when in operation.

*B2 – Diffusers*: A diffuser aeration system includes: 1) an array of diffusers at the bottom of the lake, 2) air compressors at the Campground, and 3) a submerged weighted hose connecting the air compressor to the diffuser. Each of 16 diffusers (4 diffusers per compressor) would create multiple columns of fine bubbles that have the potential to cause a buoyant plume of warmer water near the sediments to rise and melt the ice (creating a polynya), thus oxygenating the surrounding water. There is limited oxygen exchange/mass transfer from the bubbles due to their short contact time. Based on distances measured in geographic information systems software (ESRI, 2021), we assumed that the total distance of weighted hose from the Campground to the deployment site to be 1,220 meters, and that the area affected by the physical infrastructure to be 1.5 $m^3$ per diffuser when in operation.

### *Alternative C – Pumped Aeration*

Alternative C uses an electrical pump connected to high-density polyethylene (HDPE) pipeline to extract deoxygenated water from URRL and transfer that water to a land-based aerator (cascade or venturi technology) located in the Campground. The aerator re-oxygenates the water which is then pumped back into URRL to a separate location, increasing the oxygen content of water in URRL. The aerator and electrical centrifugal pumps would be located in the Campground and 1500 meters of permanent 0.20 m diameter (8-inch, estimated) HDPE withdrawal and return lines would be installed (within a trench) from the cascade aerator to URRL. Like Alternative B, Alternative C would require the installation of a reliable power source for continuous operation of aeration equipment.

### *Alternative D – Shambow Pond Diversion Pipeline*

Alternative D considers a buried, gravity-flow diversion pipeline that conveys water from East Shambow Creek and Shambow Pond to the center of URRL (fig. 1). Shambow Pond is a created and actively managed wetland feature located southwest of URRL and serves as a suitable diversion point for the proposed pipeline. An engineered subsurface screened intake and gate structure is recommended at the pond outlet for storing and conveying water to the lake through a HDPE pipeline. Gating would allow the pipeline to be closed when not in use (e.g., late spring, summer, and early fall) so that flow would not be affected in the natural channel of East Shambow Creek. The end of the pipeline would contain diffuser ports for distribution of tributary water. Based on an assumed target flow of 0.06 $m^3/s$ (2 $ft^3/s$) out of Shambow Pond, the engineering design indicates 1,676 meters of 0.36 m diameter (14-inch) HDPE pipeline would be required along with appurtenant intake, regulation, and aeration vault structures (Siddoway et al. 2021).

### *Alternative E – Permanent Barrier from Elk Springs Creek to the Lake Center*

Alternative E considers the installation of a permanent wall or walls of constructed of sheet piling or similar material. The impermeable wall(s) would direct the dominant flow from Elk Springs Creek into the center of the lake (approximately 1,000 meters) increasing residence time for inflows of water into URRL that have high DO concentrations. The sheet piling would be installed by launching a mobile barge onto URRL and using pile driving equipment (e.g., a vibratory hammer) to drive the sheet piling 3 – 4 meters into the substrate until stable. The construction would take approximately 1 to 2 months depending on whether a single or multiple walls were constructed.

To launch the mobile barge, the boat launch at the Campground on the southern shore of URRL would be used for site access. This boat launch is outside of designated wilderness. The launch is primitive and will have to be reinforced, widened, and deepened to deploy the barge.

### *Alternative F – Dredge and Berm Elk Springs Creek*

Alternative F considers using a shallow floating dredge to remove sediments near the mouth of Elk Springs Creek. Dredging would cover 25 hectares (62 acres) with removal of up to a meter of sediment (plus sediment storage), tying into existing bathymetry. To launch the floating dredge the boat launch at the Campground on the southern shore of URRL would be used. This boat launch is outside of designated wilderness and the same improvements discussed in Alternative E would be required. Mechanical dredging requires staging and operating construction equipment in the wilderness area, as well as development of temporary construction access, hauling roads, staging areas, and dredged material drying pads.

Considering ice-cover conditions and sedimentation, the Elk Springs Creek inflow would be dredged to a depth of 1.25 m (4.1ft) noting the total dredged volume is considerable and needs to be defined through an engineering design. The depth criteria was identified according to previous work by Davis (2016) that established significant selection by CV grayling for water in URRL that exceeded 1 m depth. Alternative F would consider the construction of an earthen berm using the dredge cuttings and large geotextile bags, scaled at a size equivalent to the cut volume, which would require additional in-water construction measures and fill material to ensure berm stability. To prevent impacts to other locations in the lake, floating silt and turbidity curtains (effective only in certain dredging environments; Francingues and Palermo, 2005) or temporary dikes may be required during placement activities. The generation of turbidity by hydraulic dredge type has already been characterized by the U.S. Army Corps of Engineers and impacts are expected (USACE, 2015).

With preliminary volume estimates, this project is expected to take about 12 – 14 months of continuous activity with multiple dredges. To avoid disturbing birds during the nesting season and the early onset of ice cover on URRL, a 4-month dredging window is assumed for each year. In total, the duration of the dredging operation would be expected to last 3 years. Dredging may need to occur repeatedly over time to maintain depths of >1m due to sedimentation and resuspension of in-lake sediments. Based on monitoring with sediment traps, dredging is not expected to be a long-term solution and dredged areas will likely fill in with sediment.

## Methods

The use of multi-criteria decision analysis requires each of the Alternatives to be evaluated across all fundamental objectives. In the case of the decision on conservation actions for CV grayling on the Refuge, effects were analyzed using three science teams including: a Grayling team (12 members), a Wilderness team (10 members), and a Stakeholder team (6 members; total of 18 participants across all teams; table A1). Each of these science teams estimated the effect sizes for each of the measurable attributes that aligned with their expertise. The science teams used a combination of expert elicitation, empirical information, direct estimation, and modeling in their quantitative evaluations.

### *Modeling*

To estimate the effects of the Alternatives on URRL overwinter conditions, and ultimately, CV grayling recovery potential, the Grayling team further developed an existing hydrodynamic and dissolved oxygen (DO) water-quality model to evaluate the performance of proposed engineering Alternatives during wintertime implementation in URRL. Results were then used to inform overwinter habitat in an existing CV grayling population projection model. Each of these components of the modeling are described subsequently.

### *Effects of alternatives on habitat in URRL*

Hydrodynamic and water-quality modeling software was used to evaluate increases in wintertime habitat for each of the Alternatives (Environmental Fluid Dynamics Code, EFDC). The hydrodynamic and water-quality modeling software simulates the water budget, temperature, and water-quality processes of lakes, wetlands, estuaries, and coastal regions for environmental assessment or regulatory management (DSI, LLC, 2020). Prior work by Flynn (2022) describes the setup and application of the model to URRL for simulating two-dimensional vertically averaged DO dynamics in the lake (e.g., ice cover, sediment oxygen demand) for the purpose of evaluating restorative strategies that improve wintertime DO for grayling conservation. The original model was updated herein to reflect the influence of the evaluated Alternatives on wintertime habitat. For model evaluations, lake environments ≥1.25 meters in depth and ≥4 milligrams dissolved oxygen per liter (mg$O_2$/L) concentration are considered habitat for CV grayling (fig. 1), noting that when the lake becomes ice-covered, DO is depleted, and the quality of CV grayling habitat is reduced. Our assumption on what constitutes suitable overwinter habitat in URRL (i.e., ≥1.25 meters in depth and ≥4 mg$O_2$/L concentration) was based on previous work by Davis et al. (2016) and Warren and Jaeger (2017). Simulations were executed in modeling software (version 11.5 of EFDC+ through the EE Modeling system (EEMS) (DSI, LLC, 2020)).

The modeling software requires specification of lake geometry, meteorological forcing functions, and boundary conditions to simulate the lake environment. An existing bathymetric digital elevation model (DEM) developed by Andrews (2017) was used to develop elevation-area-volume attribute data for the two-dimensional 25 m × 25 m cartesian model grid. A remote weather observation tracker (e Remote Automated Weather Station Red Rock RRDM8 (https://mesowest.utah.edu/)) was used to provide atmospheric pressure, air temperature, relative humidity, rainfall, and solar radiation for the site. Flow, temperature, and DO concentration inputs from five tributaries that enter URRL (Elk Springs, Red Rock, East Shambow, Grayling, and Tom creeks, fig. 1) were incorporated. The tributaries alter the hydrodynamics, thermal, and oxygen balance of URRL, including the timing and spatial and patterns of DO during the winter months; however, none of the inflows have been gaged consistently. Thus, expert opinion was used to develop inflow hydrographs for the sites.

Four of the tributaries (Elk Springs, Red Rock, East Shambow, and Grayling creeks) were considered to have significant groundwater inflow components (McCarthy et al. 2016). Thus, historical measurements during all months of available observation data were used to generate flow values that approximate quantiles of the available data, noting the quantity and quality of data were limited, with most of the flow estimates older than 20 years old and interpolated from other months based on expert opinion rather than direct statistical summaries. For Tom Creek, a smaller tributary with seasonally varying flows was used based on estimates from Parrett (1989) to determine the monthly flow conditions. Outflow of URRL was assumed to reflect the sum of the inflows, with no lag in time or storage accommodation. Inflow and outflow estimates used in the modeling software, which included the stored water release of Alternative A into Elk Springs Creek, are shown in Table 2.The temperature and DO concentration in winter tributary flows is an important input to the EFDC model. There are few observations to directly inform these estimates, however. Based on expert opinion of members of the Grayling team, water quality conditions associated with free-flowing tributaries into URRL were assumed to be slightly above freezing (2°C) and near atmospheric saturation for DO when corrected for elevation and temperature (10.5 $mgO_2/L$).

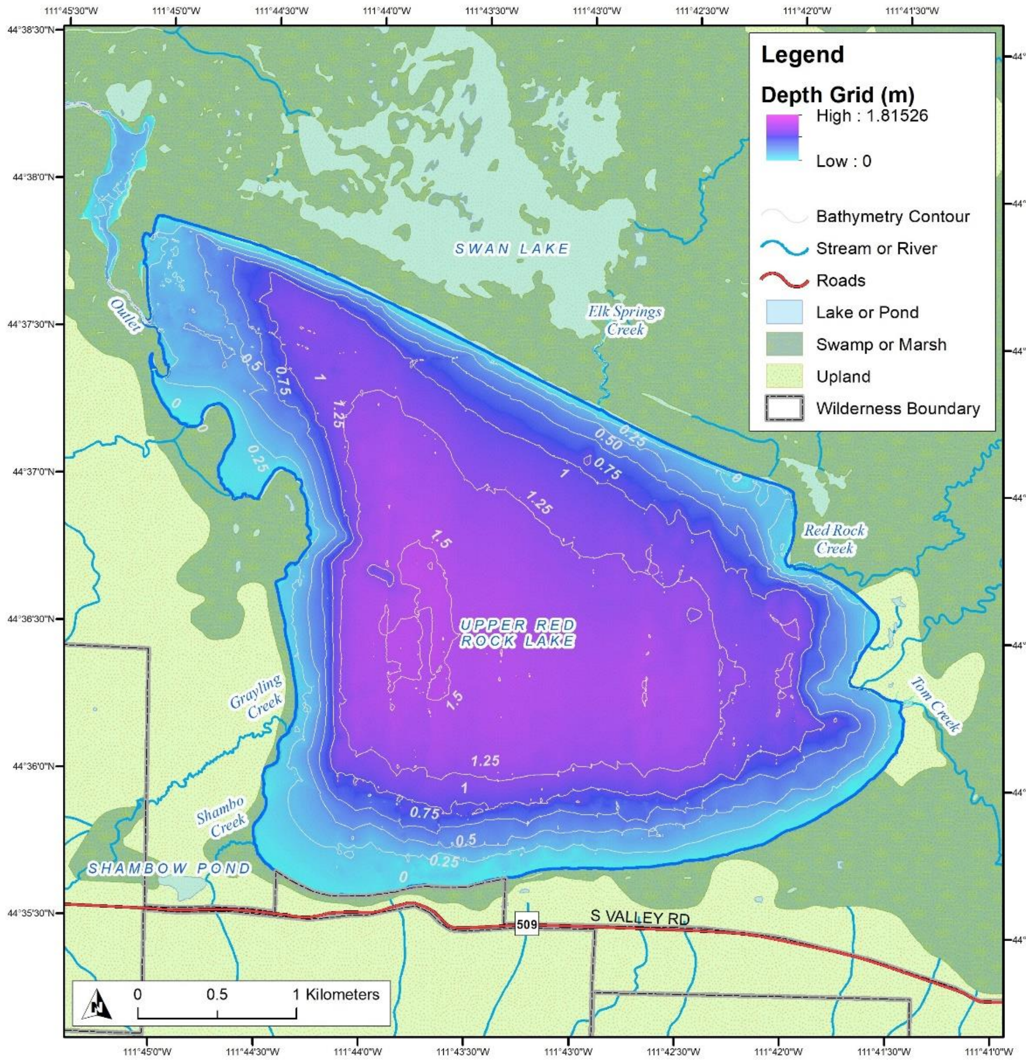

**Figure 1.** Bathymetry (depth in meters) of Upper Red Rock Lake (URRL) in the Centennial Valley of Beaverhead County, Montana used in the hydrodynamic and water-quality modeling software (Environmental Fluid Dynamics Code, EFDC).

To simulate ice cover processes in URRL, an external ice time series (e.g., ISER and ICEMAP input files for the EFDC software) were used in the hydrodynamic and water-quality modeling software was used, placing an ice cover over the lake on day 51 of the simulation (November 21) and removing it on Day 181 (March 31), representing a 130-day ice-cover duration. The specified duration is comparable to that described by Davis et al. (2021), although some studies suggest a longer period (Flynn et al., 2022). We did not incorporate future changes in ice cover that could result from climate forcing. Gas exchange does not occur in the hydrodynamic and water-quality modeling software when the waterbody is ice covered; however, some of the Alternatives will likely generate open water (polynya) which require specification of covered and non-ice-covered cells in the model. Polynya generation therefore accommodated using the ICEMAP file.

The external ice cover approach is further limited in that there is not an adjustment to lake water volume due to ice-thickness, which affects both hydrodynamic and water quality computations. As such, variations in water depth (i.e., lake volume) and ice-thickness were evaluated for the seven Alternatives to better approximate the range of hydrodynamics, winter oxygen depletion rates (Mathias and Barica, 1980), and subsequent CV grayling habitat expected that might result from the Alternatives. Separate runs were completed in the simulated environment reflecting the following: (1) water depth and outlet location as identified in the original USFWS bathymetry (Andrews, 2017) characteristic of a larger lake volume or thinner ice cover and (2) a condition reflecting 0.5 m ice thickness over the same bathymetry which leads to shallower URRL depths and a thicker ice cover. We also included both flow quantiles as probabilistic events each year, where the probabilities were estimated by experts or historical conditions.

**Table 2.** Inflow boundary condition estimates of tributaries flowing into Upper Red Rock Lake (URRL) in the Centennial Valley of Beaverhead County, Montana. Boundary conditions were used in the hydrodynamic and water-quality modeling software (Environmental Fluid Dynamics Code, EFDC). Outflow is located at the northwestern part of URRL and flows into Lower Red Rock Lake.

[Q25, lower quartile discharge; Q50, median]

| **Tributary** | **November ($m^3/s$)** | | **December ($m^3/s$)** | | **January ($m^3/s$)** | | **February ($m^3/s$)** | | **March ($m^3/s$)** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Q25** | **Q50** | **Q25** | **Q50** | **Q25** | **Q50** | **Q25** | **Q50** | **Q25** | **Q50** |
| Red Rock Creek | 0.345 | 0.691 | 0.241 | 0.482 | 0.230 | 0.460 | 0.226 | 0.453 | 0.257 | 0.515 |
| Elk Springs Creek | 0.349 | 0.698 | 0.275 | 0.549 | 0.270 | 0.540 | 0.269 | 0.538 | 0.294 | 0.587 |
| Tom Creek | 0.011 | 0.023 | 0.011 | 0.017 | 0.008 | 0.014 | 0.008 | 0.011 | 0.008 | 0.011 |
| East Shambow Creek | 0.033 | 0.065 | 0.030 | 0.060 | 0.026 | 0.053 | 0.025 | 0.051 | 0.027 | 0.054 |
| Grayling Creek | 0.043 | 0.087 | 0.044 | 0.044 | 0.042 | 0.042 | 0.041 | 0.041 | 0.043 | 0.043 |
| Outflow | 0.781 | 1.564 | 0.601 | 1.152 | 0.576 | 1.109 | 0.569 | 1.094 | 0.629 | 1.210 |

Q25 = lower quartile discharge, Q50 = median

Hydrodynamic and water-quality model simulations were then completed using a dynamic time-step (minimum 0.4 seconds) using the Smagorinsky water column diffusion formulation, where a background/constant horizontal eddy viscosity coefficient of 0.001 $m^2/s$ was applied (Smagorinsky 1963; DSC, LLC, 2020). In those runs, oxygen losses were represented using a constant sediment oxygen demand (SOD), which reflects the combined effect of oxidation of organic material at the sediment-water interface as well as senescent decay of macrophytes once the lake becomes snow covered. SOD was specified at −0.7 $g/m^2/d$ at 20°C, which corresponds to an SOD of −0.26 $g/m^2/d$ at in-situ wintertime temperatures of 4°C.

Using the previously described boundary conditions, inputs, and assumptions for the hydrodynamic and water-quality model, we ran 36 scenarios that varied ice thickness, tributary inflows, presence of polynya, and the seven NEPA Alternatives. The sequencing for these events was as follows. For each Alternative, a low flow (Quantile (Q)25) and average flow condition (Q50) inflow estimate was made for each tributary inflow boundary condition to URRL, which was then combined with a low volume (LV, thick ice) or moderate volume (MV, thin ice) approximation of the lake condition based on expected probabilities of each of those events occurring.

Additional scenarios were then incorporated to evaluate the possibility of occurrences associated with each of the Alternatives such as the likelihood that a technology would result in an open water polynya that could increase atmospheric gas exchange (and thus further improve DO conditions), or whether mechanized failure (either due to freezing or loss of power) may affect the outcome. The final estimate of habitat derived from the hydrodynamic and water-quality model under each scenario was calculated on March 1st, when DO is expected to be at, or around, its lowest concentration in URRL. An example of simulated habitat through time for Alternative A is shown in fig. 2, noting all No-action (Alternative A) runs result in critical habitat at about the same time in early March.

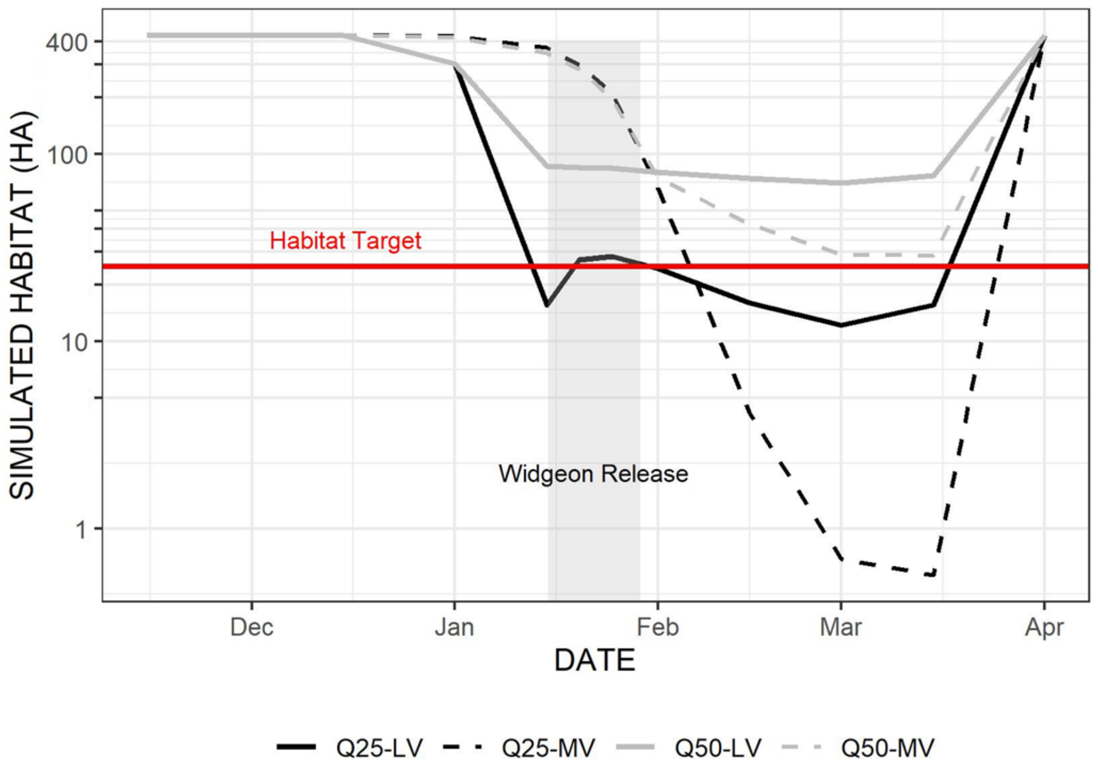

**Figure 2.** Simulated winter habit for Alternative A under various hydrodynamic and water-quality model configurations. Lower Quantile (Q25)-LV = low flow and low lake volume, Q25-MV = low flow and moderate lake volume, Median Quantile (Q50)-LV = average flow and low lake volume, Q50-MV = average flow and average lake volume. Red line indicates habitat target of 25 ha from Warren and Jaeger (2021). Model output tabulated at 15-day intervals pre- and post-Widgeon Pond (lat/lon: 44.64362, -111.65164) release and 5-day intervals during the release.

Further specifics of how each of the Alternatives were conceptualized in hydrodynamic and water-quality model are discussed briefly below.

*Alternative A – No Action Alternative Assumptions*

Alternative A entails all current management activities at URRL including water releases from Widgeon Pond into URRL, beaver dam notching to improve spawning habitat, and seasonal fishing closures to reduce stress associated with angler handling. The primary consideration evaluated in the hydrodynamic and water-quality model is the Widgeon Pond flow release, which increases the inflow of Elk Springs Creek and the outflow of URRL. An assumed 24.6 ha (200 acre-feet) of stored water was introduced to the Elk Springs Creek boundary condition over a two-week period in mid-January (beginning on January 15) to deliver oxygenated water to URRL. The water is assumed to have the same temperature and water quality constituents of the other tributaries, and the inflow time-series to URRL from the release was estimated daily using the standard weir equation (Eqn 1)

$$Q = CLH^{3/2} \tag{1}$$

where $Q$ is the flow rate [$m^3/s$], $C$ is the weir coefficient [assumed 1.66 in SI units], $L$ is the weir width [m, assumed to be 1 m], and $H$ is the height of the water behind the weir [m], which is drawn down during the release.

The height of water for the weir calculation was determined by estimating the surface area of Widgeon Pond (77.9 acres or 31.5 ha) and implying a stored volume of 24.6 ha (200 acre-feet), such that the initial depth of stored water was 0.783 m (2.57 ft). A daily mass balance calculation was then used to determine the change in storage and the subsequent height of water for the next day weir flow calculation. No attenuation or translation of the inflow hydrograph was assumed, and the water was added directly to the existing inflow of Elk Springs Creek.

### *Alternative B – Electric Powered Splashers or Diffusers*

Alternative B consists of electric aeration, with separate scenarios: $B_1$-surface splashers and $B_2$-diffusers, noting each have a different mode of action and may have different levels of success based on wintertime conditions at URRL. Each variation is described subsequently.

*Alternative $B_1$ – Electric Powered Splashers*

McCord and Shladow (2001) provide design guidance for splasher aeration suggesting criteria that are dependent on the waterbody and splasher properties. A waterbody-specific dimensionless value relating water depth to surface aerator energy and distance of influence of the splasher (*M*) must first be determined (Eqn 2):

$$M = \frac{0.32\, H^{5/6}}{Q^{1/3}} \tag{2}$$

where $H$ is the depth of water [m] and $Q$ is the flow rate of the splasher [$m^3/s$], noting McCord et al. (2000) indicate the typical flow rate of a 1 horsepower (HP) splasher is 0.093 $m^3/s$, which is used in this work. A second term ($M^*$) must also be determined, which relates the localized splasher influence to the overall lake surface area (Eqn 3):

$$M^* = \frac{MA^{1/2}}{nH} \tag{3}$$

where $A$ is the lake surface area [$m^2$], and $n$ is the total number of independent locations where the assumed 1-HP splashers are located.

Using site-specific information from URRL (e.g., $H = 1.0$ m at the implementation location and a minimum surface area to be aerated of 25 ha or 250,000 $m^2$), the number of 1-HP splashers required to stay within the “ideal design region” per McCord and Shladow (2001) is between two and four. $M$ is 0.7 in all cases, with $M^*=177$ for 2 splashers, $M^*=118$ for 3 splashers, and $M^*=88$ for 4 splashers. As such, four aerators were considered for the modeling of Alternative $B_1$ which is the maximum envisioned through design guidance and is below the 10-HP constraint of available single-phase power. It is important to note that $M^*$ for four splashers is slightly lower than the design threshold, which runs the risk of dropping the water temperature to near freezing, noting that URRL is atypical in its geometry and may not behave like the systems evaluated in the design guidance.

When operational, surface splashers create a polynya through which gas transfer can occur, generating additional reaeration due to the splashing mechanism of the water. For the former, the hydrodynamic and water-quality model uses the O'Connor-Dobbins (1958) surface renewal equation to estimate reaeration as function of waterbody properties (e.g., depth and velocity, and DO concentration and saturation level) with a liquid diffusion ($D_l$) constant of 3.933 m/d, which at 1 m depth is also 3.933 /d (expressed in the more typical units of reaeration). The influence of wind is additive with the equation of Banks and Herrera (1977). For the latter, McCord et al. (2000) indicate a reaeration coefficient of $k_a$=0.25 /d should be used for 1-HP splashers. Given the site depths, the reaeration rate ($k_a$, /d) and liquid mass transfer coefficient $K_l$ (m/d) are interchangeable (Chapra, 1997)[1], and a reaeration constant of 3.933 + 0.25 = 4.183 m/d was used for simulation of the splashers. A polynya the size of a single grid cell (625 m$^2$) was assumed to occur for each of 4 splashers with an occurrence probability of 0.36 based on the aggregated expert data.

### *Alternative B$_2$ – Electric Powered Diffusers*

The same design guidance used in determining the number of splashers for URRL was applied to compressed air diffusers, applying a 4-HP limit to the number of compressors and diffusers to prevent negative outcomes such as excessive lake cooling. In contrast to the splashers, air bubbles in the upwelling water have limited contact time as they rise through the polynya and leave the aqueous phase to the atmosphere. Alternative B$_2$ therefore has a lower reaeration

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[1] The governing differential equation is $Vdo/dt = K_l A_s(o_s\text{-}o)$, noting $V = A_s H$, and thus $Vdo/dt – k_a V(o_s\text{-}o)$ when $H$=1, where $K_l$ is the liquid diffusion constant having units of m/d and $k_a$ is the reaeration coefficient with units of /d.

coefficient. Based on guidance from McCord et al. (2000), the reaeration coefficient for diffusers is $k_a$=0.008 /day. Accordingly, the reaeration coefficient used for the diffuser evaluation was determined as 3.933 + 0.008 =3.941 /d, again over a polynya the size of a single grid cell (625 $m^2$). A polynya the size of a single grid cell was assumed to occur with an occurrence probability of 0.79 based on the aggregated expert data.

A condition is also envisioned where the diffusers do not open a polynya due to the shallow depths of URRL. In this case, there is no atmospheric gas transfer from the polynya and the only oxygen added to the system is contained in the pumped air. A typical aeration system (such as the Kasco RA4 DP system), will deliver 0.27 $m^3$/minute (9.6 cubic feet per minute) (Kasco Marine, 2023). Assuming a U.S. standard atmospheric density of 1.0052 kg/$m^3$ at URRL elevation with 21% oxygen, and a standard oxygen transfer efficiency of 2% per foot of depth, each 1 HP system will deliver 5.4 $kgO_2$/d to the lake (NOAA 1976, EDI 2023). The oxygen was added in the hydrodynamic and water-quality model at four locations (representing an array of diffusers) using an inflow boundary of 0.001 $m^3$/s, with a concentration of 62.7 $mgO_2$/L. The small flow and excessive DO concentration (well beyond saturation levels) was used to provide an appropriate DO load while not influencing the water balance of the lake.

*Alternative C – Electrical Pump with Aeration*

Alternative C comprises pumping deoxygenated water out of URRL, re-aerating the water through a cascade or venturi technology (e.g., introduction of air into a water flow either through a series of steps that cause aeration of the water, or injection of air into a pipeline in a contracted region called the Venturi throat), and then pumping the aerated water back into the lake near the center of URRL. Pumping rates were assumed to be 0.057 $m^3$/s (2 $ft^3$/s), which are within the limits of the available single-phase power supply at the site. The cascade pump inlet was located so that oxygenated water would not be entrained into the pipeline inlet and the outlet location was sited near the west central part of the lake like other alternatives. Due to cooling of the water, influent temperatures of the water in the pipeline were assumed to be 1°C while the same oxygen saturation (10.5 mg$O_2$/L) was used as other boundary conditions. Given the cooling during aeration, cascade aeration will likely not open a polynya.

### *Alternative D – Shambow Pond Diversion Pipeline*

Alternative D evaluated a gravity flow pipeline with capacity to deliver 0.057 $m^3/s$ (2 $ft^3/s$) of aerated water from Shambow Pond to the southwest center of URRL, in accordance with the design of Siddoway et al. (2021). The piped discharge was assumed to occur at 2°C and saturation with atmospheric DO (10.5 mg$O_2$/L). In cases where estimated flows in Shambow Creek were less than the design capacity of the pipeline, only the available discharge was piped to URRL. If excess streamflow was available, the pipeline operated at full capacity, and the remainder of the streamflow discharged at the Shambow Creek inlet to the lake.

Two scenarios reflecting the presence/absence of a polynya were considered: (1) where a polynya formed at the point of discharge with a size equal to a single grid cell (625 $m^2$), and (2) a separate run where the polynya did not form. The reaeration coefficient with the assumed polynya was 3.933/d, whereas no gas transfer was allowed in the second scenario. A polynya the size of a single grid cell was assumed to occur with an occurrence probability of 0.77 based on the aggregated expert data.

### *Alternative E – Permanent Barrier from Elk Springs Creek to the Lake Center*

Alternative E is intended to interrupt the short circuiting of Elk Springs Creek flows towards the URRL outlet during the Widgeon Pond storage release and at other times of the year, deflecting water further into the center of the lake and into depths preferred by CV grayling (Davis et al.

2016). The barrier was conceptualized in the hydrodynamic and water-quality model as a 1,000 m long mask (barrier in effect) configured on the cell faces west and south of the Elk Spring Creek inflow to fully block flow and mass transport between cells. The mask essentially prevents advective or turbulent diffusive transport between adjacent grid cells, thus functioning as a hydrodynamic barrier in the model.

### *Alternative F – Dredge and Berm Elk Springs Creek*

Alternative F is intended to create habitat by adding depth in proximity to Elk Springs Creek through dredging. No proposed dredging surface exists and for the purpose of the Alternative evaluation, the 2013.25 m (1.25 m depth) contour of the lake bathymetry was dredged inward towards Elk Springs Creek to allow for 1-m or greater of habitat plus a sediment and/or ice allowance. The barrier like Alternative E was implemented on the downstream side of the dredged location and west of the Elk Springs Creek inflow, representing a dike/berm where the dredge spoils would be retained. The current size and length of the dike/berm is not quantified with exact measure but is expected to be between 600 and 1000m long (600 m was used in the hydrodynamic and water-quality model; 1000 m was used in wilderness effects calculations).

### *Effects of alternatives on CV grayling*

The results of the EFDC model were used in combination with other existing data to project the performance of CV grayling under the seven alternatives. A prior population projection model was selected (Appendix 2, figs. A1 and A2) and used to assess CV grayling outcomes across 25 years and under the seven alternatives. It was adapted from an existing density-dependent population model described in the AMP (Warren and Jaeger 2017). We assumed that there was no direct harm from any of the management actions because CV grayling are not in areas of activity during implementation. The model was used to estimate the spawning population of CV grayling as a function of demographic parameters and the effect of overwinter survival on the population of grayling in the next year given by (Eqn 4):

$$N_{t+1} = N_t s_t p_t + F_{t-2}\alpha_{t-2}\gamma_{t-2}(\delta_{t-2}p_{t-2})(\varepsilon_{t-1}p_{t-1})(\theta_t p_t) \qquad (4)$$

where,

| | |
|---|---|
| $N_t$ | is the number of spawning CV grayling in year t, |
| $F_{t-2}$ | is the number of adult females in the spawning run in year t-2, |
| $s_t$ | is the maximum annual survival of adult grayling (aged 3+) in year t, |
| $p_t$ | is the proportional change in the maximum winter or annual survival as a function of overwinter habitat in year t (described below), |
| $\alpha_{t-2}$ | is the length specific fecundity rate, |
| $\beta_{t-2}$ | is the probability of an egg being fertilized and hatching in year *t*-2, |
| $\gamma_{t-2}$ | is the age-0 fish in-stream survival (emergence to September 1st), |
| $\delta_{t-2}$ | is the age-0 fish maximum winter survival (September 2st – May 15th), |
| $\epsilon_{t-1}$ | is the age-1 fish maximum annual survival (May 16th – May 15th), |
| $\theta_t$ | is the age-2 fish maximum annual survival (May 16th – May 15th). |

Estimates of demographic rates were taken from published values for salmonids of similar size, age, and life history when empirical data for CV grayling were not otherwise available (fig. A2 Warren and Jaeger 2017). Distributions were calculated using maximum and minimum observed confidence intervals (95%) from each study and averaged among studies to obtain distribution bounds. Minimum and maximum values were assumed to represent upper and lower quantiles (0.00001 and 0.99999) and were used to calculate standard deviation using the standard score equation ($Z = (x - \mu) / \sigma$), where Z in the distance from the mean in standard deviations (derived from quantiles), x is the observed value (i.e., the minimum or maximum vital rate). $\mu$, (the mean of the sample), and $\sigma$ (the standard deviation) were unknown quantities. The standard score equation was used for both the lower and upper quantiles, and we simultaneously solved the two equations for $\sigma$.

Values for $\gamma_{t-2}$ (age-0 fish in-stream survival) were based on survival rates for chum salmon (*Oncohynchus keta*) fry because of similar body size and migration timing after hatch (Peterson 1998). The survival rate was standardized to 90 days in stream based on reported stream residence time of age-0 CV grayling in Red Rock Creek (Mogen 1996, Katzman 1998). Survival rates for age-0 survival in Upper Lake ($\delta_{t-2}$) and age-1 annual survival ($\varepsilon_{t-1}$) were estimated by averaging survival rates across studies from salmonids with similar body sizes to the CV grayling life stage of interest (Achord et al. 2007, Al-Chokhachy and Budy 2008, Dieterman and Hoxmeier 2011; Bowerman and Budy 2012).

Age 0 survival rates were estimated from bull trout (*Salvelinus confluentus*; Al-Chokhachy and Budy 2008) and mean age 0 survival rates were standardized to 0.75-year survival rates. Age-2 survival, $\theta_t$, was estimated using the upper confidence interval of annual survival for age-3 Red Rock Creek CV grayling (Paterson 2013). The upper confidence interval was selected because age-2 fish generally do not incur the risk of predation and physiological demands associated with spawning and, resultantly, likely have higher annual survival than age-3 fish. The maximum age-2 survival rate was the highest annual adult survival rate estimated from available mark-recapture data.

We incorporated environmental stochasticity and vital rate uncertainty into our simulations by taking annual random draws from the normal distributions describing vital rates (Table A1). We drew from additional statistical distributions to incorporate demographic stochasticity in our simulations (Schaub and Kery 2022). We assumed that the number of surviving adults came from a binomial distribution with $N_t$ trials and a probability of $s_t p_t$ (the annual survival). The number of juveniles surviving to recruitment came from a binomial distribution with $F_{t-2}\alpha_{t-2}$ (the total number of hatching eggs at year *t*-2) trials and a probability of

$Y_{t-2}(\delta_{t-2}p_{t-2})(\varepsilon_{t-1}p_{t-1})(\theta_t p_t)$ (survival from hatching to recruitment). Mean fecundity $\alpha_{t-2}$ was drawn from a Poisson distribution.

The realized proportion of maximum grayling survival ($p_t$) was related to winter habitat conditions using a Holling saturation function given as (Eqn 5):

$$p_t = \frac{aw_t}{b+w_t}, \qquad (5)$$

where $a$ is the maximum realized proportion of grayling survival, which was set to be equal to 1 (Warren and Jaeger 2017), and b represents the value of $w_t$ when the proportional change in survival is 50% of the maximum (Hilborn and Mangel 1997), and $w_t$ is the hectares of winter habitat per fish in year $t$. $w_t$ was calculated as (Eqn 6):

$$w_t = \frac{a_t+h+c_i}{N_t}, \qquad (6)$$

where available winter habitat ($a_t$) is defined as previously described, the minimum area (ha) of water in URRL from January to March with ≥ 4 ppm dissolved oxygen and ≥ 1 m in depth (Davis 2016). Data were collected 2-6 times each winter from permanent sampling locations selected using a stratified random design across URRL; 1 within 300m of each stream mouth and lake outlet ($n$ = 6) and 10 within the lake (Warren et al. 2020). We used a gamma distribution fit to twelve habitat measurements recorded between 1995 and 2022. The gamma shape parameters were estimated using a generalized linear model that estimated the intercept only based on observed habitat values. We took a random draw from the gamma distribution in each year of the simulation.

The parameter $h$ indicates the amount of baseline, unmeasured winter habitat that was available in all years due to springs; $h$ is estimated to be 4.66 ha on average. However, because we were not able to estimate annual variation in $h$, we assume a uniform distribution from 0 to 6.99 ha based on the geologic and aquifer characteristics and variation in flow of surface springs in the Centennial Valley adjacent to URRL (oral communication from Andrew Brummond on February 3, 2023).

The last input is suitable winter habitat created by the different management alternatives, $c_i$. The $c_i$ was computed as the average contribution of the alternative to winter habitat accounting for year-to-year variation in flow, ice thickness, and polynya occurrence. For each alternative, the low (Q25) and average (Q50) flow scenarios were assumed to have an 0.4 and 0.6 probability, respectively, of occurring in each year of the simulation. Likewise, for each alternative, the thin ice (or high URRL volume) and thick ice (or low URRL volume) scenarios and a probability of 0.5. For alternatives in which polynyas can form ($B_1$, $B_2$, and D), the probability of a polynya forming was included as the proportion of total iterations under each alternative, and a polynya thus did or did not form for all years under a given simulation iteration. To define the probability of CV grayling extinction and recovery, we ran 100,000 iterations of each alternative using statistical software (Program R version 4.2.2 (R Core Team 2021). See table A2 for contributions of each alternative for each flow, ice thickness and polynya scenario; these values are averaged over simulations.

### *Effects of alternatives on wilderness*

The Wilderness team was composed of 10 participants with diverse expertise including knowledge of the biological and physical resources of the Refuge, Wilderness Act policy, Refuge-specific planning documents and other legislative acts, engineering design, and Refuge management activities. During a series of six meetings, USGS facilitated discussions to define and understand wilderness characters (based on Landres et al. 2015) and how each character would be measured. We focused on 4 of the 5 characters (untrammeled, undeveloped, natural, and solitude/primitive) and excluded features of value because there were no existing features identified in the wilderness area of the Refuge.

Each character was measured using a mixture of direct estimation (e.g., construction duration and extent) and expert elicitation of effects using standardized constructed scales. The elicitation process relied on experts providing their most likely point estimates for each wilderness character following a modified Delphi approach with the IDEA protocol ("Investigate, Discuss, Estimate, Aggregate"; Hanea et al. 2017). The protocol allowed for each expert panelist to work within the group to develop and understand the constructed scale in a general sense and then perform independent estimation of the specific effects using that scaling. Following the first round of independent estimation, experts engaged in facilitated discussion to consider mechanisms, share unique insights, and explore any differences in effects. Experts then revisited their estimations and made any necessary updates to their initial responses.

The untrammeled character was defined as any action by Refuge staff, or other authorized entities, that manipulate the biophysical environment (Landres et al. 2015). We considered the biophysical environment to consist of four distinct ecosystems on the Refuge, including open water in URRL (i.e., lacustrine), wetlands surrounding URRL, tributaries flowing into URRL including Elk Springs, Red Rock Creek, Tom Creek, Shambow Creek, and Grayling Creek, and upland ecosystems. The effects of the alternatives to these ecosystems could be temporary (i.e., during construction) or permanent (i.e., persistent disturbance beyond construction activities); across small (<50 $m^2$) or large (>50$m^2$) spatial extents; and, differ in magnitude ranging from minor (few species affected, or limited effect to ecological processes or functions), to intermediate (considerable species affected or considerable affects to ecological processes or functions), to major (irreversible and system altering changes in ecological processes or functions). We summed the effects of each of the three categories for each expert (permanence, scale, magnitude) and then averaged the summed scores across experts to derive an aggregate measure of trammeling under each alternative and ecosystem type.

The undeveloped character was defined as any non-recreational installations, structures, and developments in the designated wilderness of the Refuge (Landres et al. 2015). We considered any infrastructure, whether seasonal, permanent year-round, earthen or using manufactured materials to degrade the undeveloped character of Refuge wilderness. We also considered the visibility of such structures to similarly affect the “primeval character and influence” (Wilderness Act, 1964) of the wilderness area of the Refuge such that visible structures were given a greater penalty. The final aggregated score for infrastructure was a direct measure calculated as the size of infrastructure (in $m^3$) multiplied by the penalty scores for visibility and material type.

The natural character of Refuge wilderness was defined as any disturbance or disruption to the abundance or distribution of plant and animal species. We first brainstormed a complete list of species that were present in the focal areas in and around URRL. We then developed a constructed scale for each of 18 species (table 5) that measured increases or declines in abundance or distribution. The constructed scale supports values from -2 to 2 (decline or increase in each condition) for both abundance and distribution. A value of 0 indicates there are no anticipated changes to distribution or abundance under the alternative, whereas a value of 4 (or -4) represents permanent, large-scale changes in both distribution and abundance of a species or assemblage. To aggregate across experts and to reduce the cognitive burden of evaluating the effects on Refuge biota for decision makers, we first took the individual effects for the 18 species (or groups of species for ducks and coots) and then combined them into three categories: species of concern, invasive species, and other native biota. Each category was calculated as the sum of the average scores for each species divided by the maximum available score (e.g., 4 species in a category has a maximum score within the range of {-16, 16}). The final aggregate measure represented the percent of the maximum score, where the maximum score represents permanent changes to the distribution and abundance of all species within each category.

The last wilderness character was the provision of solitude or primitive and unconfined type of recreation (Landres et al. 2015). We quantified the effect of the alternatives on the primitive and unconfined character of Refuge wilderness by considering both the visual and auditory disturbance of construction, maintenance, and operations of any alternatives that occur within the designated boundary. Each of the metrics represents a direct measure of the duration of construction, maintenance, and operation activities (days) multiplied by a penalty for the magnitude of visual impairment (constructed scale) or sound emission (in decibels).

### *Effects of alternatives on stakeholders and costs*

The Stakeholder team was composed of six participants with diverse experience including Refuge uses and management, engineering design, and hydrology. During a series of 4 meetings, USGS facilitated discussion with the team to identify any stakeholders that would experience localized and immediate effects from the management alternatives. The stakeholders included a diversity of recreational user-groups, including campers, boaters, big game and waterfowl hunters, anglers, and education, interpretation, and research users. Downstream water users were also considered as a separate measurable attribute. Other stakeholders (e.g., conservation organizations) were considered, but their effects (or interests) were not considered independent of other objectives and measurable attributes that were already being measured. The measurable attributes for general refuge users and hunters were estimated using direct estimates of disturbance (e.g., days of construction, operation, and maintenance).

Alternative F (Dredge and Berm) was the only alternative that is expected to affect the availability of water to downstream water users. The change in flow under this alternative was estimated using the monthly estimated dredge production rates for Alternative F. We assumed that all dredge material is removed from the lake, at least temporarily. We also assumed that excess water removed from the lake during dredging would infiltrate the local groundwater system and return to the lake. Our estimate does not consider any onshore evaporative losses which would be comparable to evapotranspiration losses of the covered land area, or the effects of attenuation that will mitigate abrupt changes in outflow to Red Rock River.

The monetary costs (in U.S. Dollars) of the seven alternatives were direct estimates from contractors, engineers, and vendors. The construction costs were primarily modified using Flynn et al. (2019) as a general template and are considered Level 5 estimates (i.e., concept screening, −50 to +100%) at best according to the Association for the Advancement of Cost Engineering (AACE 2005). Construction costs were made under a tight timeline and with insufficient information on material quantities, local construction costs, or site conditions. The operational costs were projected across 25 years assuming a current electrical rate of $0.058 per kW/hr (current electric rate of Vigilante Electrical Cooperative in Dillon, MT), escalating at 2% per year representing the target inflation rate, which works out to an average rate of $0.074 per kW/hr over 25 years.

## Results

### *Effects of alternatives on habitat in URRL*

Example output of the EFDC model runs for the March 01 snapshot for simulated DO under the Q25 flow and low volume (LV) outputs are shown in figs. 3 and 4 (complete results in Table A2). The greatest areal extent of oxygenated water is near the mouths of the largest tributaries (e.g., Red Rock and Elk Spring creeks), although depths in proximity to the tributaries are exceptionally shallow and are not suitable for grayling habitat.

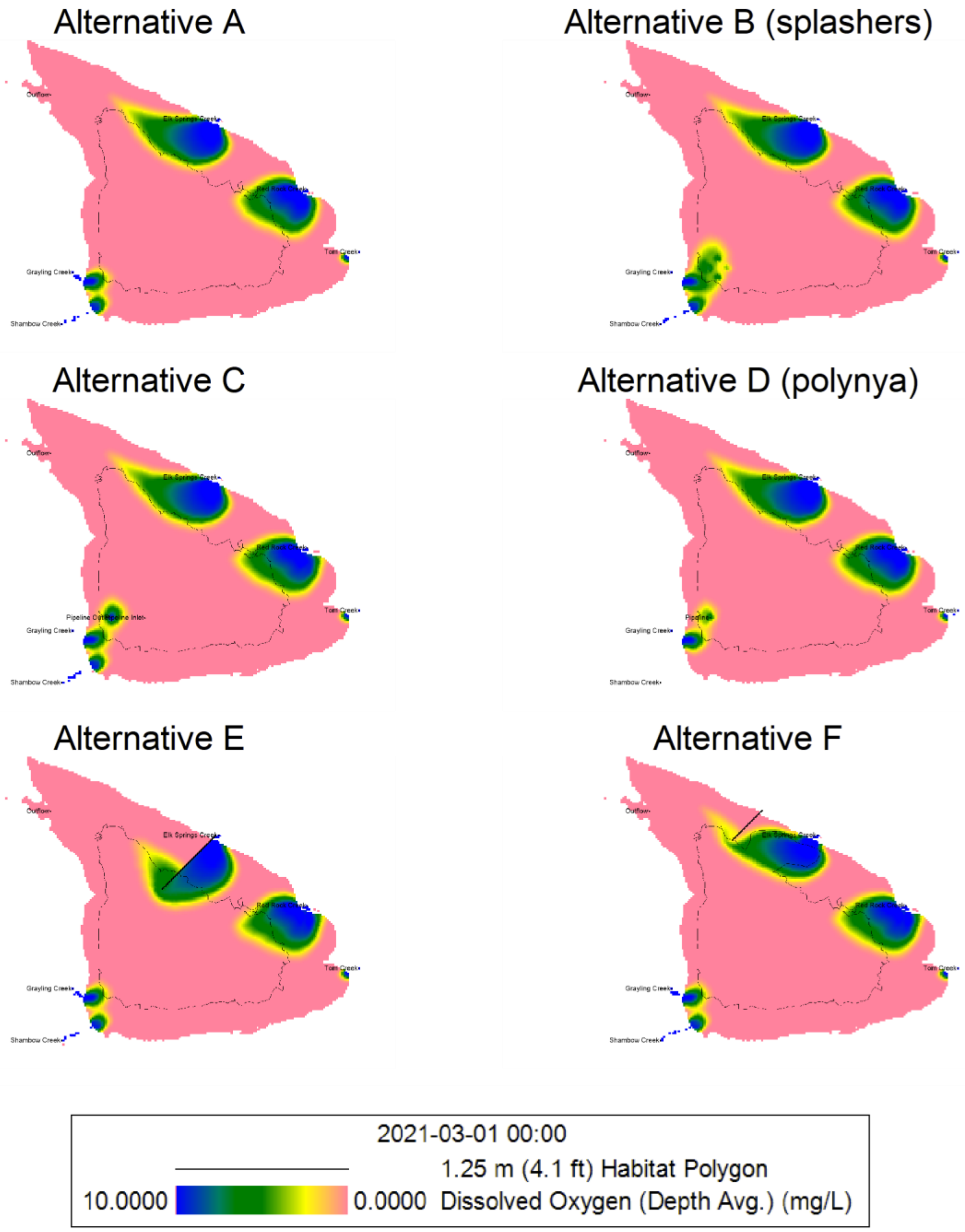

**Figure 3**. Simulated dissolved oxygen in Upper Red Rock Lake (URRL) using the hydrodynamic and water-quality model and the lower 25th quantile of tributary inflow and low lake volume. The alternatives were developed as part of a U.S. Fish and Wildlife decision on whether and how to improve the overwinter conditions of URRL in the Centennial Valley (CV) of Beaverhead County, Montana improve the long-term viability of CV grayling (*Thymallus arcticus*).

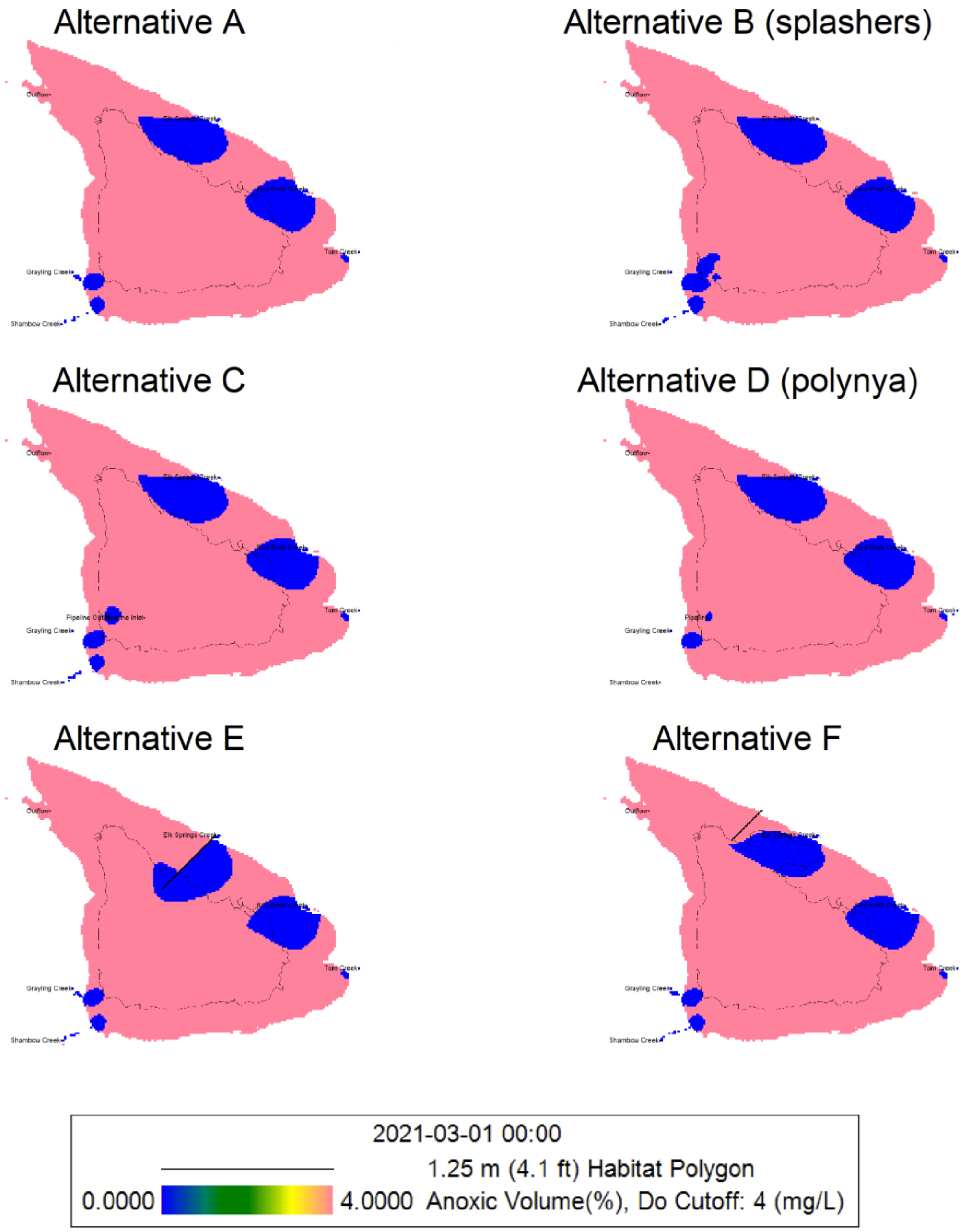

**Figure 4**. Simulated habitat (≥4 milligrams per liter of dissolved oxygen [$mgO_2/L$] and ≥1.25 meters in depth) in Upper Red Rock Lake (URRL) using the hydrodynamic and water-quality model for the lower 25th quantile of tributary inflow and low lake volume. The alternatives were developed as part of a U.S. Fish and Wildlife decision on whether and how to improve the overwinter conditions of URRL in the Centennial Valley (CV) of Beaverhead County, Montana improve the long-term viability of CV grayling (*Thymallus arcticus*).

The expected value of habitat created by the Alternatives is shown in Table 4, noting the amount reflects the increase over the baseline of Alternative A. What is apparent from examination of the figures and table is that technologies cluster together, with Alternatives B through D (e.g., splashers, diffusers, pumped aeration, and the pipeline) providing similar magnitudes of habitat, while Alternatives E through F group together. The outcome generally reflects the level of invasiveness of the project, with Alternatives B through D having lower levels of disturbance and Alternatives E and F requiring large-scale construction efforts to develop.

### *Effects of alternatives on CV grayling*

Extinction risk is minimized, and likelihood of recovery maximized, under Alternatives E and F (fig. 5, table 3).  Likelihood of extinction under status quo management (Alternative A) is high (0.46) relative to other alternatives (fig. 5, table 3). Alternatives $B_1$, $B_2$, C, D create similar amounts of habitat (1.45-2.74 ha; table 2). However, the degree to which they minimize risk of extinction varies based on their respective likelihood of creating a polynya (table 3); CV grayling have a higher risk of extinction under $B_1$ than the other action alternatives (fig. 5). Likelihood of recovery is low under alternatives A, $B_1$, $B_2$, C, D (table 3).

**Table 3.** Consequences for measurable attributes of Centennial Valley grayling (*Thymallus arcticus*) population performance (1A1 and 1A2) across the decision alternatives. The measurable attributes and alternatives were designed to inform a U.S. Fish and Wildlife decision on whether and how to improve the overwinter conditions of Upper Red Rock Lake in the Centennial Valley (CV) of Beaverhead County, Montana improve the long-term viability of CV grayling (*Thymallus arcticus*). The table shows results for two extinction thresholds individually (i.e., <25 individuals for a single year or <50 for three consecutive years) and a combined metric (Pr(extinction)both thresholds). Across the two metrics, we selected the most conservative (i.e., highest probability of extinction) estimate for the consequences summaries discussed in the next section.

| **Alternative** | | **(URRL Habitat Created)** | **1A1: CV Grayling Extinction** | | | **1A2: CV Grayling Recovery** |
|---|---|---|---|---|---|---|
| | | (Created habitat area [hectares]) | Pr(extinction) <25 individuals in a single year | Pr(extinction) <50 individuals across 3 yrs. | Pr(extinction) both thresholds | Freq(CV grayling greater than 400) |
| | | **Maximize** | **Minimize** | **Minimize** | **Minimize** | **Maximize** |
| A | Status quo | 0.0 | 0.41 | 0.31 | 0.46 | 0.05 |
| $B_1$ | Splashers | 1.5 | 0.30 | 0.22 | 0.33 | 0.07 |
| $B_2$ | Diffusers | 2.6 | 0.17 | 0.11 | 0.19 | 0.09 |
| C | Cascade | 2.7 | 0.11 | 0.06 | 0.13 | 0.09 |
| D | Pipeline | 1.5 | 0.18 | 0.11 | 0.21 | 0.07 |
| E | Barrier | 26.9 | <0.01 | <0.01 | <0.01 | 0.62 |
| F | Dredge/ Berm | 37.3 | <0.01 | <0.01 | <0.01 | 0.80 |

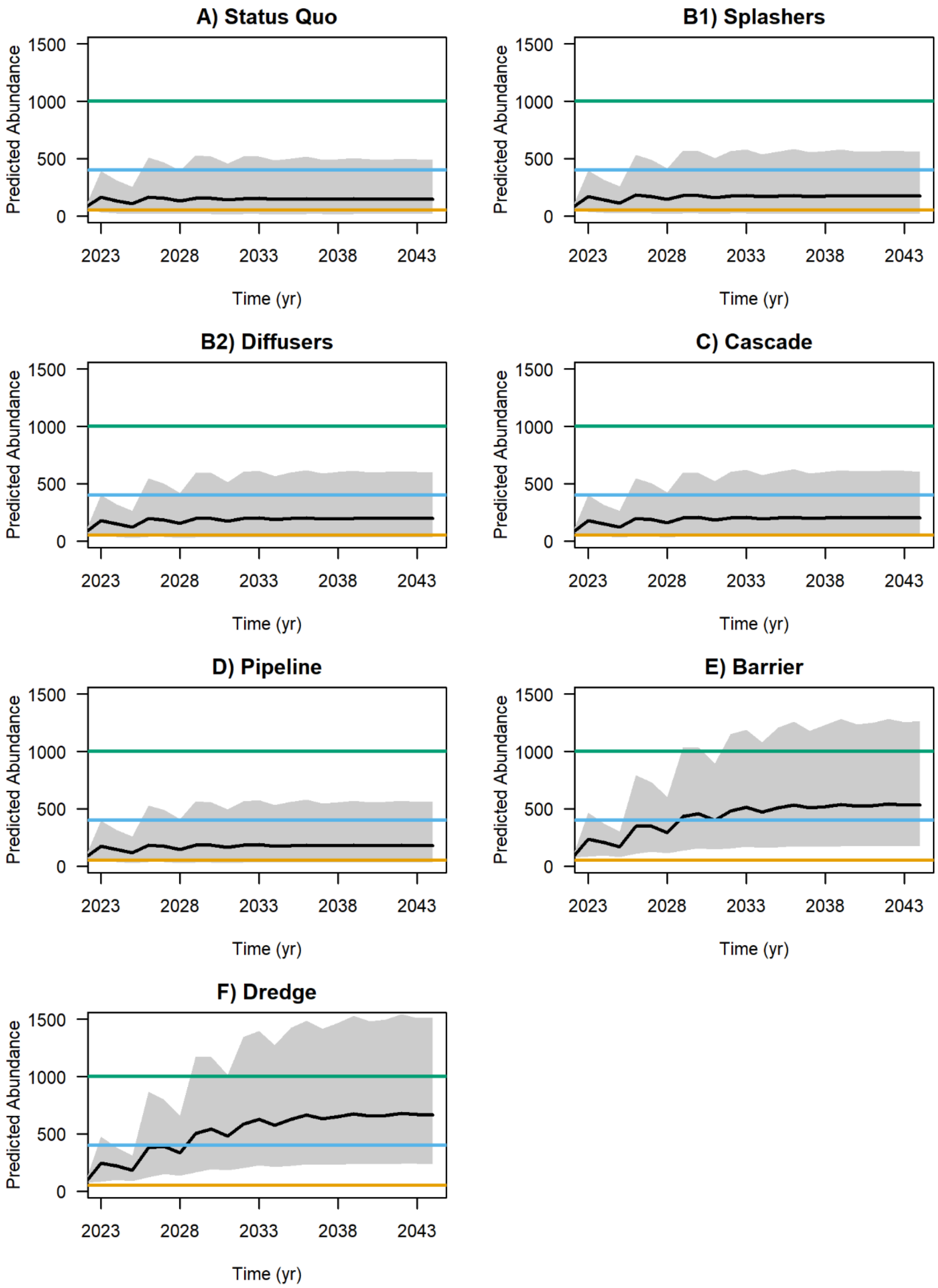

**Figure 5.** Predicted abundance of Centennial Valley arctic grayling from 2023 through 2045 under the seven management alternatives. The abundance estimates were designed to inform a U.S. Fish and Wildlife decision on whether and how to improve the overwinter conditions of Upper Red Rock Lake in the Centennial Valley (CV) of Beaverhead County, Montana improve the long-term viability of CV grayling (*Thymallus arcticus*). Colored horizontal lines represent the extinction threshold of 50 (orange), the recovery threshold of 400 (light blue), and the recovery threshold of 1000 (green).

### *Effects of alternatives on wilderness characters*

We found a gradient in intensity of effects to wilderness characters across the seven alternatives. In general, Alternative A resulted in the least impact to wilderness characters. Alternatives E and F had the greatest impacts.

For the untrammeled wilderness character, the Status Quo alternative (Alternative A) was estimated to have minor effects on URRL and Elk Springs Creek during times when water is released from Widgeon Pond (table 4; table A3). Alternatives $B_1$, $B_2$, C, and D result in intermediate trammeling and Alternatives E and F would result in the greatest degree of trammeling to Refuge ecosystems considered. Alternatives $B_1$, $B_2$, and C had lower estimated effects to URRL (lacustrine ecosystem), wetlands, and upland habitats and had no estimated effects to riverine ecosystems (tributaries to URRL; table 4). Alternative D had larger effects to wetlands and upland ecosystems around URRL, primarily from temporary construction activities. Alternatives E and F are anticipated to have larger effects to URRL from the permanent barrier and resultant changes to physical properties and ecological dynamics (e.g., submerged aquatic vegetation distribution) within the lake.

The undeveloped wilderness character generally followed the same pattern as trammeling with Alternative A having no development impacts and Alternatives E and F requiring substantial development. Alternatives $B_1$, $B_2$, C, and D, require little visible infrastructure in wilderness, whereas Alternatives E and F require permanent installations that are both visible and relatively large in spatial extent.

The effects of the alternatives on natural characters are expected to be mostly minor with the greatest effects occurring to sensitive species under Alternatives $B_1$, $B_2$, C, and D, and invasive species under Alternative D. The sensitive species most affected were expected to be plants including *Carex idahoa*, *Potentilla plattensis*, *Primula incana*, *Senecio hydrophilus*, *and Thelypodium sagittatum;* however, it is important to note that not all the effects are anticipated in the designated wilderness area (table 5). Lastly, experts expect there to be the potential for increases in the distribution and abundance of Kentucky bluegrass and smooth brome under Alternative D as the pipeline is being installed through an area of mixed native and invasive vegetation.

The last character was the solitude and primitive quality of Refuge wilderness. Like the other characters, Alternative A represented the least visual and sound disturbance on wilderness and Alternatives E and F are anticipated to have the highest. Alternative E will require loud (>95 dBa) equipment on URRL to install a sheet pile wall whereas, Alternative F requires the operation of floating dredges and other construction activities across multiple summer seasons.

**Table 4.** Consequences of the alternatives on the 4 wilderness characters: untrammeled, undeveloped, natural, and solitude/primitive. The measurable attributes and alternatives were designed to inform a U.S. Fish and Wildlife decision on whether and how to improve the overwinter conditions of Upper Red Rock Lake in the Centennial Valley (CV) of Beaverhead County, Montana improve the long-term viability of CV grayling (*Thymallus arcticus*). For each measurable attribute the decision maker has an expressed preference on the direction of performance (Minimize or Maximize).

| **Alternative** | | **Untrammeled** | | | | **Undeveloped** | **Natural** | | | **Solitude/Primitive** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **2A1: Lacustrine disturbance** | **2A2: Wetland disturbance** | **2A3: Riverine disturbance** | **2A4: Upland disturbance** | **2B1: Infrastructure** | **2C1: Sensitive species** | **2C2: Invasive species** | **2C3: Other species** | **2D1: Construction days (visual)** | **2D2: Construction days (sound)** |
| | | 0 – 9 | 0 – 9 | 0 – 9 | 0 – 9 | Penalized affected area | Percent max (0 – 1) | Percent max (0 – 1) | Percent max (0 – 1) | Penalized days | Penalized days |
| | | **Min** | **Min** | **Min** | **Min** | **Min** | **Min** | **Min** | **Min** | **Min** | **Min** |
| A | Status quo | 1.2 | 0.0 | 1.0 | 0.0 | 0.0 | 0.00 | 0.00 | 0.02 | 25.0 | 50.0 |
| $B_1$ | Splashers (4) | 3.4 | 1.2 | 0.0 | 3.0 | 59.3 | 0.26 | 0.08 | 0.12 | 53.0 | 80.0 |
| $B_2$ | Diffusers (16) | 3.4 | 1.2 | 0.0 | 3.0 | 48.7 | 0.24 | 0.08 | 0.08 | 34.0 | 64.0 |
| C | Cascade | 3.6 | 1.2 | 0.0 | 1.8 | 219.6.0 | 0.25 | 0.08 | 0.12 | 45.0 | 80.0 |
| D | Pipeline | 4 | 3.6 | 3.6 | 3.2 | 309.7 | 0.38 | 0.50 | 0.07 | 145.0 | 182.0 |
| E | Barrier | 5.6 | 1.8 | 1.4 | 0.4 | 3810.0 | 0.04 | 0.00 | 0.09 | 80.0 | 110.0 |
| F | Dredge/ Berm | 5.4 | 2.2 | 1.0 | 0.4 | 9000.0 | 0.04 | 0.00 | 0.09 | 890.0 | 1325.0 |

**Table 5.** Average scores for each of the alternatives on 18 biota that inhabit Red Rock Lakes National Wildlife Refuge using the constructed scale ranging from -4 to 4. A value of 0 indicates no change to distribution or abundance, whereas -4 or 4 represents permanent, large-scale decreases or increases in the abundance or distribution, respectively. These scores were summed and divided by the maximum score for each category to represent a percent maximum score for each category: Invasive, Other, and Sensitive.

| **Species** | **Scientific Name** | **Category** | **Alternatives** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | **A** | **B1** | **B2** | **C** | **D** | **E** | **F** |
| Smooth brome grass | *Bromus inermis* | Invasive | 0.00 | 0.33 | 0.33 | 0.33 | 2.00 | 0.00 | 0.00 |
| Kentucky bluegrass | *Poa pratensis* | Invasive | 0.00 | 0.33 | 0.33 | 0.33 | 2.00 | 0.00 | 0.00 |
| Bald eagle | *Haliaeetus leucocephalus* | Other | 0.00 | -1.00 | -0.25 | -1.00 | -0.50 | -1.00 | -1.00 |
| Beaver | *Castor canadensis* | Other | -0.60 | 0.00 | -0.40 | -0.40 | -0.20 | 0.00 | 0.00 |
| Coots | *Rallidae spp.* | Other | 0.00 | -0.75 | 0.00 | -0.25 | -0.25 | -0.75 | -0.75 |
| Ducks | *Anatidae spp.* | Other | 0.00 | -0.75 | -0.50 | -0.75 | -0.50 | -0.75 | -0.75 |
| Gray wolf | *Canis lupus* | Other | 0.00 | -0.40 | -0.60 | -0.60 | -0.20 | 0.00 | 0.00 |
| Grebe | *Podicipedidae spp.* | Other | 0.00 | -0.75 | -0.25 | -0.25 | -0.25 | -0.50 | -0.50 |
| Otter | *Lontra canadensis* | Other | 0.00 | 0.20 | 0.40 | 0.20 | -0.20 | 0.00 | 0.00 |
| Shiras moose | *Alces alces* | Other | 0.00 | -0.40 | -0.80 | -0.80 | -0.20 | 0.00 | 0.00 |
| Grizzly bear | *Ursus arctos* | Sensitive | 0.00 | -0.20 | -0.20 | -0.20 | 0.00 | 0.00 | 0.00 |
| Idaho sedge | *Carex idahoa* | Sensitive | 0.00 | -1.33 | -1.33 | -1.33 | -2.33 | 0.00 | 0.00 |
| Franklins gull | *Leucophaeus pipixcan* | Sensitive | 0.00 | -0.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Marsh cinquefoil | *Potentilla plattensis* | Sensitive | 0.00 | -1.33 | -1.33 | -1.33 | -2.00 | 0.00 | 0.00 |
| Hoary primrose | *Primula incana* | Sensitive | 0.00 | -1.33 | -1.33 | -1.33 | -2.33 | 0.00 | 0.00 |
| Alkali-marsh ragwort | *Senecio hydrophilus* | Sensitive | 0.00 | -1.33 | -1.33 | -1.33 | -2.33 | 0.00 | 0.00 |
| Arrow thelypody | *Thelypodium sagittatum* | Sensitive | 0.00 | -1.33 | -1.33 | -1.33 | -2.33 | 0.00 | 0.00 |
| Trumpeter swan | *Cygnus buccinator* | Sensitive | 0.00 | -1.00 | -0.75 | -1.00 | -0.75 | -1.25 | -1.25 |

*Effects of alternatives on stakeholders and cost*

The estimated stakeholder effects under the seven alternatives can be found in Table 6. Overall, using direct estimates of construction, maintenance, and operation, we found that the status quo results in no additional stakeholder effects or costs to the Refuge. The other six alternatives varied in the number of days of overlap in summer months to be between 0 – 435 for general refuge users, and 0 – 60 for hunters (Table 6). Alternative F had the most substantial overlap with refuge users and hunters because of the prolonged period of construction associated with dredging activities.

For downstream water users, Alternative F could result in minor and temporary reductions in outflow of 0.006 $m^3/s$ (0.2 cfs). The other alternatives were not expected to have any effects on water availability (Table 6).

For construction costs, Alternative A required no additional costs ($0) and Alternative E and F were the most costly at $3,160,000 and $7,370,000, respectively. The other alternatives ranged between $371,000 (Alternative $B_2$) and $774,000 (Alternative C).

Three of the seven alternatives required electricity to operate. Alternative B2 was the least costly at $1,010/yr, Alternative B1 was intermediate ($800/yr) and Alternative C was the most costly ($3,240/yr) (Table 6).

**Table 6.** Consequences of the alternatives for each of five measurable attributes related to stakeholders and monetary costs. For each measurable attribute the decision maker has an expressed preference in the direction of performance (Minimize or Maximize). The measurable attributes and alternatives were designed to inform a U.S. Fish and Wildlife decision on whether and how to improve the overwinter conditions of Upper Red Rock Lake in the Centennial Valley (CV) of Beaverhead County, Montana improve the long-term viability of CV grayling (*Thymallus arcticus*).

| **Alternative** | | **3A1: General Refuge Users** | **3A2: Hunters** | **3A3: Downstream water users** | **4A1: Construction costs†** | **4A2: Operational costs†** |
|---|---|---|---|---|---|---|
| | | Days/overlap | Days/overlap | Reduction in cubic meters per second | U.S. Dollars | U.S. Dollars |
| | | **Min** | **Min** | **Min** | **Min** | **Min** |
| A | Status quo | 0.0 | 0.0 | 0.0 | $0.00 | $0.00 |
| $B_1$ | Splashers | 74.0 | 0.0 | 0.0 | $509,750 | $25,250 |
| $B_2$ | Diffusers | 74.0 | 0.0 | 0.0 | $371,000 | $20,000 |
| C | Cascade | 115.0 | 0.0 | 0.0 | $774,000 | $81,000 |
| D | Pipeline | 91.0 | 0.0 | 0.0 | $657,000 | $0.00 |
| E | Barrier | 40.0 | 0.0 | 0.0 | $3,160,000 | $0.00 |
| F | Dredge and Berm | 435.0 | 60.0 | 0.006 | $7,370,000 | $0.00 |

†Costs are not for bid or construction (Association for the Advancement of Cost Engineering 2005) Level 5 estimate at best)

## Consequences

The consequences of all 7 alternatives on each of the 16 measurable attributes can be found in Table 7. We found that there was no alternative capable of maximizing preferential outcomes for all objectives simultaneously. The alternatives that performed best in some areas also performed the worst in other areas. For example, the No Action (i.e., status quo) alternative performed best for 13 of the 16 measurable attributes but also presented the worst outcome for CV grayling.

Under the Status Quo, we estimated that the probability of extinction for CV grayling over the next 25 years was 46% if no additional action were taken to improve overwinter habitat in URRL. In contrast, two alternatives (E and F) were able to provide a high likelihood of CV grayling recovery in 25 years (62 – 80%), but also led to relatively high costs to some wilderness characteristics, stakeholders, and monetary costs. Together, these summarized results highlight the apparent tradeoffs between maximizing CV grayling recovery and maximizing wilderness characters on the Refuge.

**Table 7.** Consequences of the seven alternatives across the complete set of 16 measurable attributes. Best performing alternatives for each alternative are colored in dark blue, intermediate outcomes are colored in light blue, and worst-performing alternatives are in orange. The alternatives were designed to inform a U.S. Fish and Wildlife decision on whether and how to improve the overwinter conditions of Upper Red Rock Lake in the Centennial Valley (CV) of Beaverhead County, Montana improve the long-term viability of CV grayling (*Thymallus arcticus*). For each measurable attribute the decision maker has an expressed preference in the direction of performance (Minimize or Maximize). The alternatives and measurable attributes are described in detail in the Fundamental Objectives, Measurable Attributes, and Alternatives sections of this report.

[GEX, probability of CV grayling extinction; GRC, frequency of CV grayling exceeding 400 individuals; LCS, lacustrine disturbance; WET, wetland disturbance; RIV, riverine disturbance; UPL, upland disturbance; INF, infrastructure on wilderness; SEN, sensitive species; INV, invasive species; BIO, other biota; DYV, days of visual disturbance; DYS, days of sound disturbance; GEN, days of disturbance to refuge users; HUN, days of disturbance to hunters; DWN, reduction in daily outflow; CON, construction costs; OPR, operational costs; Max, maximum; Min, minimum; Obj; objective]

| **Alt** | **Obj. 1A** | | **Obj. 2A** | | | | **Obj. 2B** | **Obj. 2C** | | | **Obj. 2D** | | **Obj. 3A** | | **Obj. 3B** | **Obj. 4A** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1A1: GEX** | **1A2: GRC** | **2A1: LCS** | **2A2: WET** | **2A3: RIV** | **2A4: UPL** | **2B1: INF** | **2C1: SEN** | **2C2: INV** | **2C3: BIO** | **2D1: DYV** | **2D2: DYS** | **3A1: GEN** | **3A2: HUN** | **3B3: DWN** | **4A1: CON†** | **4A2: OPR†** |
| | **Min** | **Max** | **Min** | **Min** | **Min** | **Min** | **Min** | **Min** | **Min** | **Min** | **Min** | **Min** | **Min** | **Min** | **Min** | **Min** | **Min** |
| A | 0.46 | 0.05 | 1.2 | 0.0 | 1.0 | 0.0 | 0.0 | 0.00 | 0.00 | 0.02 | 25.0 | 50.0 | 0.0 | 0.0 | 0.0 | $0 | $0 |
| $B_1$ | 0.33 | 0.07 | 3.4 | 1.2 | 0.0 | 3.0 | 59.3 | 0.26 | 0.08 | 0.12 | 53.0 | 80.0 | 74.0 | 0.0 | 0.0 | $509.8 | $25.2 |
| $B_2$ | 0.19 | 0.09 | 3.4 | 1.2 | 0.0 | 3.0 | 48.7 | 0.24 | 0.08 | 0.08 | 34.0 | 64.0 | 74.0 | 0.0 | 0.0 | $371 | $20 |
| C | 0.13 | 0.09 | 3.6 | 1.2 | 0.0 | 1.8 | 219.6 | 0.25 | 0.08 | 0.12 | 45.0 | 80.0 | 115.0 | 0.0 | 0.0 | $774 | $81 |
| D | 0.21 | 0.07 | 4 | 3.6 | 3.6 | 3.2 | 309.7 | 0.38 | 0.5 | 0.07 | 145.0 | 182.0 | 91.0 | 0.0 | 0.0 | $657 | $0 |
| E | <0.01 | 0.62 | 5.6 | 1.8 | 1.4 | 0.4 | 3810.0 | 0.04 | 0.00 | 0.09 | 80.0 | 110.0 | 40.0 | 0.0 | 0.0 | $3,160 | $0 |
| F | <0.01 | 0.80 | 5.4 | 2.2 | 1.0 | 0.4 | 9000.0 | 0.04 | 0.00 | 0.09 | 890.0 | 1325.0 | 435.0 | 60.0 | 0.2 | $7,370 | $0 |

† in thousands

## Discussion

The decision to implement conservation actions in URRL for CV grayling includes considering tradeoffs across persistence and recovery potential for CV grayling, wilderness characters on the Refuge, enjoyment of Refuge resources by local stakeholders, and costs of management. Under the status quo alternative, we estimated a 46% probability that one of few remaining populations exhibiting the full spectrum of life history behaviors present in historical grayling populations in the UMR will be extirpated in the next 25 years. We also found that this extinction risk can be substantially reduced (46% to <1%) by implementing intensive management alternatives, which may result in large disturbances to four wilderness characters and Refuge stakeholders. Decision analysis provides tools and methods to navigate these difficult tradeoffs; this report was structured to make those tools available to USFWS and other stakeholders considering how to conserve CV grayling.

Implementing any action alternative other than status quo will increase the likelihood of achieving the fundamental objective for CV grayling (*maximize CV grayling probability of persistence),* although we find that recovery is only expected to be probable under alternatives with relatively large wilderness disturbances. We found that the current release of water from Widgeon Pond creates additional, but temporary winter habitat that was insufficient to prevent hypoxic conditions across the entire winter season and in the deeper regions of URRL that CV grayling select for. It is important to note, however, that Refuge staff continue to experiment with the timing and duration of Widgeon Pond releases such that increases in available habitat may be possible under this alternative. Other alternatives, including diffusers, cascade aeration and tributary pipelines, would provide persistent habitat and substantially improve the probability of long-term persistence of CV grayling (13 to 21% chance of extinction versus 46%

under status quo); however, recovery is not expected under those alternatives by themselves. Recovery is up to twice as likely under Alternatives $B_2$ and C compared to the status quo (a 9% versus 5% chance); a coincident natural improvement in winter habitat (i.e., increased tributary input, additional water depth under ice, less snow cover) relative to what has been observed over the past six years would be required to reliably produce a population of over 400 CV grayling.

The most substantial improvements in overwinter CV grayling habitat were estimated under Alternatives E and F, although they required the most visible infrastructure on wilderness. Alternative F (dredge and berm) would also require continuous construction on the Refuge and in wilderness for at least two consecutive summer seasons but would lead to an 80% chance that CV grayling recover to a population greater than 400 individuals in the next 25 years and less than 1% chance of extirpation. The dredged depths may not be permanent, however, due to in-lake sedimentation processes. Alternative E (barrier) provides similar benefits to CV grayling with fewer wilderness disturbances than dredge and berm but with a higher level of visible infrastructure than alternatives A, $B_1$, $B_2$, C and D.

There are several caveats that should be considered when interpreting the results of the hydrodynamic water-quality and fish population models. Although the EFDC+ model provides an indication of wintertime lake dynamics in URRL, it is an approximation that simplifies complex lake DO processes. Data on boundary conditions and initial conditions within URRL are limited. Moreover, the ice simulation method employed is simplistic. Because of this, results are approximations only. Nonetheless, some conclusions can be made about proposed alternatives that could benefit grayling in URRL, most notably that improvements to winter habitat could increase the likelihood of CV grayling recovery.

Fish population models also have constraints. For example, we assumed that suitable overwinter habitat was defined by areas in URRL that met or exceeded 1.25 meters in depth and 4 $mgO_2/L$ concentration. While this assumption was based on previous work by Davis (2016) and supported by later work by Warren and Jaeger (2017), it is possible that these estimates are conservative. Further, winter habitat values have been measured at various times over the last 30 years; however, 9 of the 12 measurements have been taken in the last 10 years (2013-2022). This period has been characterized by extreme drought, and the high density of sampling during this period may result in biased or skewed representation of future distribution of available winter habitat. For this reason, the gamma distribution used in CV grayling projections may represent a conservative characterization of future conditions if drought subsides. Other options could include simulation draws from normal or uniform distributions of winter habitat centered around the long-term mean and would result in higher likelihood of recovery and lower likelihood of extinction for all alternatives. However, these distributions and their underlying assumption (i.e., drought will wane, and the lake will naturally revert to more favorable habitat conditions) do not fit the available data as well as the gamma distribution and their use would be speculative. Thus, our use of the gamma distribution to characterize future winter habitat conditions and project grayling population sizes best represents the available data.

The density dependence of the CV grayling model may provide an optimistic assessment of extinction and recovery probabilities. The CV grayling model commonly predicted recovery from very low population sizes (< 5 individuals) during simulations because of the strong density dependence in the Holling function. However, this model was fit to and closely predicted observed CV grayling abundances at low population sizes during the past 7 years (Table A2). We also considered density independent models, but they performed poorly relative to the density dependence parameterization, and underestimated the observed grayling population at low abundances, which provides support for a density-dependent response in the population (Table A2). Moreover, compensatory density dependence has been described for fish populations, but reliably modeling and predicting its effects is notoriously difficult (Rose et al 2001). While the strength of the density dependence in the model may still underestimate extinction probability and overestimate recovery probability, selection of extinction thresholds based on conservation genetic theory mitigated this problem in a biologically meaningful way.

Although overwinter habitat in URRL is the primary population driver for CV grayling, they are also dependent on access to high quality spawning habitat in tributaries. Over $1M has been spent during the past 15 years to improve quality and connectivity of tributary habitat in the Centennial Valley (MFWP unpublished data). Projects range from standalone large-scale habitat restoration of Hell Roaring, Elk Springs, Long, and Corral creeks on and off the Refuge to the establishment of a CCAA program designed specifically to improve tributary habitat for grayling on private lands by improving instream flow, riparian health, fish passage and entrainment in irrigation diversions (USFWS 2018). Past and ongoing restoration and protection tributaries where CV grayling spawn ensure that any improvements to overwinter habitat in URRL will be maximized for CV grayling. However, habitat improvements in tributaries are not expected to result in CV grayling recovery without concurrent improvements to overwinter habitat in URRL (Warren et al. 2022).

The use of SDM to frame and evaluate a decision on what actions to take in URRL for CV grayling makes available deliberative tools from decision analysis. In this context, it would allow USFWS to deliberate tradeoffs between an ability to achieve CV grayling recovery while also preserving wilderness characteristics and stakeholder benefits on the Refuge. The quantitative analysis of all Alternatives provided in this report could be considered an intermediate step in the identification of the best performing alternative. The next step could use multi-criteria decision analysis to specify the relative importance of each of the different objectives (i.e., by providing an objectives weight) and formally analyzing tradeoffs in a transparent and defensible manner.

## References

Achord, S., R. Zabel, and B. Sanford. 2007. Migration timing, growth, and estimated parr to smolt survival rates of wild Snake River spring-summer chinook salmon from the Salmon River Basin, Idaho, to the lower Snake River. Transactions of the American Fisheries Society 136:142-154.

Al-Chokhachy, R. and P. Budy. 2008. Demographic characteristics, population structure, and vital rates of a fluvial population of bull trout in Oregon. Transactions of the American Fisheries Society 137:1709-1722.

Ashley, K., and Nordin, R. (1999). Lake aeration in British Columbia: Applications and experiences. In T. Murphy, & M. Munawar, Aquatic restoration in Canada (pp. 87-108). Leiden, The Netherlands: Backhuys Publishers.

Association for the Advancement of Cost Engineering (AACE). 2005. Cost estimate classification system - as applied in engineering, procurement, and construction for the process industries. Recommended practice no. 18R-97. URL: https://www.costengineering.eu/Downloads/articles/AACE_CLASSIFICATION_SYSTEM.pdf

Andrews, J., 2017. Red Rock Lakes Bathymetry and GPS Survey: Project Summary & Meta Data. U.S. Fish and Wildlife Service.

Banks, R.B. and F.F. Herrera. 1977. Effect of wind and rain on surface reaeration. Journal of the Environmental Engineering Division, 103(3): 489-504.

Bowerman, T., and P. Budy. 2012. Incorporating movement patterns to improve survival estimates for bull trout. North American Journal of Fisheries Management 32: 1123-1136.

Boyd, J.W. 2008. Effects of water temperature and angling on mortality of salmonids in Montana streams. Thesis, Montana State University, Bozeman, Montana.

Chapra, S. 2008. Surface water-quality modeling. Long Grove, IL: Waveland Press, Inc.

Davis, M. N. 2016. Winter survival and habitat as limiting factors for Arctic grayling at Red Rock Lakes National Wildlife Refuge. Thesis, Montana State University, Bozeman, Montana.

Davis, M., McMahon, T., Cutting, K., & Jaeger, M. 2020. Environmental and climatic factors affecting winter hypoxia: Evidence for a hypoxia refuge and for reoxygenation prior to spring ice loss in a large winter-kill prone lake. Hydrobiologia 847, 3983-3997.

Dieterman, D. J., and R. J. H. Hoxmeier. 2011. Demography of juvenile and adult brown trout in streams of southeastern Minnesota. Transactions of the American Fisheries Society 140:1642-1656.

DSI, LLC. 2020. EFDC+ Theory, Edmonds, WA: DSI, LLC.

Emergency Wetlands Resources Act 1986; 16 U.S. Code 3901

Endangered Species Act of 1973; 16 U.S.C. 1531-1544

Environmental Dynamics International (EDI). 2023. Field performance of fine and ultra fine bubble diffusers. Accessed 1/28/2023. URL: https://blog.wastewater.com/field-performance-of-fine-and-ultra-fine-bubble-diffusers

ESRI 2021. ArcGIS Pro 2.9.1. Redlands, CA: Environmental Systems Research Institute.

Fish and Wildlife Act 1956; 16 U.S. Code 742(a)-754

Flynn, K. F., T. J. Johnson, W. S. Parker, and J. Lovell. 2019. Upper Red Rock Lake, MT: Preliminary engineering and feasibility analysis to improve winter habitat for Arctic grayling. CDM Smith, Inc., Helena, MT.

Flynn, K. F. 2022. EFDC+ dissolved oxygen modeling of Upper Red Rock Lake. KF2 Consulting. Helena, MT.

Francingues, N. R. and M.R. Palermo. 2005. Silt curtains as a dredging project management practice. DOER Technical Notes Collection (ERDC TN-DOER-E21). U.S. Army Engineer Research and Development Center. Vicksburg, MS.

Hanea, A. M., McBride, M. F., Burgman, M. A., Wintle, B. C., Fidler, F., Flander, L.,...Mascaro, S. (2017). I nvestigate D iscuss E stimate A ggregate for structured expert judgement. International Journal of Forecasting, 33, 267–279.

Hemming, V., Camaclang, A.E., Adams, M.S., Burgman, M., …, Martin, T.G. 2022. An introduction to decision science for conservation. Conserv Biol. 36(1):e13868. doi: 10.1111/cobi.13868.

Hilborn, R. and M. Mangel. 1997. The ecological detective: confronting models with data.

Monographs in Population Biology 28. Princeton University Press, Princeton, NJ.Improvement Act of 1997; 20 U.S. Code § 1400

Jamieson, I. G., and Allendorf, F. W. 2012. How does the 50/500 rule apply to MVPs?. Trends in ecology & evolution, 27(10), 578-584.

Kasco Marine. 2023. Robust-Aire Systems 1, 2, & 3 specifications. http://www.kascomarine.com/pdfs/robust_aire_detailed_specs.pdf. Accessed 1/27/2023).

Kovach, R. P., A. R. Whiteley, M. E. Jaeger, S. Painter, A. Lodmell, and R. F. Leary. 2020. Genetic monitoring informs conservation status and trend of Arctic grayling at the southern edge of their distribution. Canadian Journal of Fisheries and Aquatic Sciences 77(12):1934-1942.

Landres, P., Barns, C., Boutcher, S., Devine, T, Dratch, P., Lindholm, A., Merigliano, L., Roeper, N., Simpson, E. 2015. Keeping it wild 2: An updated interagency strategy to monitor trends in wilderness character across the National Wilderness Preservation System. Gen. Tech. Rep. RMRS-GTR-340. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 114 p.

Mathias, J., and J. Barica. 1980. Factors controlling oxygen depletion in ice-covered lakes. Canadian Journal of Fish and Aquatic Sciences, 37(2), 15-194.

McCarthy, P.M., Sando, Roy, Sando, S.K., and Dutton, D.M., 2016. Methods for estimating streamflow characteristics at ungaged sites in western Montana based on data through water year 2009: U.S. Geological Survey Scientific Investigations Report 2015–5019–G, 19 p., http://dx.doi.org/10.3133/sir20155019G.

McCord, S., Schladow, S., and T. Miller 2000. Modeling artificial aeration kinetics in ice-covered lakes. Journal of Environmental Engineering. 126(1): 21-31.

McCord, S. and S. Schladow. 2001. Design parameters for artificial aeration of ice-covered lakes. Journal of Lake and Reservoir Management. 17(2): 121-126.

Mogen, J. T. 1996. Status and biology of the spawning population of Red Rock Lakes Arctic grayling. Thesis, Montana State University, Bozeman, Montana.

National Oceanic and Atmospheric Administration (NOAA). 1976. U.S. standard atmosphere, 1976. Washington, D.C.

National Wildlife Refuge System Administration Act of 1966; 16 U.S. Code 668dd et seq.

O'Connor, D.J. and W.E. Dobbins. 1958. Mechanism of reaeration in natural streams. Transactions of the American Society of Civil Engineers 123(1): 641–666.

Parrett, C., Johnson, D. R., and Hull, J. A. 1989. Estimates of monthly streamflow characteristics at selected sites n the Upper Missouri River Basin, Montana. Base period water years 1937 – 1986. U.S. Geological Survey Scientific Investigations Report 89-4082.

Paterson, T. 2013. Estimation of the abundance and apparent survival of spawning Arctic grayling in Red Rock Creek; Red Rock Lakes National Wildlife Refuge. Thesis, Montana State University, Bozeman, Montana.

R Core Team. 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.URL https://www.R-project.org/.

Refuge Recreation Act 1962; 16 U.S. Code 460k-460k-4

Rose, K. A., J. H. Cowan, K. O Winemiller, R. A. Myers, R. Hilborn. 2001. Compensatory density dependence in fish populations: importance, controversy, understanding and prognosis. Fish and Fisheries 2: 293-327.

Runge, M.C., LaGory, K.E., Russell, K., Balsom, J.R., Butler, R.A., Coggins, L.G.J., Grantz, K.A., Hayse, J., Hlohowskyj, I., Korman, J., May, J.E., O'Rourke, D.J., Poch, L.A., Prairie, J.R., VanKuiken, J.C., Van Lonkhuyzen, R.A., Varyu, D.R., Verhaaren, B.T., Vesekla, T.D., Williams, N.T., Wuthrich, K.K., Yackulic, C.B., Billerbeck, R.P., and Knowles, G.W., 2015, Decision analysis to support development of the Glen Canyon Dam long-term experimental and management plan: U.S. Geological Survey Scientific Investigations Report 2015–5176, 64 p., accessed January 2023, at https://doi.org/10.3133/sir20155176.

Siddoway, B., Flynn, K. & Vincent, J., 2021. Winter habitat improvement for Arctic Grayling in Upper Red Rock Lake preliminary design analysis, Butte, MT: Water & Environment Technologies.

Smagorinsky, J., 1963. General circulation experiments with the primitive equations: I. The basic experiment. Monthly Weather Review. 91(3): 99-164.

Warren, J. M., and Jaeger, M. E. 2017. Centennial Valley Arctic grayling adaptive management plan. Available from Montana Fish Wildlife and Parks, Dillon, MT.

Warren, J. M. and M. Jaeger, K. Cutting, K. Cook. 2020. Site-specific protocol for the Centennial Valley Arctic grayling adaptive management plan. U.S. Fish and Wildlife Service, Denver, CO.

Warren, J. M., M. Jaeger, R. Kreiner, K. Cutting, L. Bateman, T. Gander, T. Paterson, J. Payne, and M. Duncan. 2022. Centennial Valley Arctic grayling adaptive management project annual report, 2021. USFWS and FWP, Lima, Montana.

Wilderness Act of 1964; 16 U.S.C. 1121 (note), 1131-1136.

U.S. Army Corps of Engineers. 2015. Dredged and dredged material management. EM 1110-2-5025. Department of the Army. Washington, DC.

USFWS (U.S. Fish and Wildlife Service). 2009. Comprehensive Conservation Plan Red

Rock Lakes National Wildlife Refuge. Lima, MT.

USFWS (U.S. Fish and Wildlife Service). 2014. Endangered and threatened wildlife and plants: revised 12-month finding on a petition to list the upper Missouri River distinct population segment of Arctic grayling as an endangered or threatened species, proposed rule. Federal Register, Vol. 79, No 161, 49384-49422.

USFWS. 2018. Candidate conservation agreement with assurances for Arctic grayling in the Centennial Valley, Montana. Helena, Montana.

USFWS and Montana Fish, Wildlife and Parks. 2023. Draft environmental assessment Arctic grayling conservation Red Rock Lakes National Wildlife Refuge: U.S. Fish and Wildlife Service.

# *Appendices for* Decision-Making for Centennial Valley Arctic Grayling (*Thymallus arcticus*) Conservation on Red Rock Lakes National Wildlife Refuge

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# Appendix 1. Supporting tables for methods and results of report.

**Table A1.** Names and affiliations (at the time of the elicitation and in alphabetical order) of expert panelists and team members who provided judgement on estimates of hydrology, grayling, wilderness, and stakeholder parameters or measurable attributes for each of the seven alternatives. The science team columns identify which teams each expert served on and the expert column indicates whether the expert provided data for the analyses. The contributions of science team members and experts were used to inform a U.S. Fish and Wildlife decision on whether and how to improve the overwinter conditions of Upper Red Rock Lake in the Centennial Valley (CV) of Beaverhead County, Montana improve the long-term viability of CV grayling (*Thymallus arcticus*).

[Affiliation key: MFWP, Montana Fish, Wildlife and Parks; TU, Trout Unlimited; USFWS, U.S. Fish and Wildlife Service; LSU, Louisiana State University; NPS, U.S. National Park Service; KF2 Consulting is a water resources engineering firm based in Helena, Montana]

| Name | Affiliation | Science Team | | | Expert |
|---|---|---|---|---|---|
| | | CV Grayling Team | Wilderness Team | Stakeholder Team | |
| **Jaron Andrews** | USFWS | X | | | Yes |
| **James Boyd** | USFWS | X | | | No |
| **David Brooks** | TU | | | X | No |
| **Andrew Brummond** | MFWP | X | | X | Yes |
| **Kellie Carim** | USFS | | X | | No |
| **Kyle Cutting** | NPS | X | X | | Yes |
| **Michael Dance** | LSU | X | | | No |
| **Kyle Flynn** | KF2 Consulting | X | X | | Yes |
| **Claire Gower** | MFWP | | X | | Yes |
| **Matthew Jaeger** | MFWP | X | | | Yes |
| **George Jordan** | USFWS | X | | | No |
| **Ryan Kreiner** | MFWP | X | X | | Yes |
| **James Magee** | USFWS | | | X | No |
| **Jarrett Payne** | MFWP | X | X | X | Yes |
| **Michelle Reilly** | USFWS | | X | | No |
| **Jeff Warren** | USFWS | X | X | | Yes |
| **Bill West** | Retired (FWS) | X | X | X | No |
| **Marina Yoshioka** | MFWP | | X | X | No |

**Table A2.** Estimates of overwinter habitat on March 1 for each scenario and alternative. For each alternative, the scenarios included a low flow (25th percentile) and average flow condition (50th percentile) inflow estimate was made for each tributary inflow boundary condition to URRL, which was then combined with a low volume (thick ice; 0.5m) or large volume (thin ice; 0.25m) approximation of the lake condition, both of which have an influence on hydrodynamics and water quality constituents. The alternatives were designed to inform a U.S. Fish and Wildlife decision on whether and how to improve the overwinter conditions of Upper Red Rock Lake in the Centennial Valley (CV) of Beaverhead County, Montana improve the long-term viability of CV grayling (*Thymallus arcticus*). A polynya is an area of open water in an otherwise ice-covered lake. Alternative A was not expected to result in a polynya, thus the polynya column for that alternative was labeled n/a. The alternatives are described in detail in the Alternatives section of the report.

| Alt | Tributary outflow (average or low) | Ice thickness (0.25m or 0.5m) | Polynya (yes/no) | Habitat (ha) |
|---|---|---:|---|---:|
| A | average | 0.50 | n/a | 0.0 |
| A | average | 0.25 | n/a | 0.0 |
| A | low | 0.50 | n/a | 0.0 |
| A | low | 0.25 | n/a | 0.0 |
| B1 | average | 0.50 | yes | 7.2 |
| B1 | average | 0.25 | yes | 0.5 |
| B1 | low | 0.50 | yes | 7.6 |
| B1 | low | 0.25 | yes | 1.6 |
| B2 | average | 0.50 | yes | 6.0 |
| B2 | average | 0.25 | yes | 0.3 |
| B2 | low | 0.50 | yes | 5.4 |
| B2 | low | 0.25 | yes | 1.1 |
| B2 | average | 0.50 | no | 0.9 |
| B2 | average | 0.25 | no | 0.0 |
| B2 | low | 0.50 | no | 0.3 |
| B2 | low | 0.25 | no | 0.0 |
| C | average | 0.50 | yes | 4.8 |
| C | average | 0.25 | yes | 0.6 |
| C | low | 0.50 | yes | 4.8 |
| C | low | 0.25 | yes | 0.8 |
| D | average | 0.50 | yes | 3.6 |
| D | average | 0.25 | yes | 1.4 |
| D | low | 0.50 | yes | 0.8 |
| D | low | 0.25 | yes | 0.3 |
| D | average | 0.50 | no | 1.3 |
| D | average | 0.25 | no | 0.4 |

| | | | | |
|---|---|---|---|---|
| D | low | 0.50 | no | 0.1 |
| D | low | 0.25 | no | 0.0 |
| E | average | 0.50 | y | 30.4 |
| E | average | 0.25 | y | 36.8 |
| E | low | 0.50 | y | 20.6 |
| E | low | 0.25 | y | 13.1 |
| E | average | 0.50 | y | 41.8 |
| E | average | 0.25 | y | 40.9 |
| E | low | 0.50 | y | 37.6 |
| E | low | 0.25 | y | 25.0 |

**Table A3.** Direct estimates of wilderness effects for each alternative. The direct measures were used to summarize measurable attributes for each alternative. This work was designed to inform a U.S. Fish and Wildlife decision on whether and how to improve the overwinter conditions of Upper Red Rock Lake in the Centennial Valley (CV) of Beaverhead County, Montana improve the long-term viability of CV grayling (*Thymallus arcticus*).

| **Activity type (location)** | **Alternative** | **Duration** | **Sound** | **Affected area** | **Season** | **Wilderness?** | **Penalty Visual** | **Penalty Sound** |
|---|---|---|---|---|---|---|---|---|
| | | **Days** | **Decibels** | **m$^2$** | **Summer/ Winter** | **Yes/No** | **0-2** | **0-3** |
| **Construction** | | | | | | | | |
| Trench power (Existing to Campground) | Splasher | 30 | 81 | 5422.4 | Summer | No | 2 | 2 |
| Install electrical service (Campground) | Splasher | 5 | 81 | 1.0 | Summer | No | 1 | 2 |
| Trench power (Campground to URRL) | Splasher | 2 | 81 | 55.0 | Summer | Yes | 2 | 2 |
| Enhance boat launch (URRL) | Splasher | 10 | 80 | 13.5 | Summer | Yes | 2 | 2 |
| Install power cable (Campground to URRL) | Splasher | 2 | 90 | 1220.0 (times 4) | Summer | Yes | 2 | 3 |
| Trench power (Existing to Campground) | Diffuser | 30 | 81 | 5422.4 | Summer | No | 2 | 2 |
| Install electrical service (Campground) | Diffuser | 25 | 81 | 1.0 | Summer | No | 1 | 2 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Trench air hose (Campground to URRL) | Diffuser | 2 | 81 | 55.0 | Summer | Yes | 2 | 2 |
| Install air hose (URRL) | Diffuser | 5 | 80 | 1220.0 | Summer | Yes | 1 | 2 |
| Trench power (Existing to Campground) | Cascade | 30 | 81 | 5422.4 | Summer | No | 2 | 2 |
| Install electrical service (Campground) | Cascade | 25 | 81 | 1.0 | Summer | No | 1 | 2 |
| Construct pump house (Campground) | Cascade | 10 | 81 | 244.0 | Summer | No | 2 | 2 |
| Construct cascade aerator (Campground) | Cascade | 10 | 81 | 244.0 | Summer | No | 2 | 2 |
| Trench 8" HDPE (Campground to URRL) | Cascade | 5 | 81 | 55.0 | Summer | Yes | 2 | 2 |
| Install 8" HDPE inflow/outflow (URRL) | Cascade | 10 | 85 | 1220.0 | Summer | Yes | 1 | 2 |
| Cut temporary access road (Shambow Pond) | Pipeline | 5 | 85 | 670.0 | Summer | Yes | 2 | 2 |
| Install 14" HDPE (Shambow to URRL) | Pipeline | 49 | 85 | 7000.0 | Summer | Yes | 2 | 2 |
| Enhance boat launch (URRL) | Wall | 10 | 80 | 13.5 | Summer | Yes | 2 | 2 |
| Drive sheet pile (URRL) | Wall | 30 | 95 | 1000.0 | Summer | Yes | 2 | 3 |
| Enhance boat launch (URRL) | Dredge | 10 | 80 | 13.5 | Summer | Yes | 2 | 2 |
| Dredge (URRL) | Dredge | 870 | 90 | 250000.0 | Summer | Yes | 2 | 3 |
| **Operation** | | | | | | | | |
| Run Splasher | Splasher | 2500 | 45 | | Winter | Yes | | 0 |
| Run 10 HP compressor | Diffuser | 2500 | 75 | | Winter | No | | 2 |
| Run Circulator Pump | Cascade | 2500 | 80 | | Winter | No | | 2 |
| None | Pipeline | - | - | - | - | - | | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| None | Wall | - | - | - | - | - | | - |
| None | Dredge | - | - | - | - | - | | - |
| **Maintenance** | | | | | | | | |
| Snowmobile to access | No Action | 25 | 78 | | Winter | Yes | 1 | 2 |
| Seasonal removal (URRL) | Splasher | 25 | 80 | | Summer | Yes | 1 | 2 |
| Annual inspection (URRL) | Diffuser | 25 | 85 | | Summer | Yes | 1 | 2 |
| Annual inspection (URRL) | Cascade | 25 | 85 | | Summer | Yes | 1 | 2 |
| Pipeline operations (Shambow Pond) | Pipeline | 25 | 78 | | Winter | Yes | 1 | 2 |
| Inspect pipeline cleanouts (Shambow Pond) | Pipeline | 12 | 78 | | Winter | Yes | 1 | 2 |
| | | | | | | | | |
| | | | | | | | | |

## Appendix 2. Grayling projection model fitting and supporting material

To select the best model for future simulations, we assessed the fit of three density-dependent and two density-independent versions of this model structure: 1) AMP winter habitat model (eqns. 4,5,6) with vital rates other than YOY in the lake, age-1, and age-2 survival drawn from normal distributions (fig. A1), 2) AMP winter habitat model as described above with reoptimized Holling *b*, 3) AMP winter habitat model with all vital rates drawn from normal distributions and reoptimized Holling *b*, 4) AMP winter habitat model with vital rates other than YOY in the lake, age-1, and age-2 survival drawn from normal distributions and optimized Holling *b* with density independence, and 5) AMP winter habitat model with all vital rates drawn from normal distributions and reoptimized Holling b and density independence (not shown). Predictions from each model were compared to actual grayling abundance estimates and 1,000 simulations over 25 years were conducted for each model for the gamma and truncated normal distributions described above. The best fitting density dependent model (2) and density independent model (5) were compared using model weights calculated using Aikake Information Criterion. All model weight was assigned to the density dependent model, which was used for all subsequent projections (fig. A2).

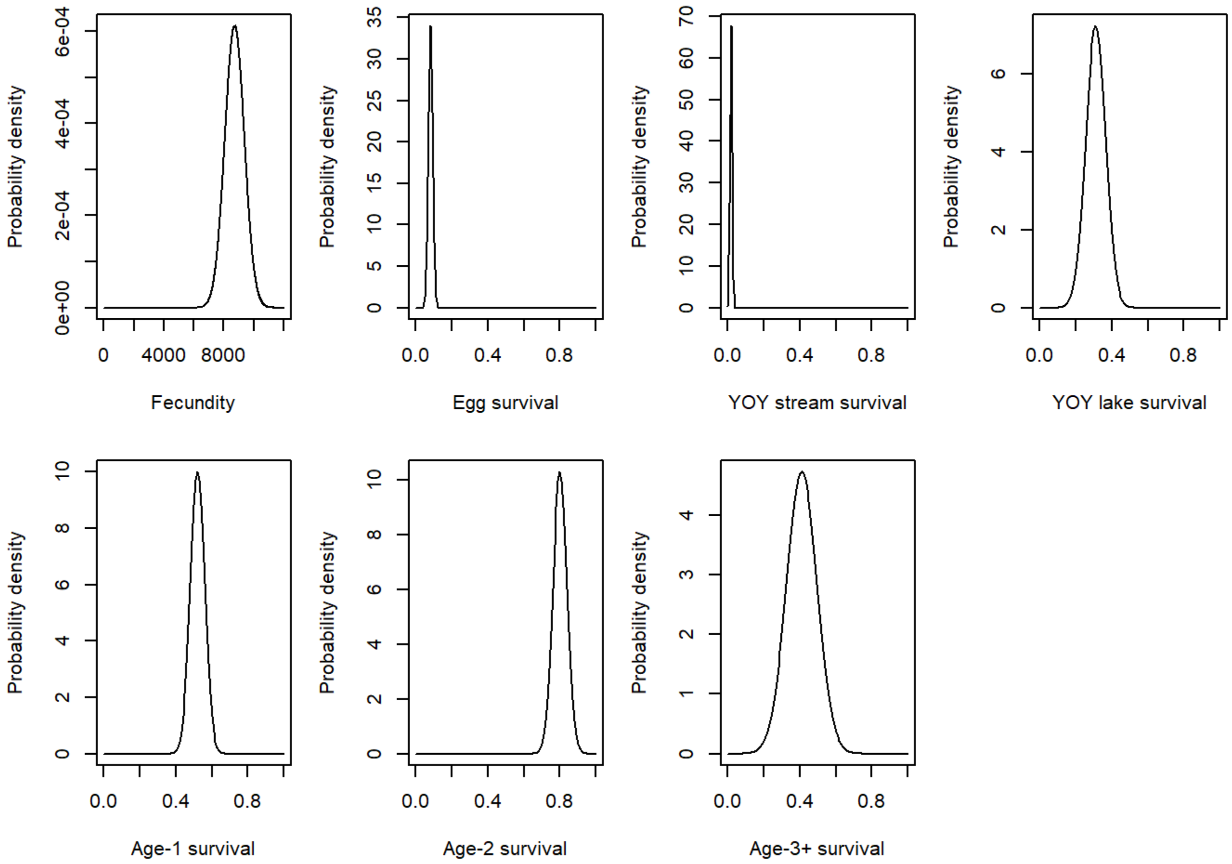

**Figure A1.** Normal probability distributions of vital rates used in the simulations of the CV grayling projection model. YOY = young of year Centennial Valley grayling (*Thymallus arcticus*).

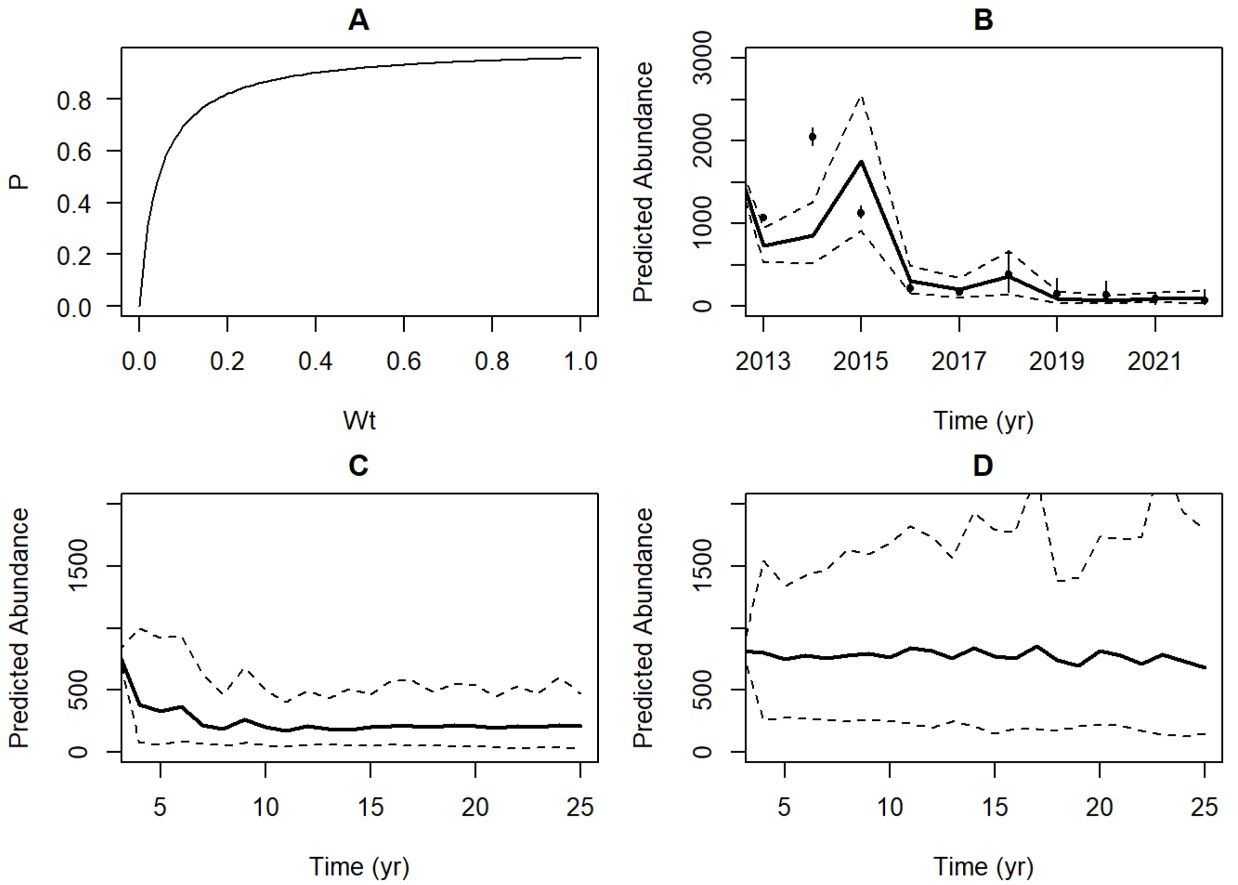

**Figure A2.** Simulation results for Adaptive Management Plan winter habitat model 2 with reoptimzed Holling function b (Warren and Jaeger 2022). A) Reoptimized Holling function (*b* = 0.0427), B) simulation with actual winter habitat data and observed CV grayling (*Thymallus arcticus*) abundance with 95% confidence intervals, C) simulation with winter habitat drawn from the gamma distribution, and D) simulation with winter habitat drawn from the truncated normal distribution.

We used maximum likelihood to estimate the Holling parameter *b* and baseline habitat, *H*. Parameters were estimated using the above equations and empirical estimates of CV grayling abundance, winter habitat, and mean vital rates described above and in the AMP. We used data from 2010 to 2022 for parameter estimation. We assumed average (78 ha) winter habitat in 2012 and 2013 because no measurements were taken in those years. We used a Poisson error distribution for the likelihood to account for count data and greater residuals at higher abundance estimates. The log-likelihood was maximized using the optim function in R (R Core Team, 2021). Optimization results are included in the description of simulations below. We maximized the following likelihood function:

$$p(\boldsymbol{N}|\boldsymbol{\lambda}, H, b) = \prod_{t=3}^{T} \frac{\lambda_{t+1}^{N_{t+1}} * e^{-\lambda_{t+1}}}{N_{t+1}!}$$

where $\lambda_{t+1}$ is the predicted mean abundance at time $t$+1 from the equations described above and $T$ is the number of years of data that the model was optimized with. Predictions start at $t$=3 because the equations use the three prior years of abundance estimates.